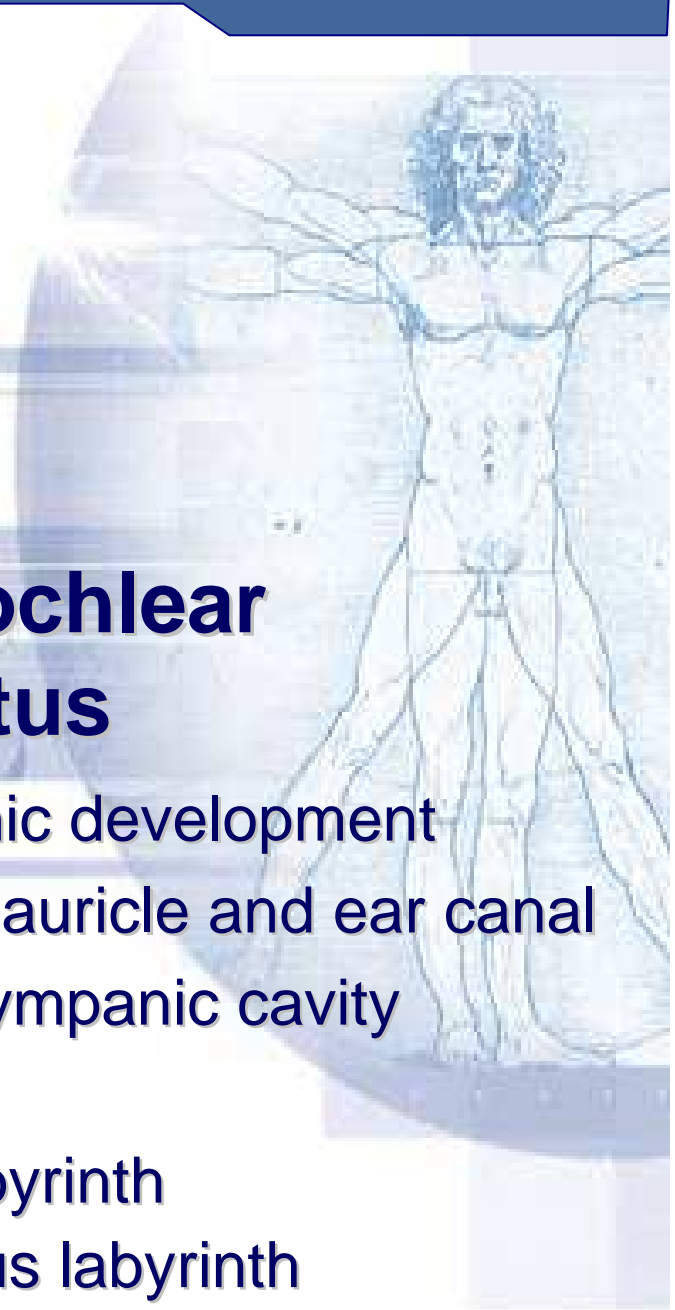


Vestibulocochlear Apparatus

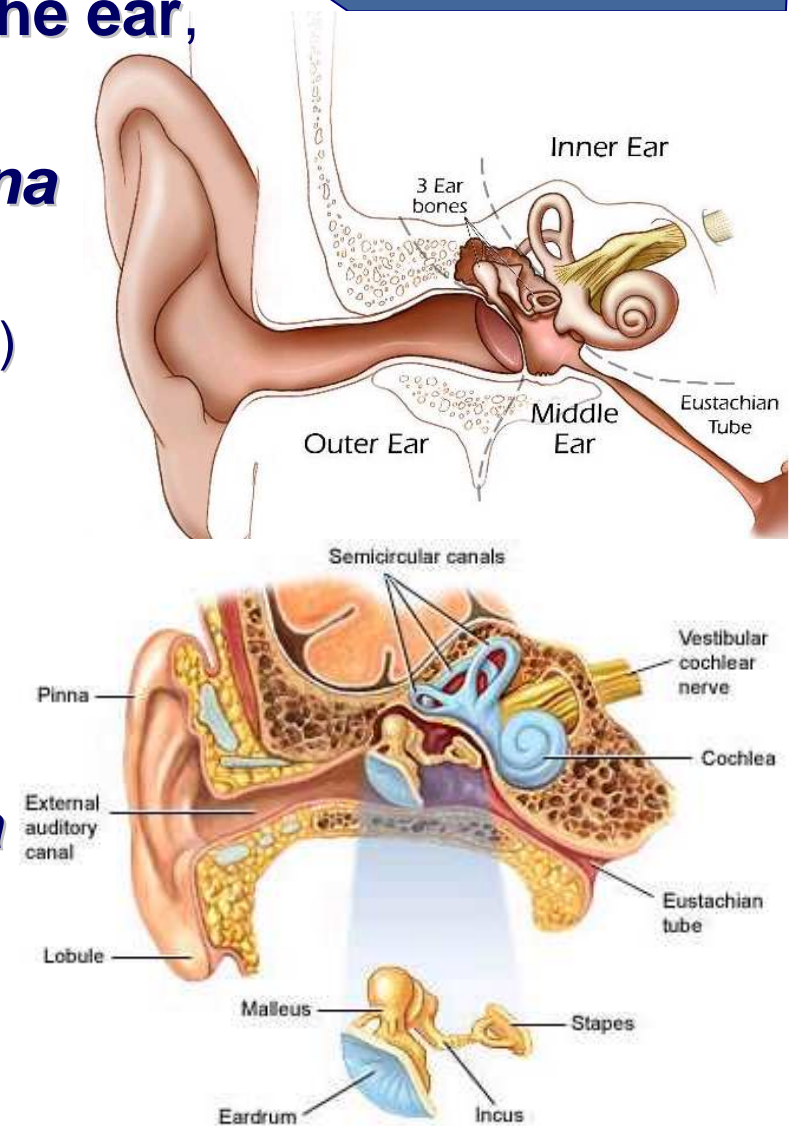
1. The ear – embryonic development
2. The external ear – auricle and ear canal
3. The middle ear – tympanic cavity
4. The internal ear:
 - ✓ the osseous labyrinth
 - ✓ the membranous labyrinth
5. Auditory and vestibular pathways





Anatomy of the ear

- The peripheral auditory apparatus, **the ear**, *auris*, Gr. *us*, *wto* = genitive for ear:
 - ✓ external (outer) ear, ***auris externa***
 - auricle (pinna)
 - external acoustic meatus (ear canal)
 - ✓ middle ear, ***auris media***
 - tympanic membrane (ear drum)
 - tympanic cavity
 - auditory (Eustachian) tube
 - auditory ossicles
 - ✓ internal (inner) ear, ***auris interna***
auditory and vestibular portions:
 - osseous labyrinth
 - membranous labyrinth





Phylogenesis of the ear

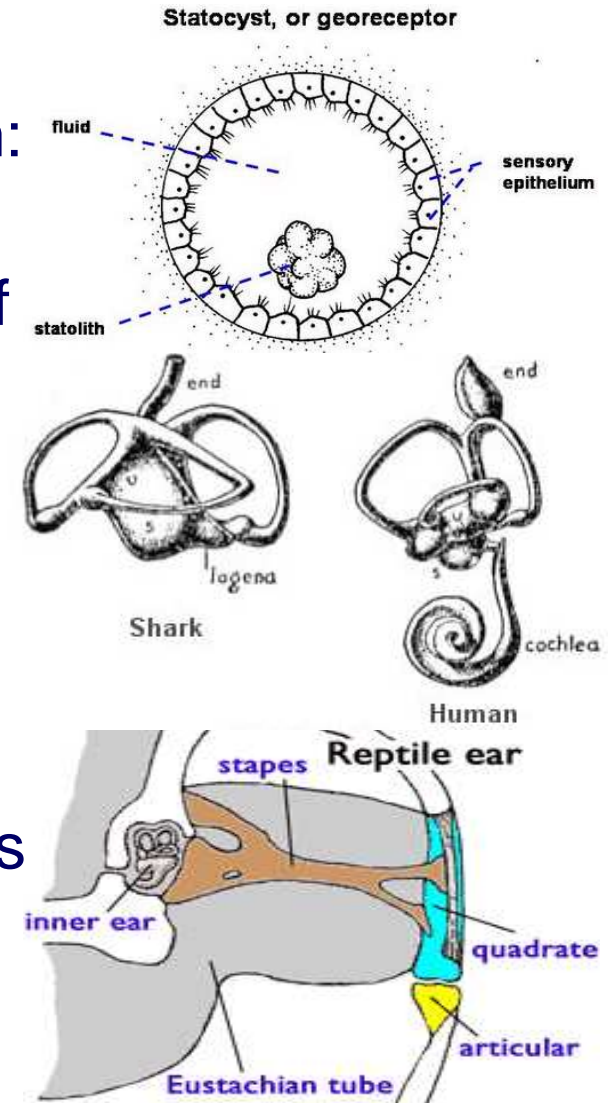
- The vestibular system – antedates the cochlear system:

- ✓ invertebrates – statocyst
- ✓ vertebrates – appearance of semicircular ducts



- The cochlear system – begins with amphibians:

- ✓ fishes – internal ear, primitive cochlea (*lagena*)
- ✓ amphibians – middle ear, sound conduction apparatus
- ✓ mammals – external ear, auricle and ear canal



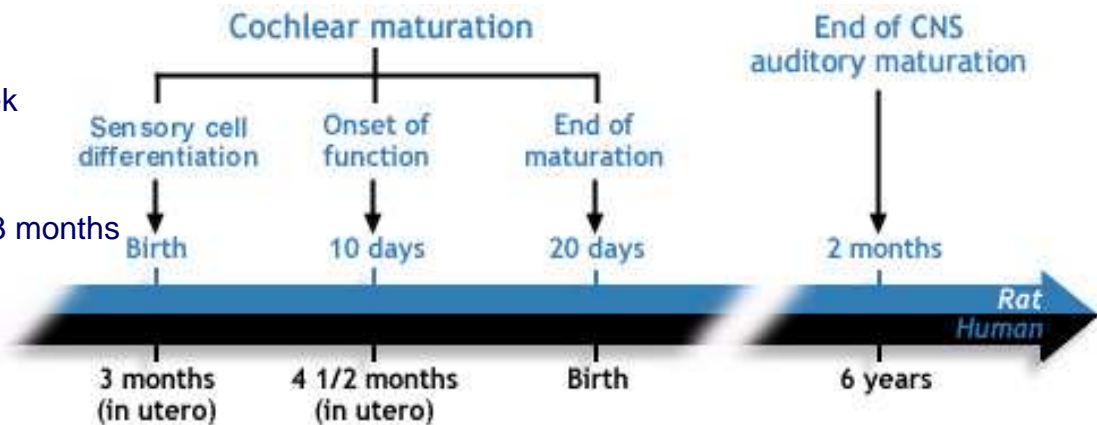


Ontogenesis of the ear

- first appearing sensory structure in developing embryo
- 3rd week – **ectodermal thickenings** ⇒ otic placodes ⇒ otocyst:

✓ internal ear:

- endolymphatic duct – 4th week
- three semicircular ducts
- membranous labyrinth – 1-3 months
- cochlear rudiment – 5th week
- osseous labyrinth – 6th month



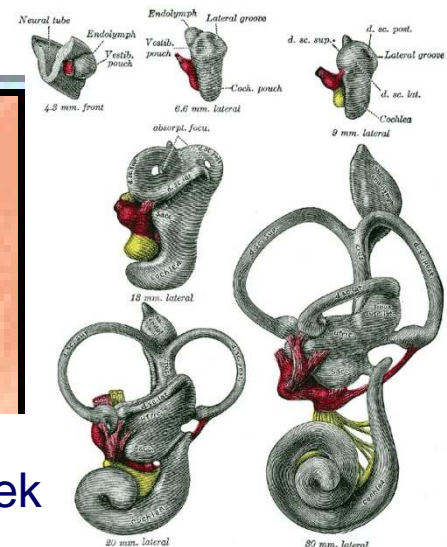
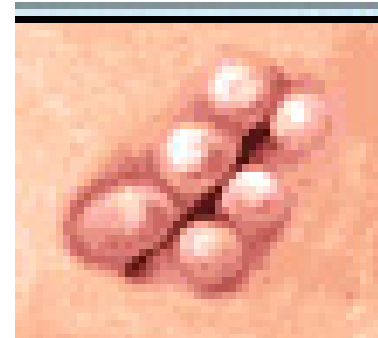
■ head mesenchyme:

✓ middle ear:

- tympanic cavity and auditory tube – derived from the first pouch in 1st month
- auditory ossicles – derived from first and second branchial arches

✓ external ear – first and second arches

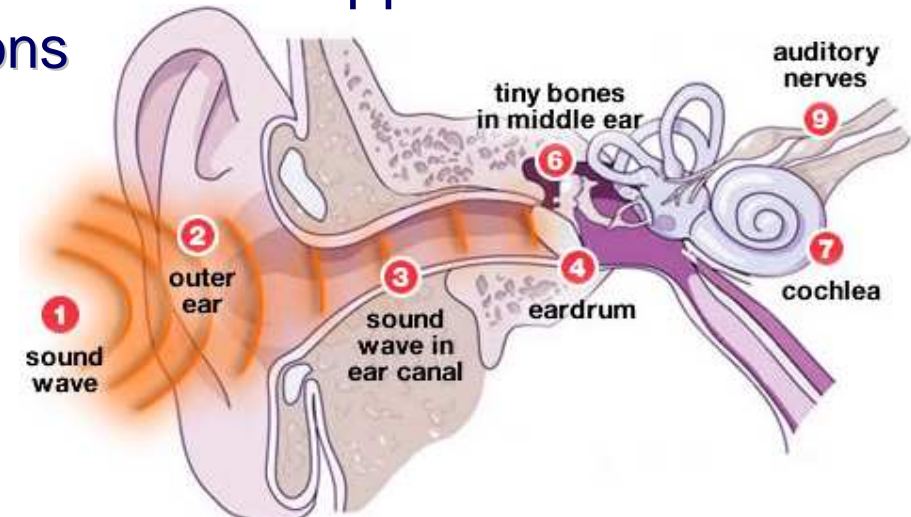
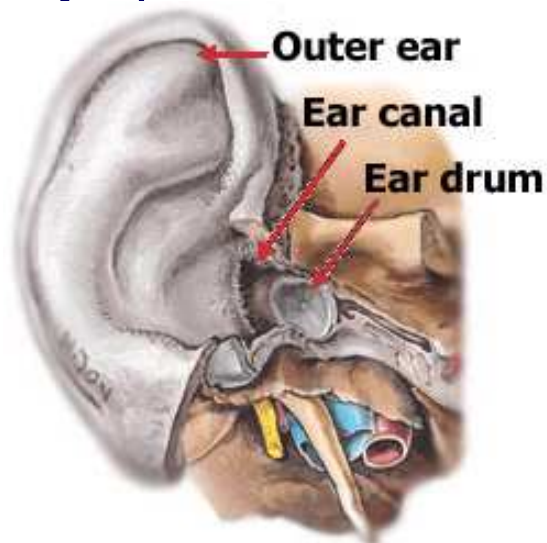
- auricle – six mesenchymal hillocks
- external acoustic meatus – begin of development: 8th week



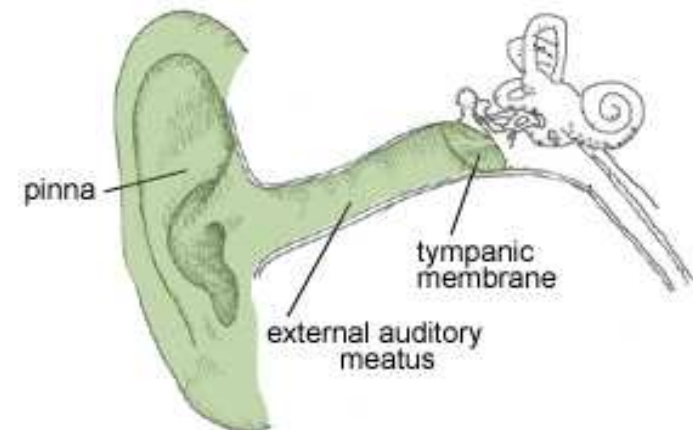


External ear, *auris externa*

- the first structure of the sound conduction apparatus – serves to collect and conduct the air vibrations to the tympanic membrane



Outer Ear



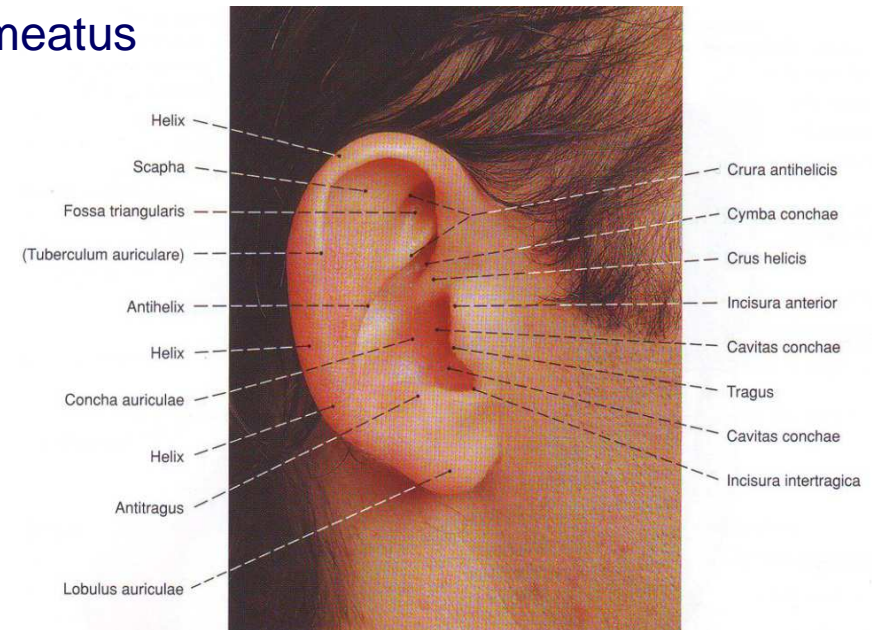
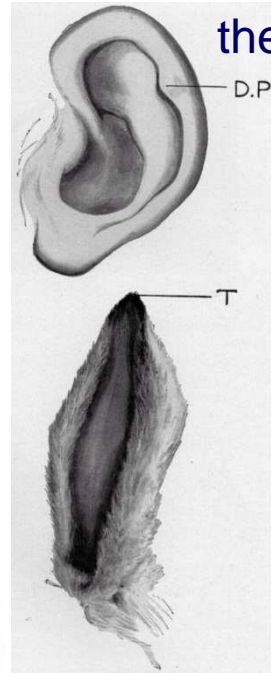
- ✓ auricle (pinna) – ***auricula***
- ✓ external acoustic meatus (ear canal) – ***meatus acusticus externus***



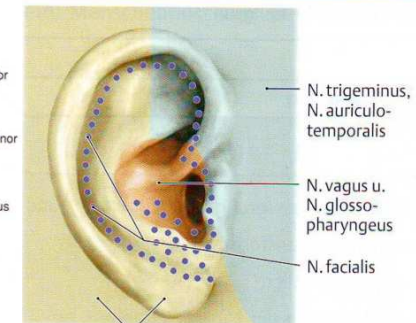
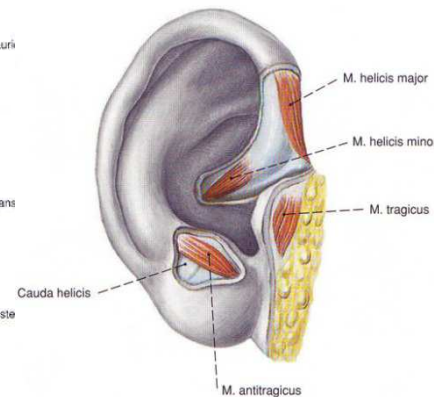
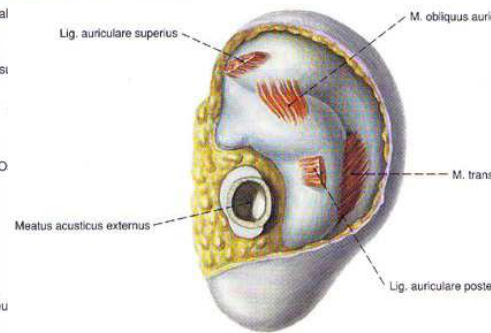
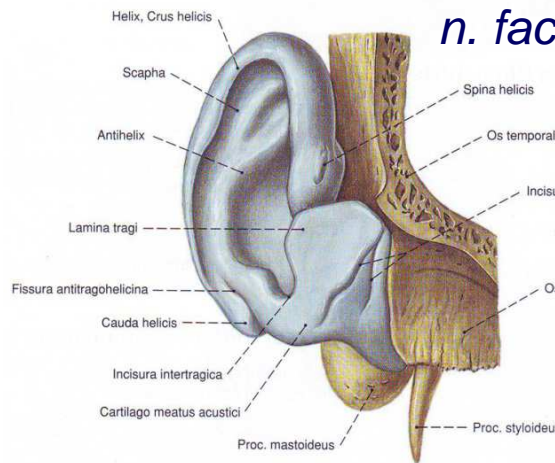
Auricle, auricula

- pinna – Lat. *pinna*, a feather:
 - collects and funnels the sound waves into the meatus

- ✓ thin skin with fine hairs
- ✓ elastic fibrocartilage
- ✓ lobule of auricle
- ✓ auricular tubercle (of Darwin)
- ✓ ligaments of auricle, extrinsic and intrinsic,
- ✓ auricular muscles – extrinsic and intrinsic, *n. facialis*



M-6.2 Sensible Innervation der Ohrmuschel



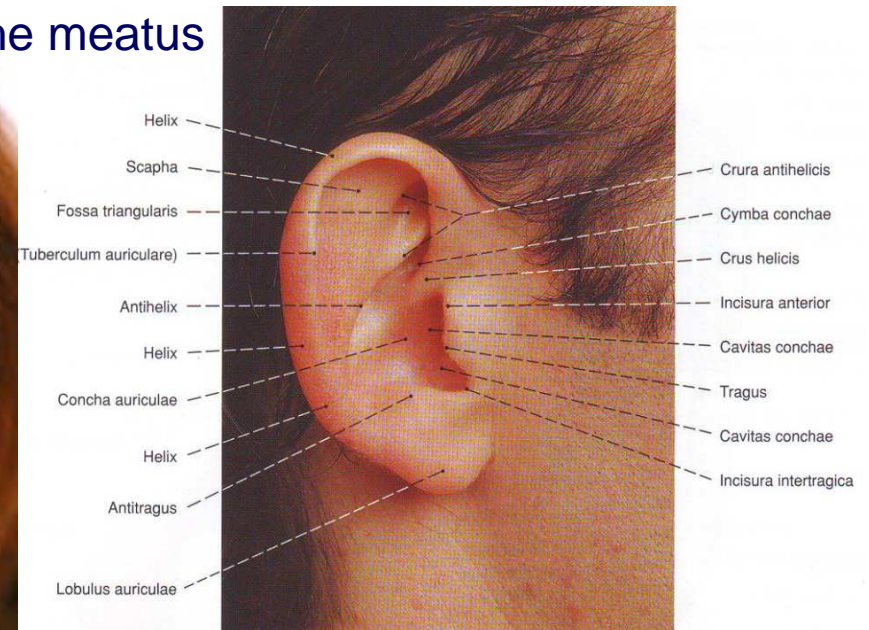
Plexus cervicalis, Nn. occipitalis minor u. auricularis magnus



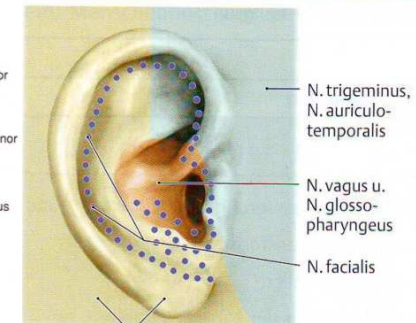
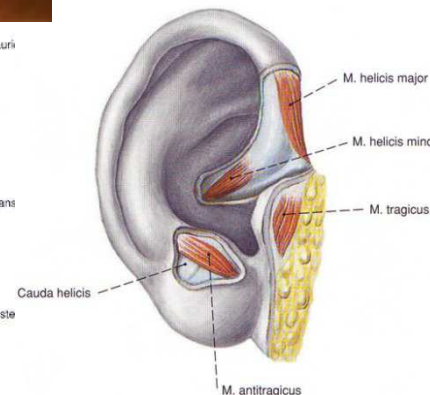
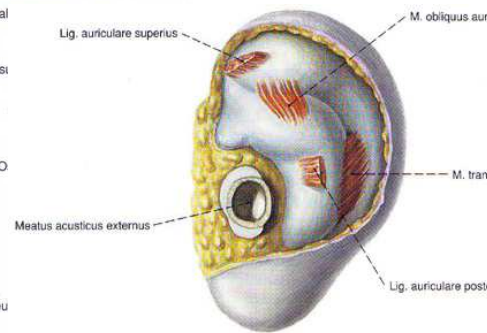
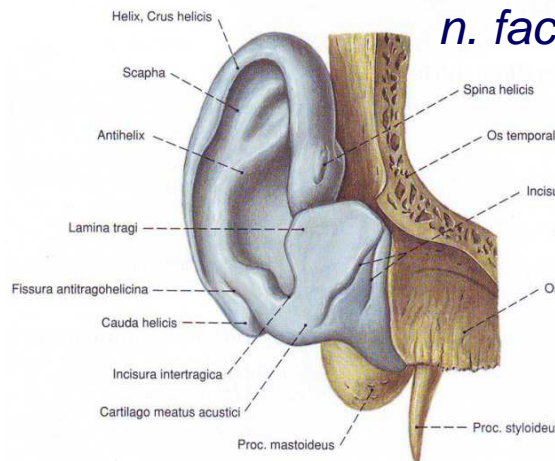
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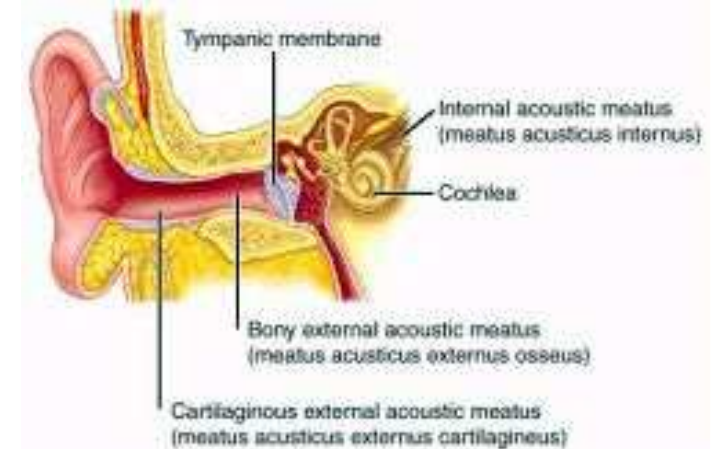
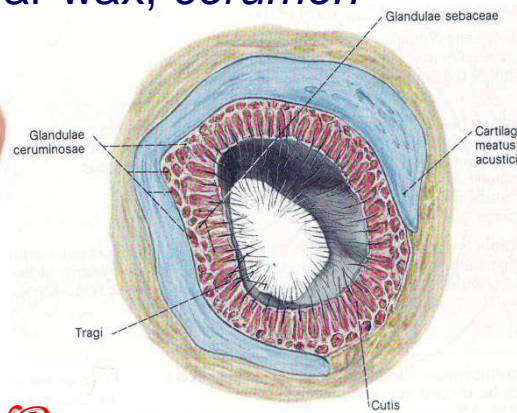
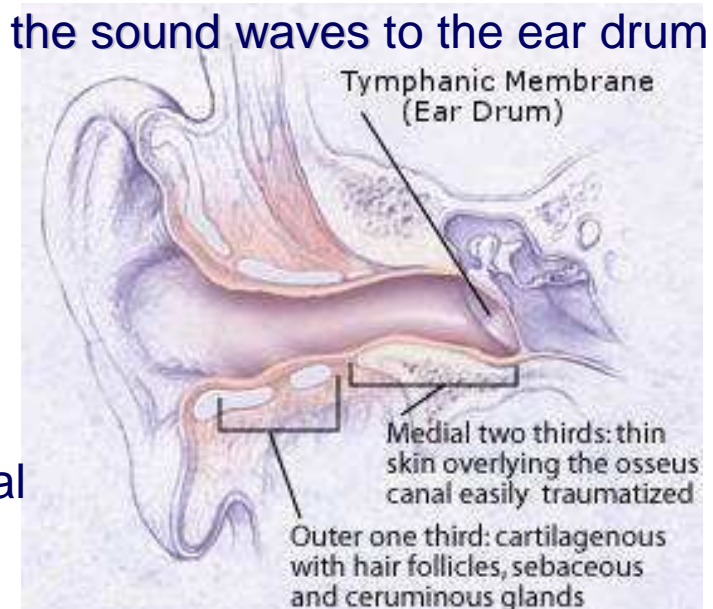


Plexus cervicalis, Nn. occipitalis minor u. auricularis magnus



External acoustic meatus, *meatus acusticus externus*

- external auditory meatus (ear canal),
Lat. *meo*, a passage
 - conducts the sound waves to the ear drum
 - ✓ length ~ 2.5 cm; 7 mm in diameter
 - ✓ S-shaped curve (140°)
- structure – two parts:
 - ✓ cartilaginous part – outer 1/3 (~8 mm long),
cartilago meatus acustici
 - ✓ osseous part – inner 2/3 (~16 mm long),
meatus acusticus externus
 - ✓ thin skin; the thicker cerumen-producing ear canal skin has fine hairs, *tragi*
 - ✓ sebaceous glands ⇒ in the hair follicles
 - ✓ ceruminous glands ⇒ ear wax, *cerumen*

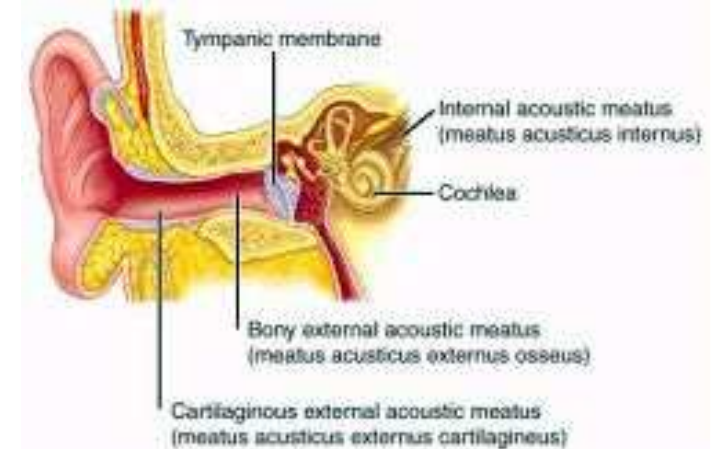
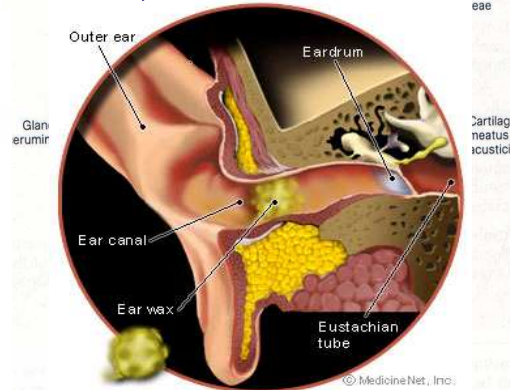
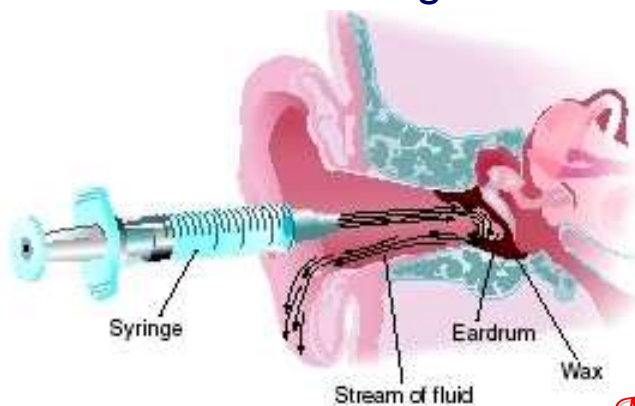
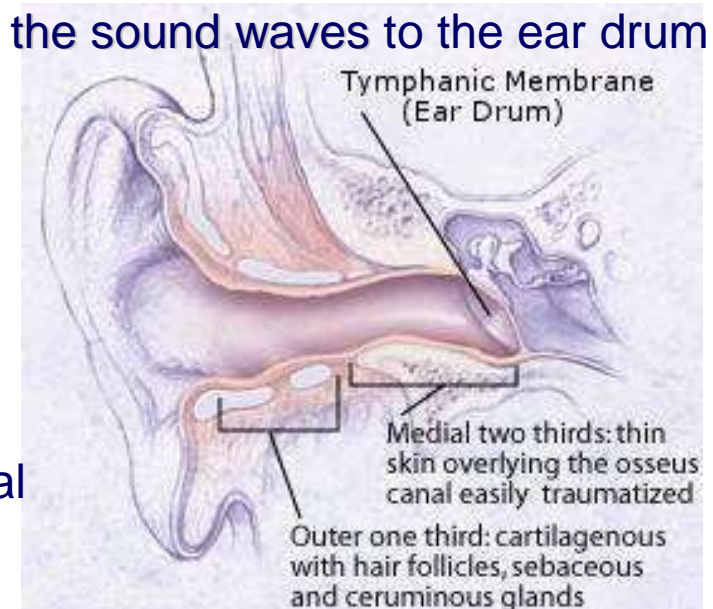


NB: The ear wax assists in cleaning and lubrication, and also



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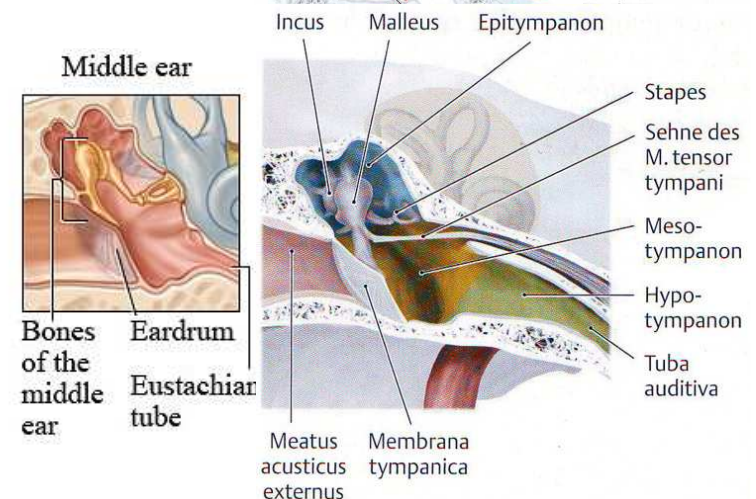
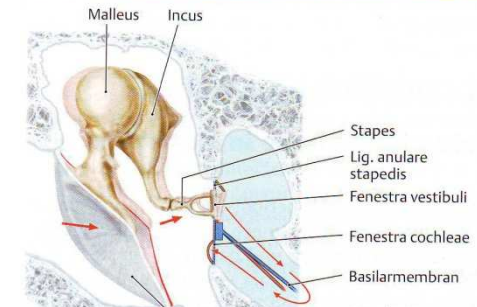
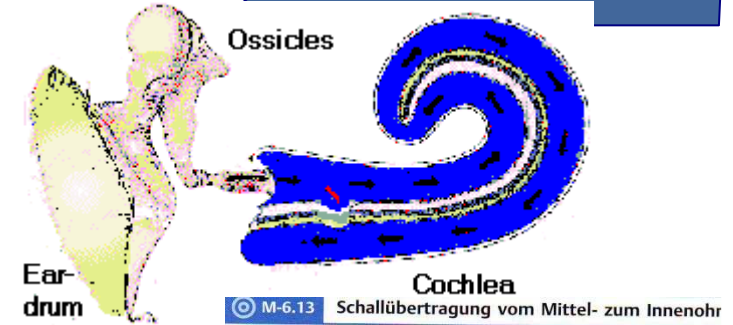
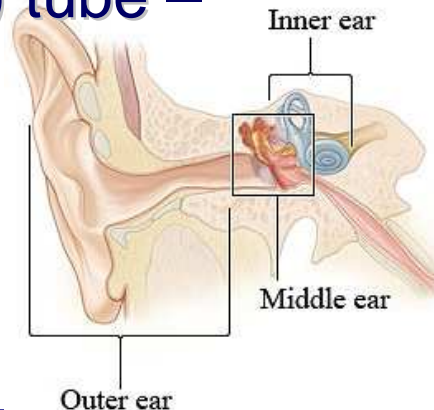
NB: The ear wax assists in cleaning and lubrication, and also

Prof. Dr. Nikolai Lazarov provides some protection from bacteria, fungi, and insects!



Middle ear, *auris media*

- a structure of the sound conduction apparatus
- primary functions:
 - ✓ transmission of the vibrations of the tympanic membrane to the internal ear
 - ✓ efficient transfer of acoustic energy from compression waves in air to fluid – membrane waves within the cochlea
- ✓ tympanic membrane – ***membrana tympani (tympanica)***
- ✓ tympanic cavity – ***cavitas (cavum) tympani***
- ✓ auditory (eustachian) tube – ***tuba auditiva (auditoria)***
- ✓ auditory ossicles – ***ossicula auditus (auditoria)***





Tympanic membrane, *membrana tympani*

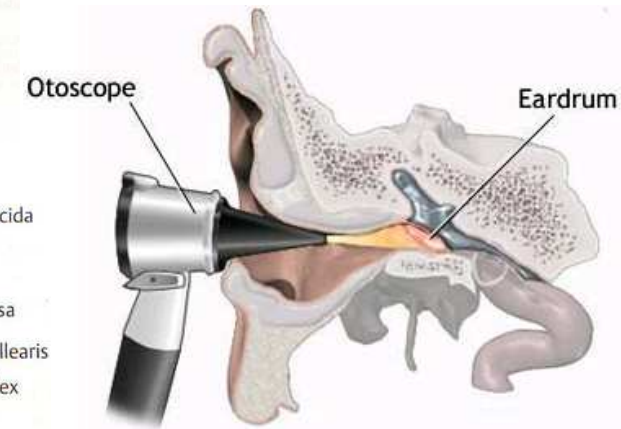
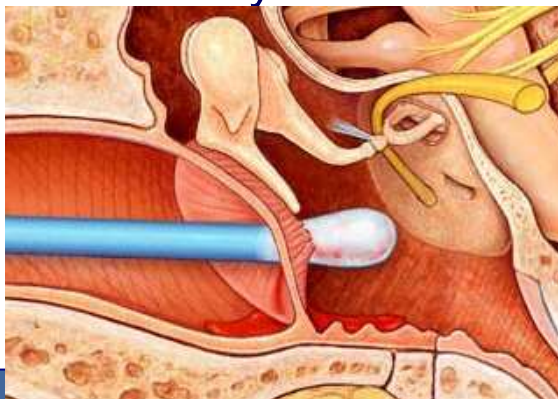
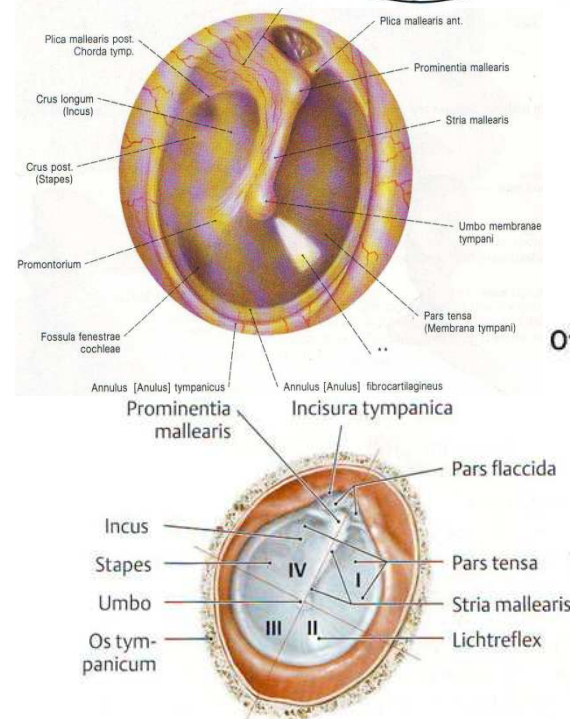
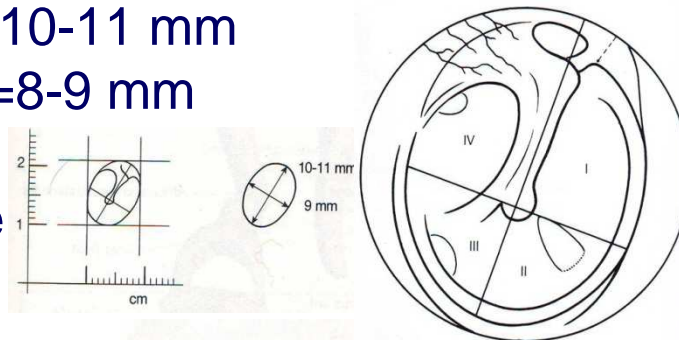
- **ear drum** – thin, semi-transparent, nearly oval in form:

- ✓ longest diameter $d=10-11$ mm
- ✓ shortest diameter $d=8-9$ mm

- *pars flaccida* – Schrapnell's membrane

- *pars tensa* \Rightarrow *umbo*

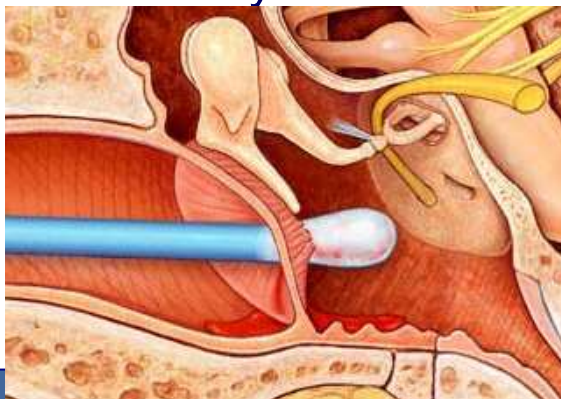
- ✓ cuticular layer
- ✓ fibrous layer – absent in *pars flaccida*:
 - radiate fibers
 - circular fibers
- ✓ mucous layer





Tympanic membrane, *membrana tympani*

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 - ✓ longest diameter $d=10-11$ mm
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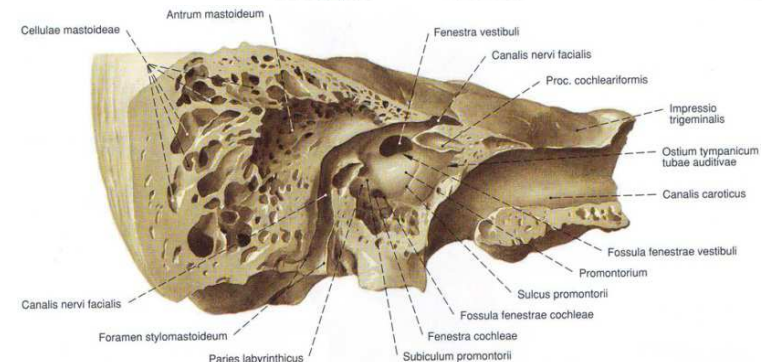
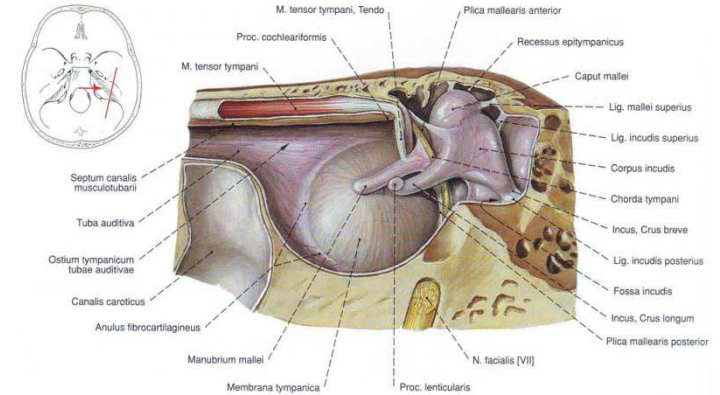
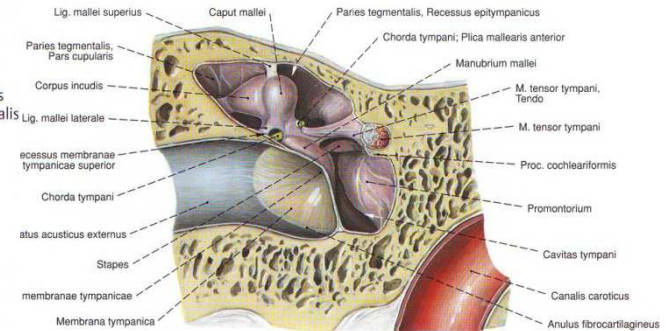
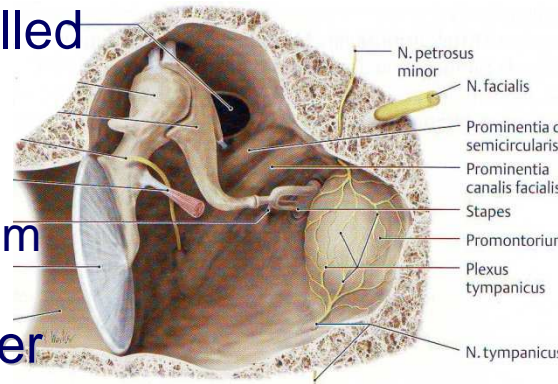


"I can see it! Boy, that is a small cellular phone!"



Tympanic cavity, *cavum tympani*

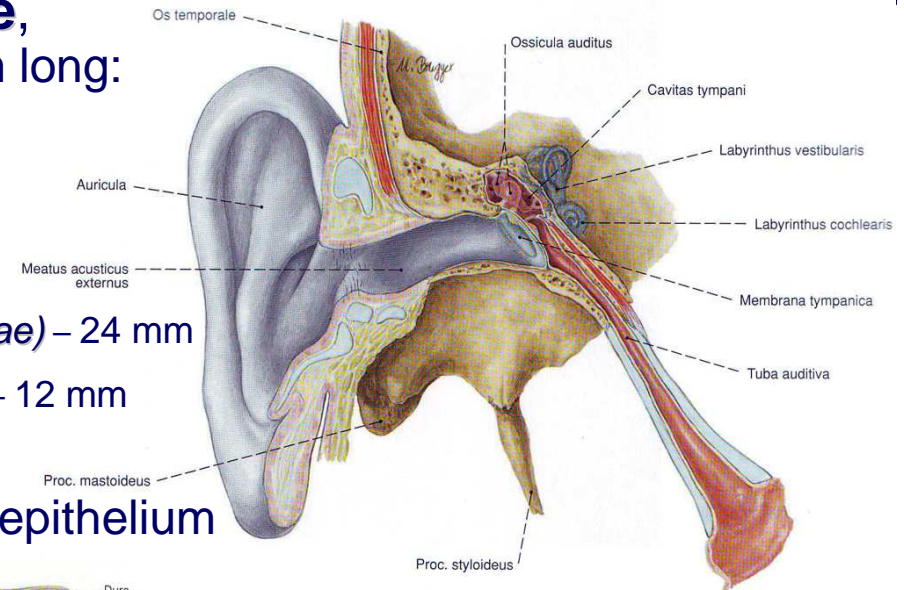
- volume – 1.5 cm³, air-filled
- diameters:
 - ✓ vertical – 15 mm
 - ✓ transverse – 6-4-2 mm
 - ✓ antero-posterior – 15 mm
- two parts:
 - ✓ tympanic cavity proper
 - ✓ epitympanic recess
- six walls, lined with mucoperiosteum:
 - ✓ lateral wall – ***paries membranaceus***:
membrana tympani et recessus epitympanicus
 - ✓ medial wall – ***paries labyrinthicus***
 - ✓ superior wall, roof – ***paries tegmentalis***:
tegmen tympani ⇒ otogenic meningitis
 - ✓ inferior wall, floor – ***paries jugularis***
⇒ *canaliculus tympanicus*
 - ✓ anterior wall – ***paries caroticus***
 - ✓ posterior wall – ***paries mastoideus***
⇒ *antrum mastoideum*



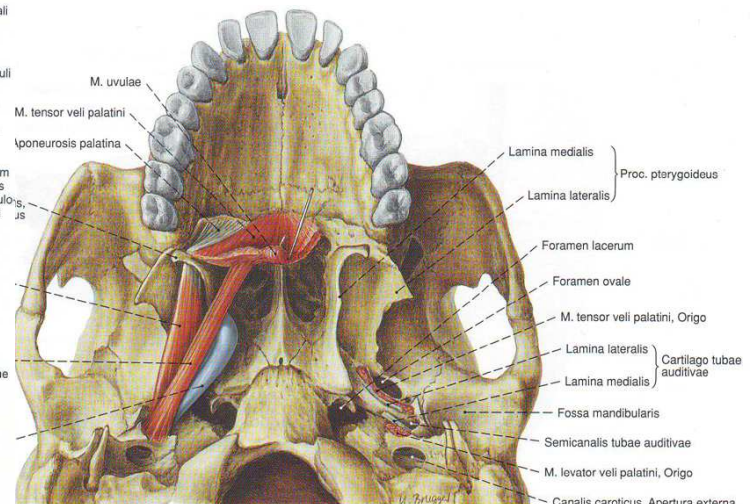
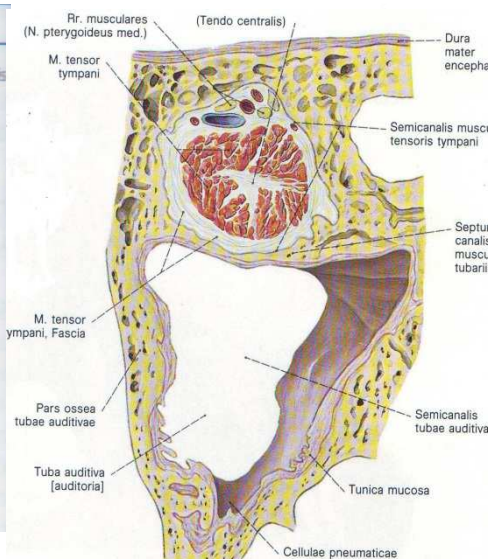
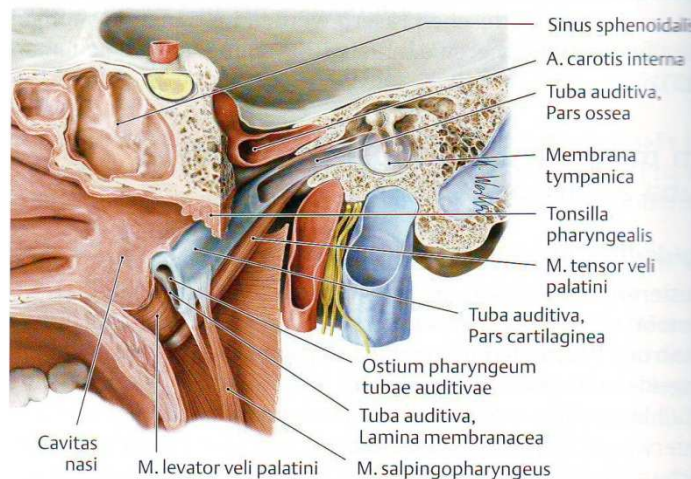


Auditory tube, *tuba auditiva*

- **Eustachian (pharyngotympanic) tube**, links the pharynx to the middle ear, ~3.5 cm long:
 - ✓ *ostium tympanicum* } *tubae*
 - ✓ *ostium pharyngeum* } *auditivae*
- two parts:
 - ✓ cartilaginous part - $\frac{2}{3}$ (*cartilago tubae auditivae*) – 24 mm
 - ✓ bony part - $\frac{1}{3}$ (in *semicanalis tubae auditivae*) – 12 mm
 - ✓ *isthmus tubae auditivae*
 - ✓ mucous membrane – ciliated columnar epithelium



© M-6.8 Tuba auditiva

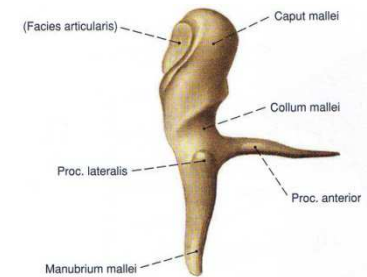
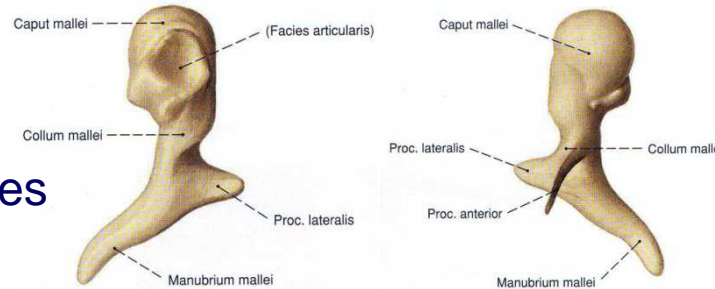




Auditory ossicles, *ossicula auditus*

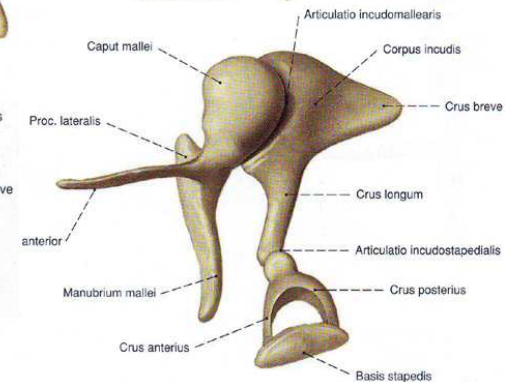
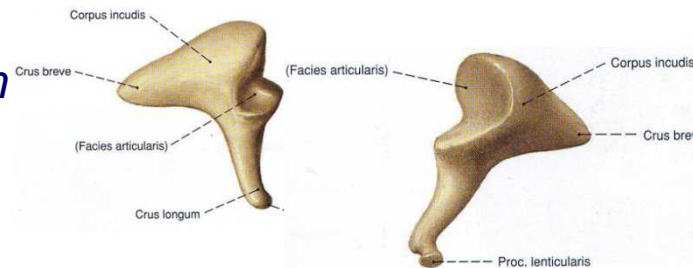
- **malleus** – Lat. = mallet, hammer; the largest, 8-9 mm long:

- ✓ head, *caput mallei*
- ✓ neck, *collum mallei*
- ✓ *manubrium mallei*
- ✓ anterior and lateral processes



- **incus** – Lat. = anvil:

- ✓ body, *corpus incudis*
- ✓ long process, *crus longum*
⇒ lenticular process
- ✓ short process, *crus breve*



- **stapes** – Lat. = stirrup:

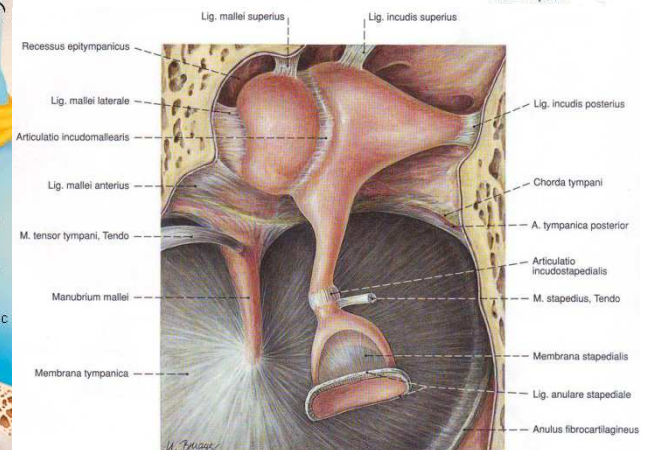
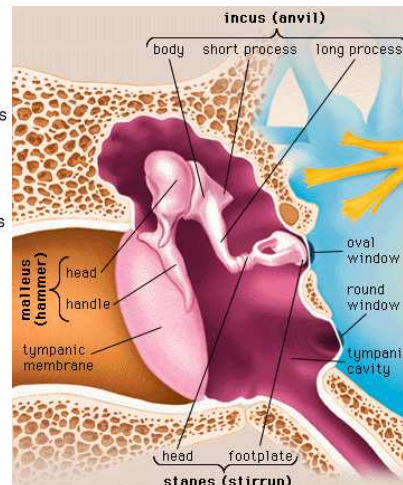
- ✓ head, *caput stapedis*
- ✓ limbs (*crura*)
 - *anterior*
 - *posterior*
- ✓ base, *basis stapedis*



- *m. tensor tympani (Eustachii)*

- *m. stapedius*

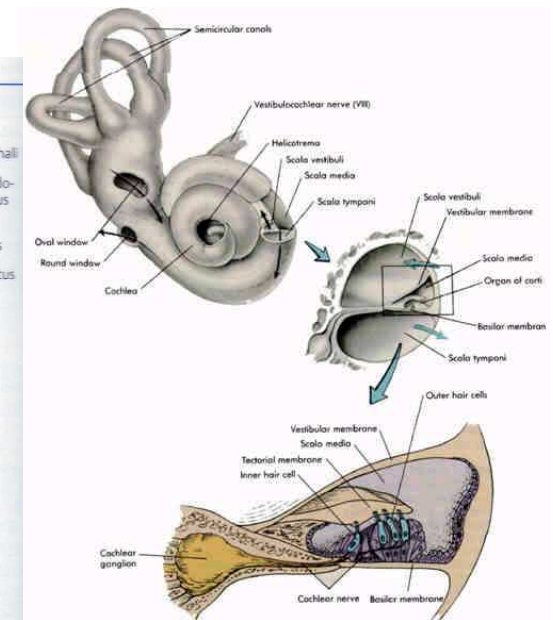
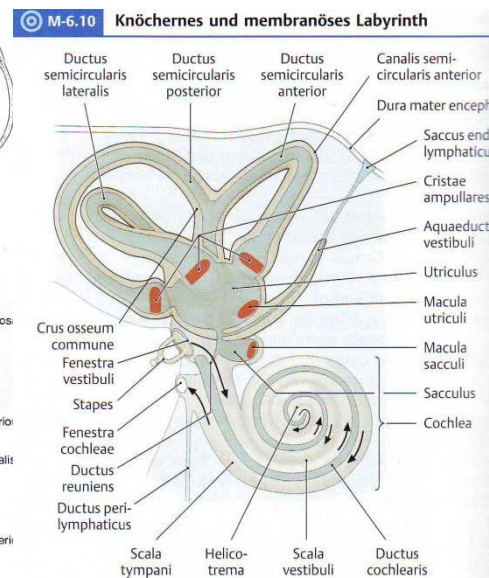
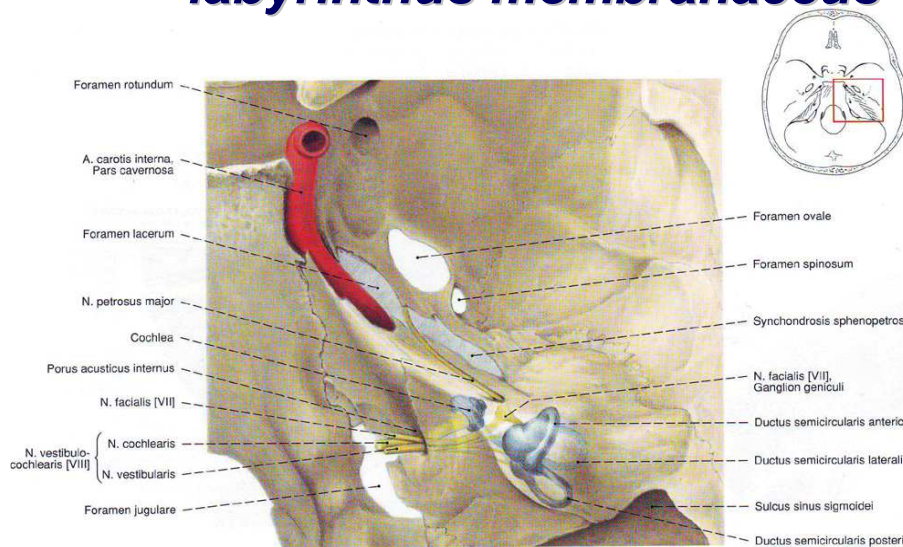
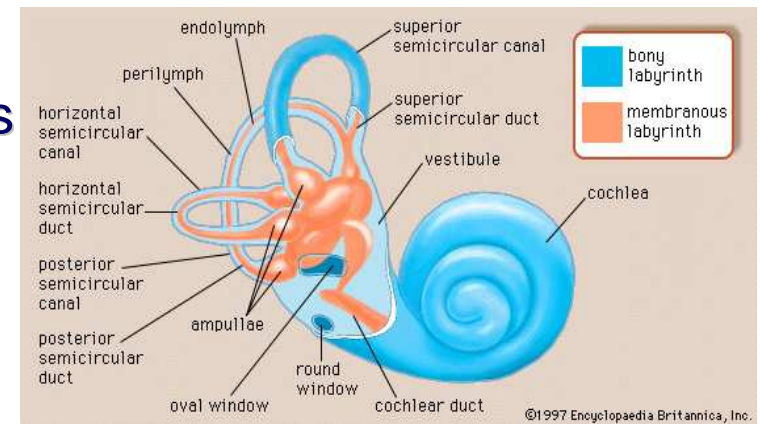
- *ligg. et artt. ossiculorum auditus*





Internal ear, *auris interna*

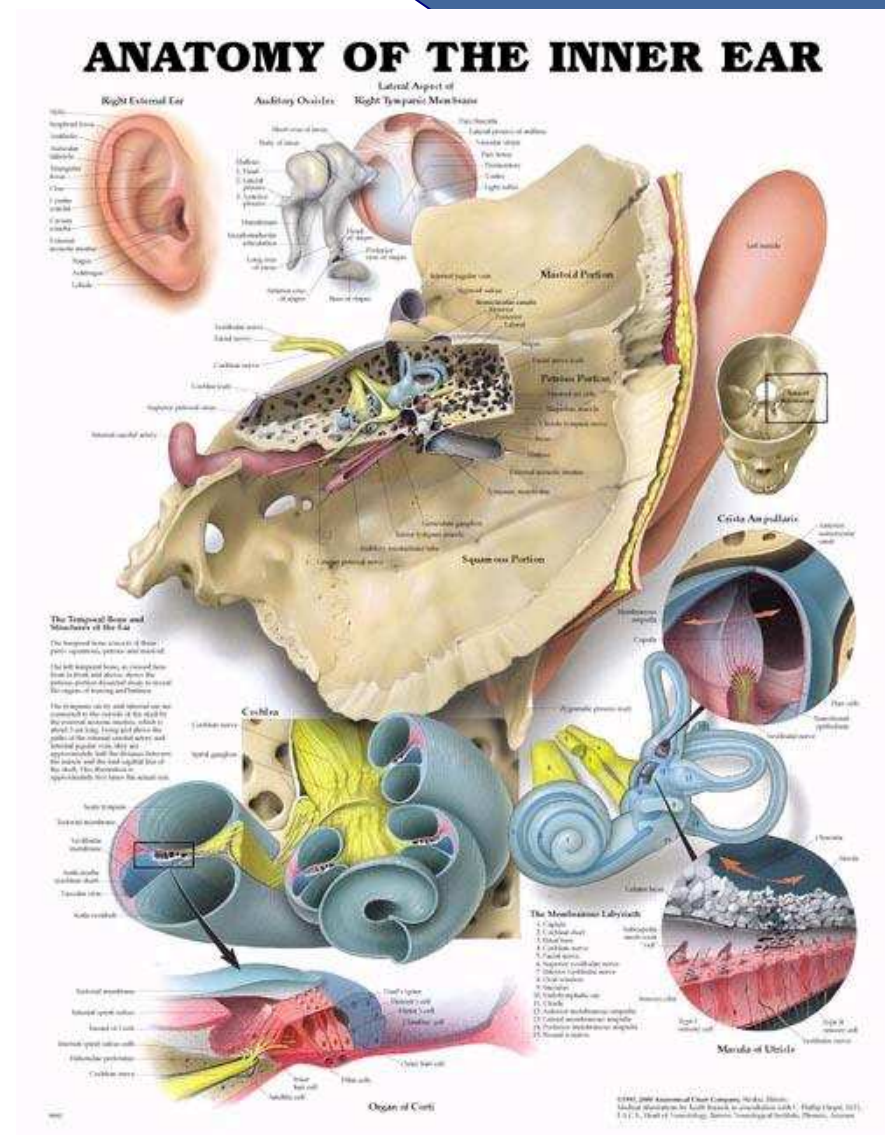
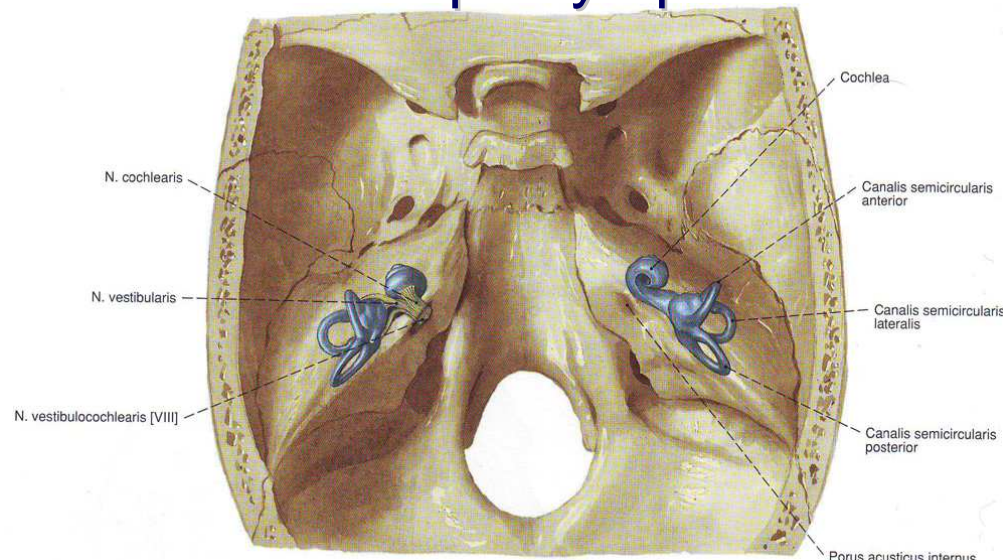
- location – in *pars petrosa ossis temporalis*
- main functions:
 - ✓ converts sound waves into nerve impulses
 - ✓ registers changes in equilibrium
- composition:
 - ✓ osseous labyrinth, ***labyrinthus osseus***
 - ✓ membranous labyrinth, ***labyrinthus membranaceus***





Osseous labyrinth, *labyrinthus osseus*

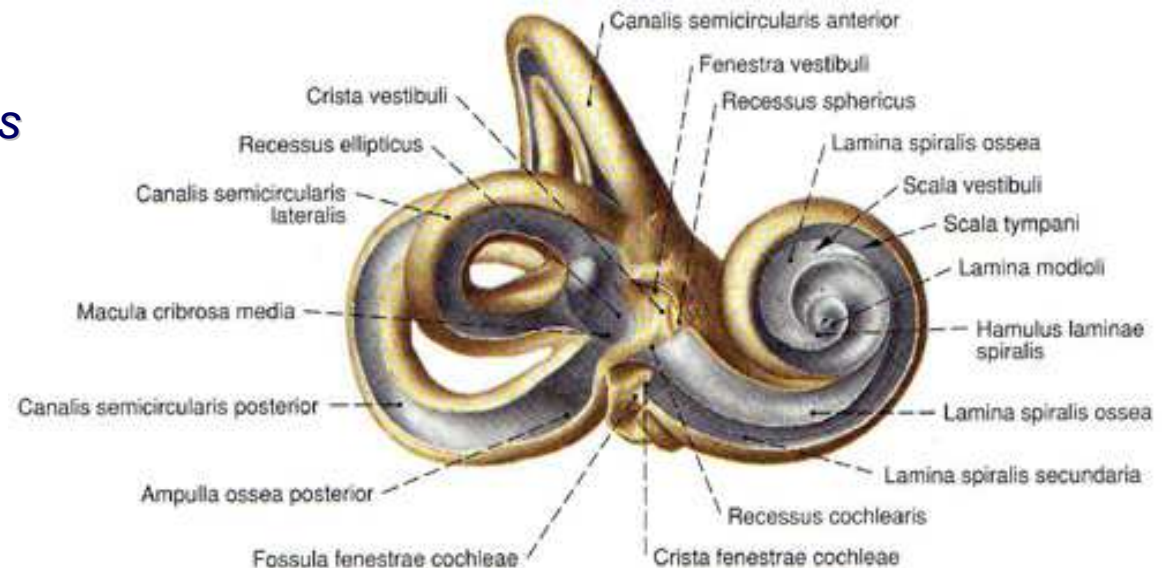
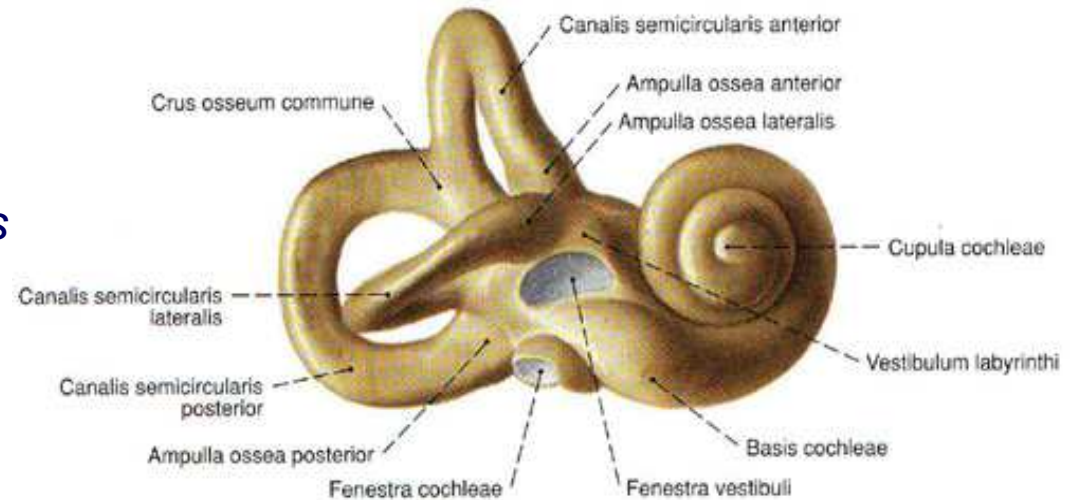
- vestibule, *vestibulum*
- three semicircular canals, *canales semicirculares*:
 - ✓ *canalis semicircularis lateralis*
 - ✓ *canalis semicircularis anterior*
 - ✓ *canalis semicircularis posterior*
- *cochlea*
- filled with perilymph





Vestibule, vestibulum

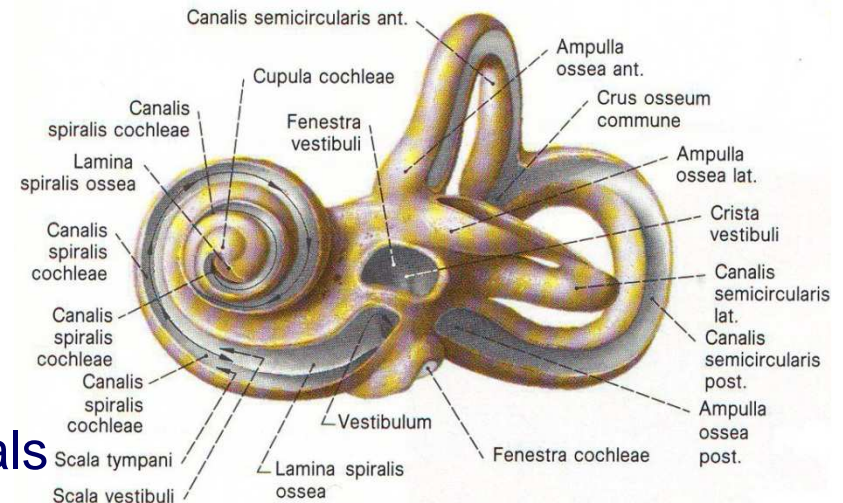
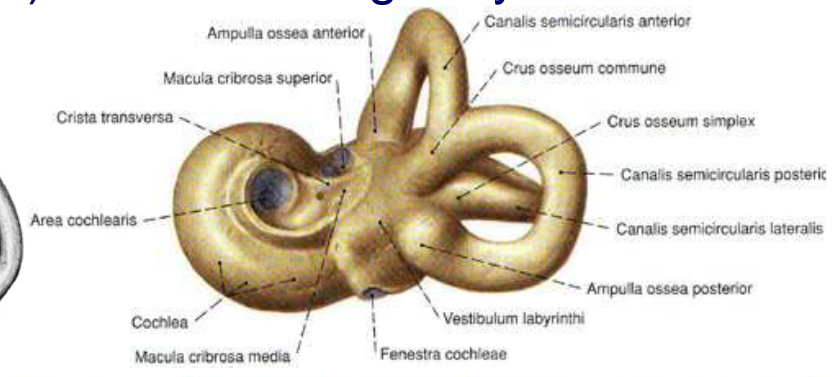
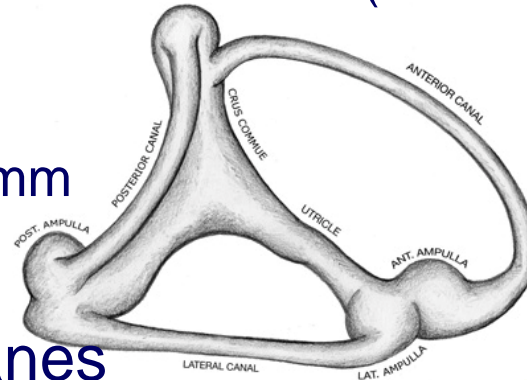
- lateral wall – *paries labyrinthicus*:
 - ✓ *fenestra vestibuli* ⇨ closed by *basis stapedis*, fixed with *lig. annulare stapedis*
 - ✓ *fenestra cochleae* ⇨ *membrana tympani secundaria*
- medial wall:
 - ✓ elliptical recess ⇨ *utricleus*
 - ✓ vestibular crest ⇨ aqueduct of the vestibule
 - ✓ spheroid recess ⇨ *sacculus*
 - ✓ cochlear recess
 - ✓ *maculae cribrosae* ⇨ *pars vestibularis n. vestibulocochlearis*:
 - *macula cribrosa superior*
 - *macula cribrosa media*
 - *macula cribrosa inferior*





Semicircular canals, *canales semicirculares*

- ✓ lateral semicircular canal (14 mm) – directed horizontally
 - ✓ anterior (superior) semicircular canal (18 mm) – vertical in direction
 - ✓ posterior semicircular canal (22 mm) – directed sagittally backwards
- $\frac{2}{3}$ of a circle
 - diameter = all ~ 1 mm
 - located in three perpendicular planes
 - filled with semicircular ducts
 - initial portion – *ampulla ossea*
 - end part – *crus osseum*:
 - ✓ *simplex* – for lateral canal
 - ✓ *commune* – for anterior&posterior canals





Osseous cochlea

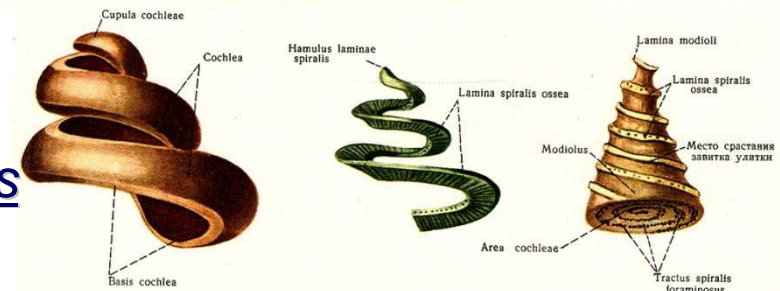
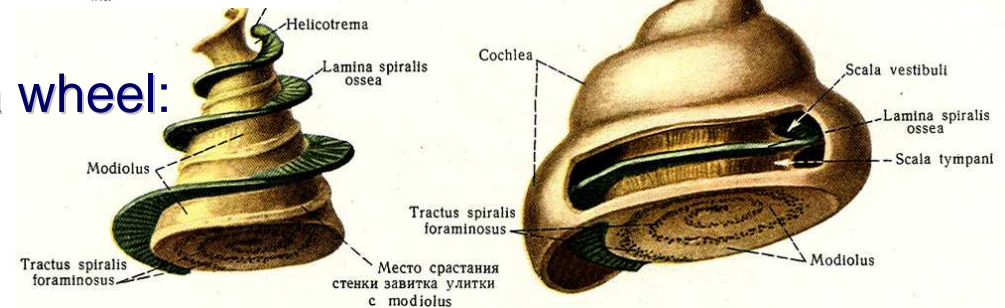
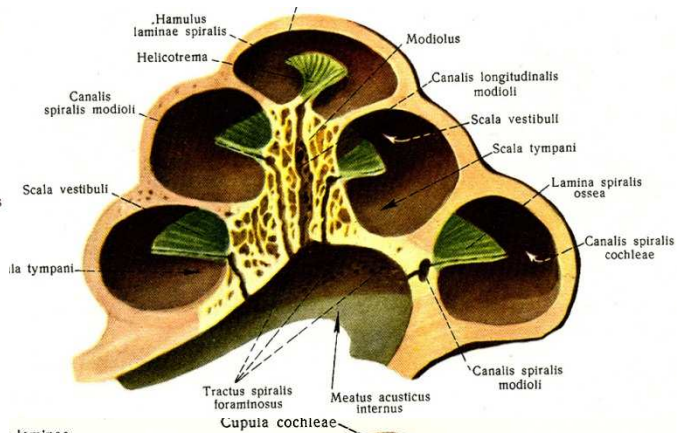
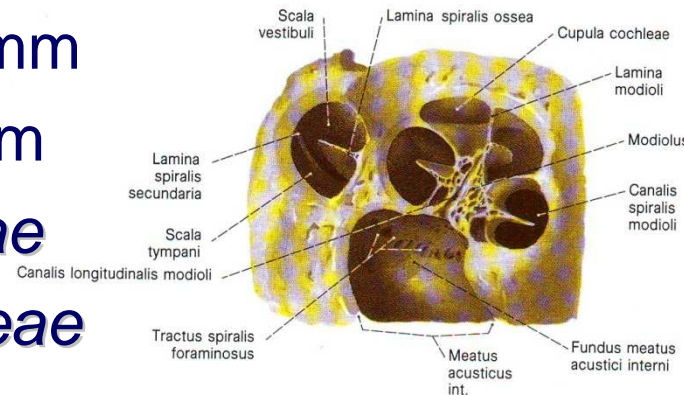
- spiral canal, *canalis spiralis cochleae* – 2½-2¾ turns (length ~ 3 cm):

- ✓ height – 4-5 mm
- ✓ base – 8-9 mm
- ✓ *basis cochleae*
- ✓ *cupula cochleae*
- ✓ structure:

➤ *modiolus* – Lat. the hub of a wheel:

- *basis modioli* ⇨ *tractus spiralis foraminosus*
- *lamina modioli*
- *canalis spiralis modioli* ⇨ *ganglion cochleare*
- *lamina spiralis ossea* ⇨ *hamulus helicotrema*
- *lamina spiralis secundaria* ⇨ *membrana basilaris*

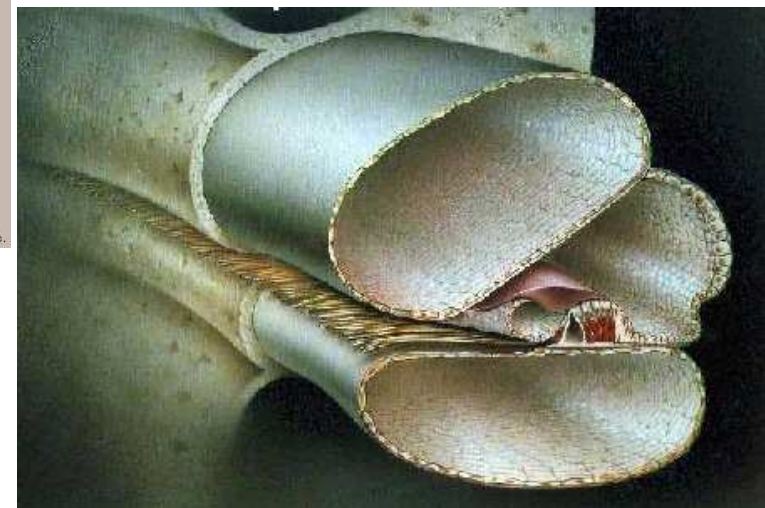
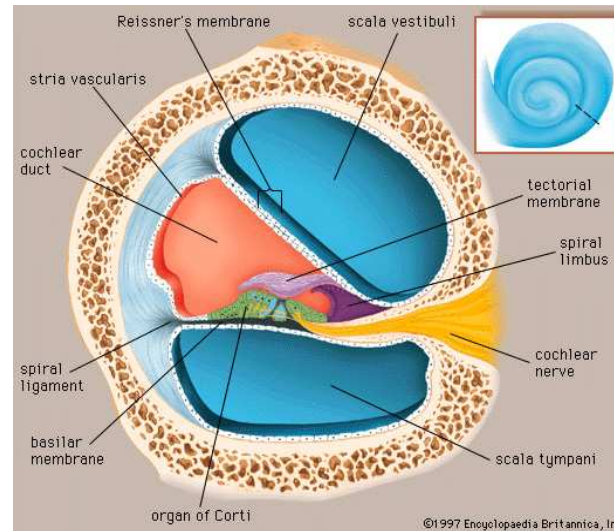
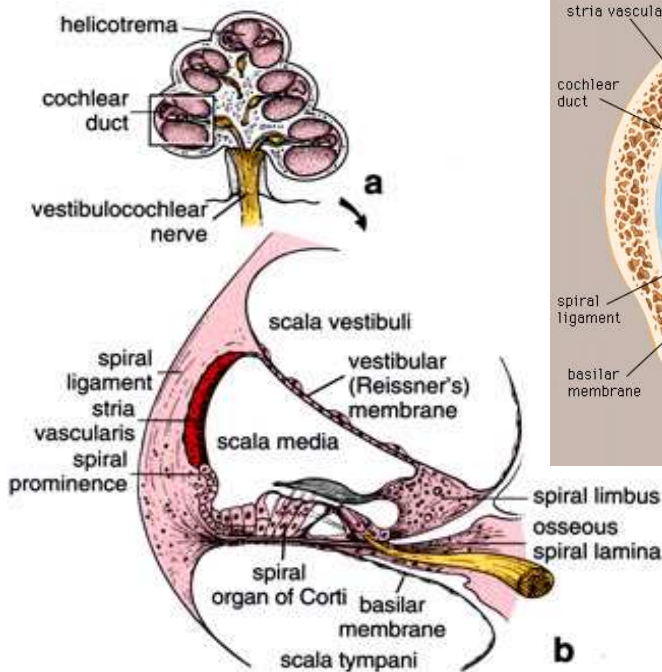
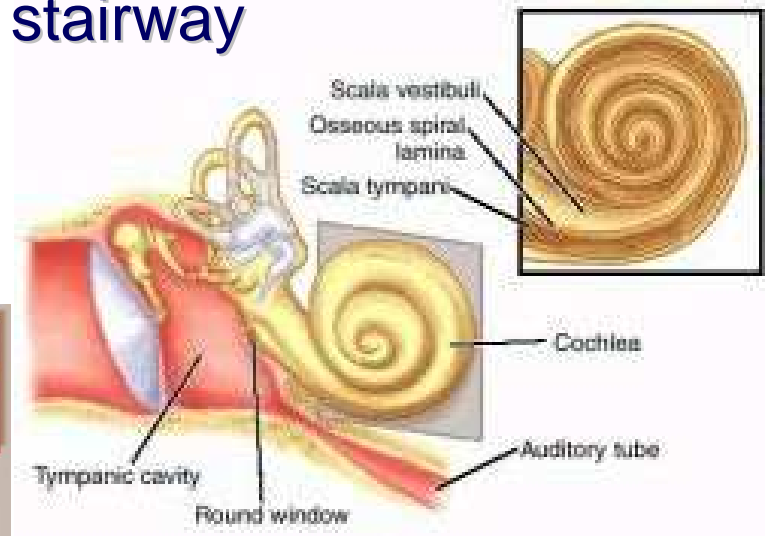
Lat. *cochlea*, snail shell





Cochlear canal, *canalis cochlearis*

- ✓ ***scala vestibuli*** Lat. *scala*, stairway
- ✓ ***scala tympani***
- ✓ ***scala media* (*ductus cochlearis*)**
 ⇒ *organum spirale Corti*



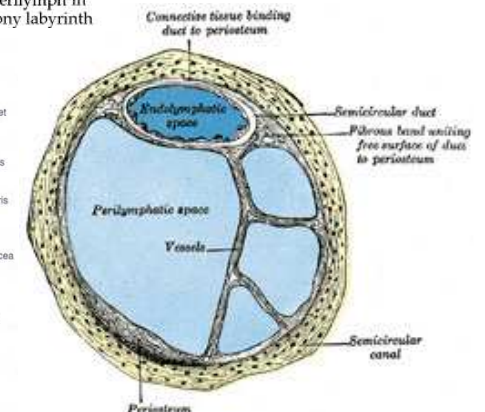
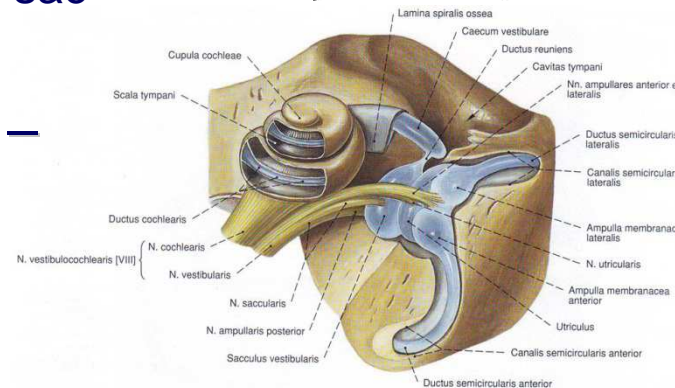
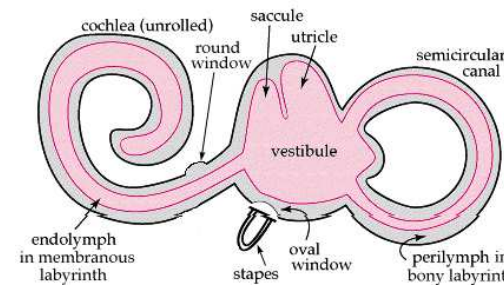
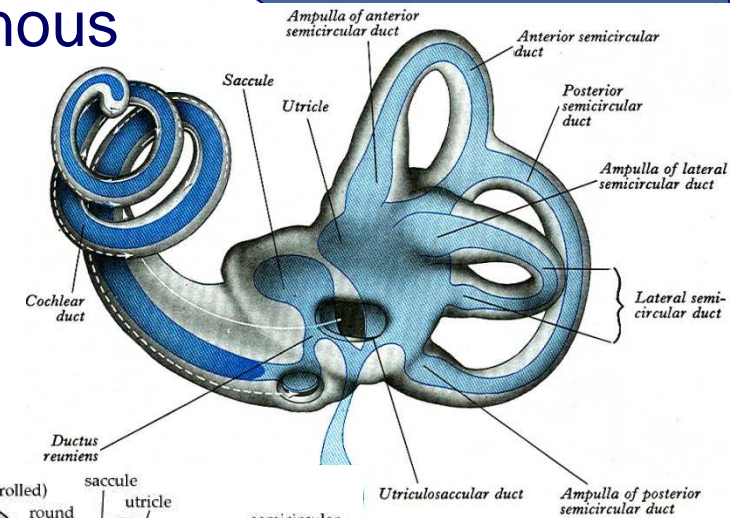


Membranous labyrinth, *labyrinthus membranaceus*

- a closed system of fluid-filled membranous channels (sacs) of ectodermal origin
- location – within the bony labyrinth
- filled with endolymph
- surrounded by perilymph – perilymphatic space

- ✓ ***labyrinthus vestibularis*** –
 - within the osseous vestibule – *utricle and saccule*
 - endolymphatic duct and sac
 - three semicircular ducts

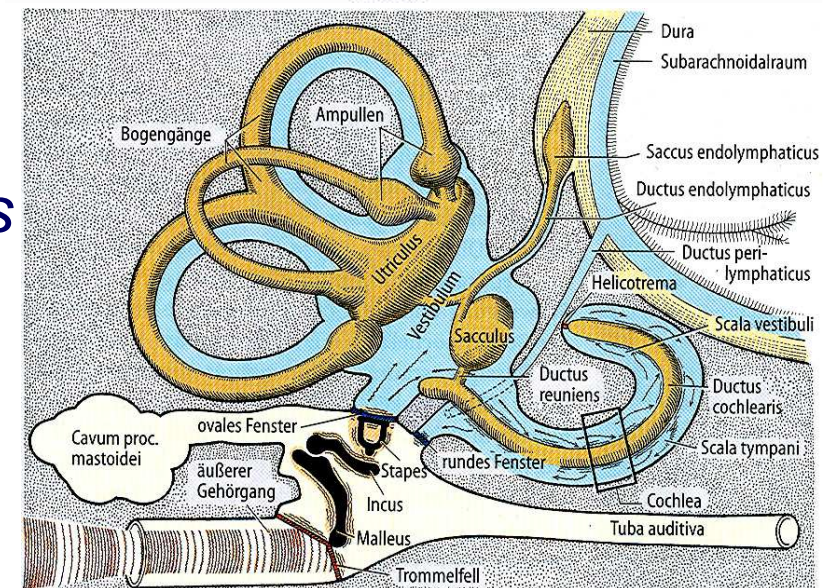
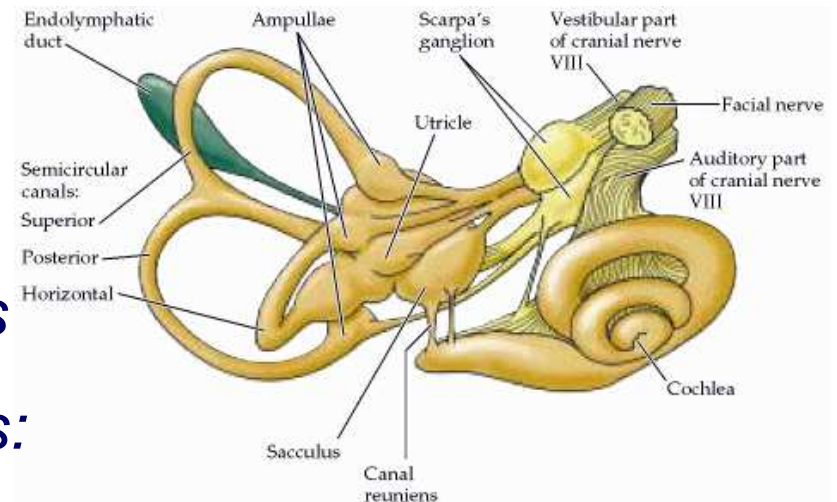
- ✓ ***labyrinthus cochlearis*** –
 - membranous cochlea (cochlear duct)
 - spiral organ of Corti





Vestibular labyrinth, *labyrinthus vestibularis*

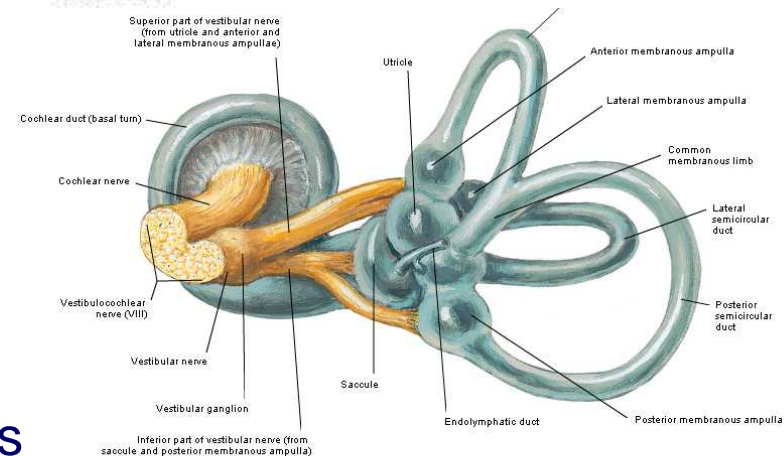
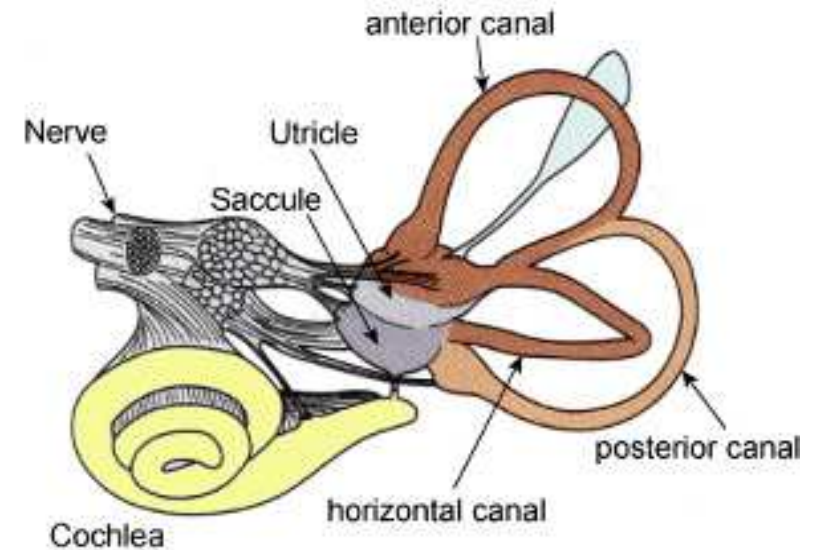
- *utricle* – in *recessus ellipticus*:
 - ✓ *ductus utriculosaccularis*
 - ✓ *macula utriculi* – $\frac{2}{3}$ mm: *pars utricularis n. vestibulocochlearis*
- *sacculus* – in *recessus sphericus*:
 - ✓ *ductus reuniens* \Rightarrow *ductus cochlearis*
 - ✓ *macula sacculi* – *pars saccularis n. vestibulocochlearis*
- *ductus endolymphaticus* \Rightarrow *saccus endolymphaticus*





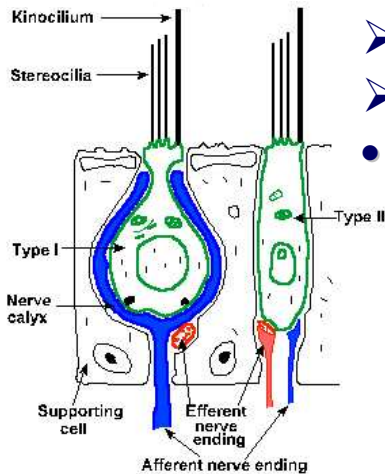
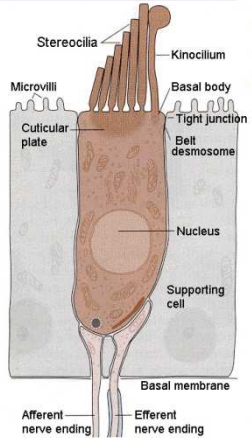
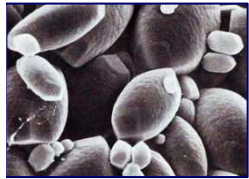
Vestibular labyrinth, *labyrinthus vestibularis*

- semicircular ducts:
 - ✓ *ductus semicircularis lateralis*
 - ✓ *ductus semicircularis anterior*
 - ✓ *ductus semicircularis posterior*
- ¼ of the semicircular canals
- *ampulla membranacea*
- *crus membranaceus*:
 - ✓ *simplex* – for lateral duct
 - ✓ *commune* – anterior&posterior ducts
- wall – thickened, three layers:
 - ✓ inner – simple squamous epithelium
 - ✓ middle – vascular connective tissue
 - ✓ outer – fibrous tissue with blood vessels clothed by flattened perilymphatic cells



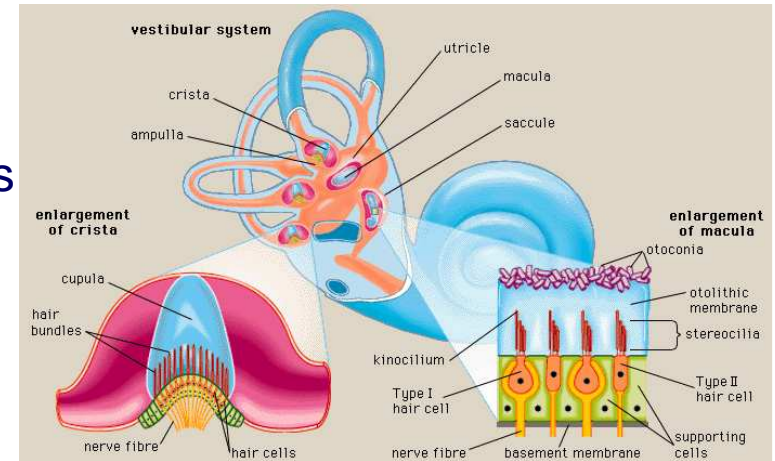
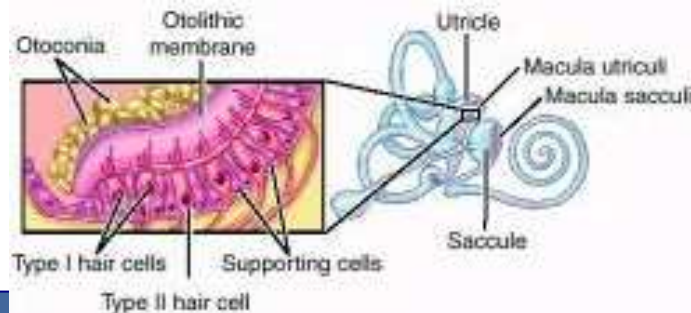


Vestibular system

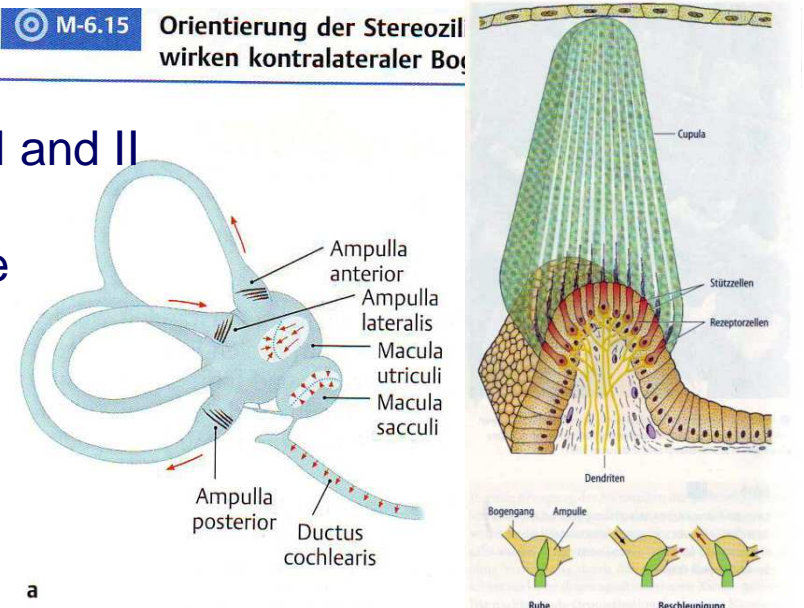


- Statoreceptor spots:
 - ✓ *macula utriculi* and *macula sacculi*:
 - neuroepithelium:
 - *epitheliocyti sensorii pilosi* – 2 types
 - ⇒ 40-80 stereocilia; 1 kinocilium
 - *epitheliocyti sustentantes*
 - *membrana statoconiorum* – otoliths, *statoconia* (Gr. *oto-*, ear + *λιθος, lithos*, a stone)

- ✓ *cristae ampullares*:
 - neuroepithelium:
 - *epitheliocyti sensorii pilosi* – type I and II
 - *epitheliocyti sustentantes*
 - *cupula* – a glycoprotein substance



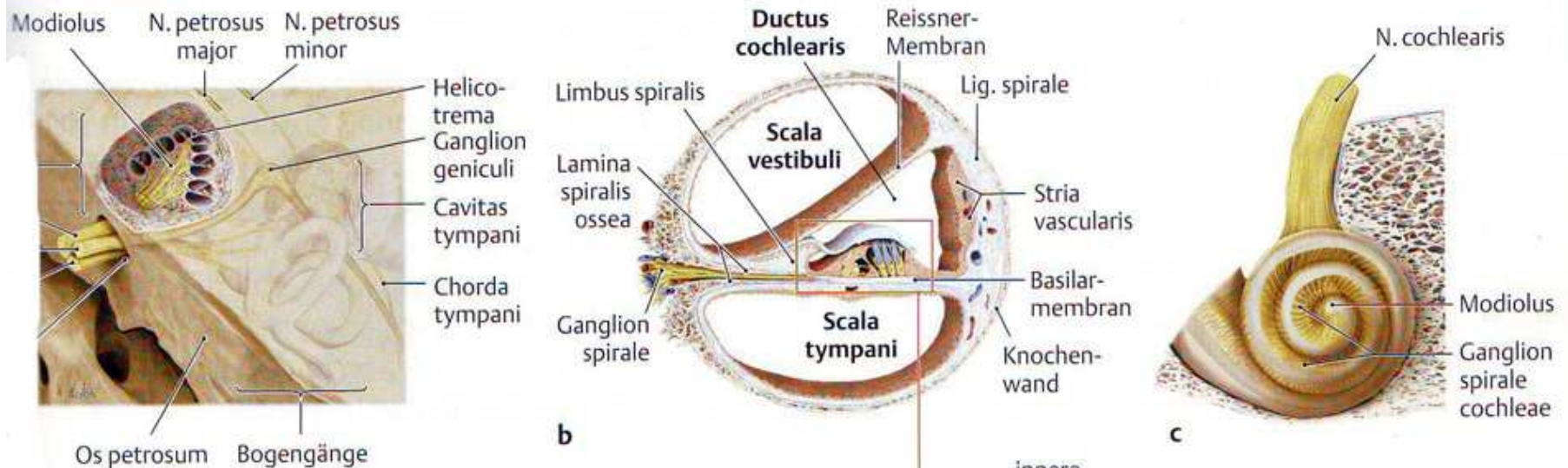
M-6.15 Orientierung der Stereozil wirken kontralateraler Bo





Cochlear labyrinth, *labyrinthus cochlearis*

Lage und Aufbau des Ductus cochlearis in der knöchernen Schnecke



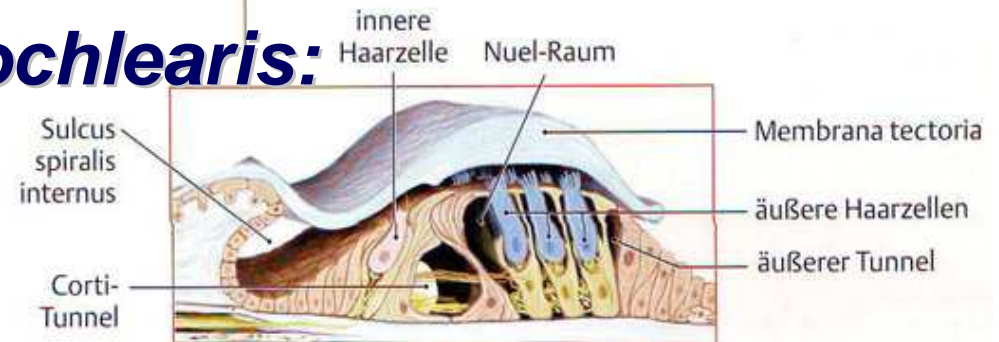
■ cochlear duct, *ductus cochlearis*:

✓ *scala media* – endolymph

✓ length ~35 mm

✓ *cecum vestibulare* – in *recessus cochlearis*

✓ *cecum cupulae* – in *cupula cochleae*





Cochlear duct, *ductus cochlearis*

- *paries vestibularis* – vestibular membrane (of *Reissner*) – two layers:

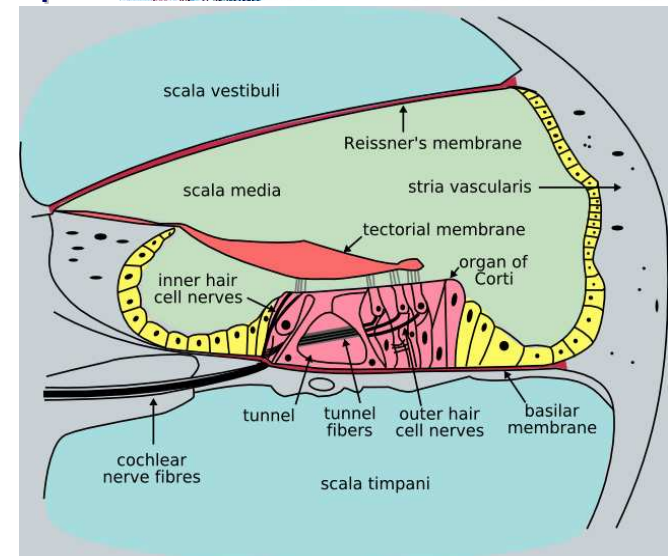
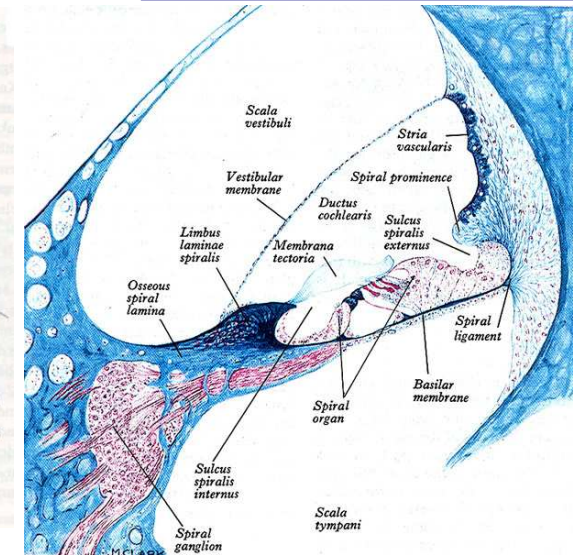
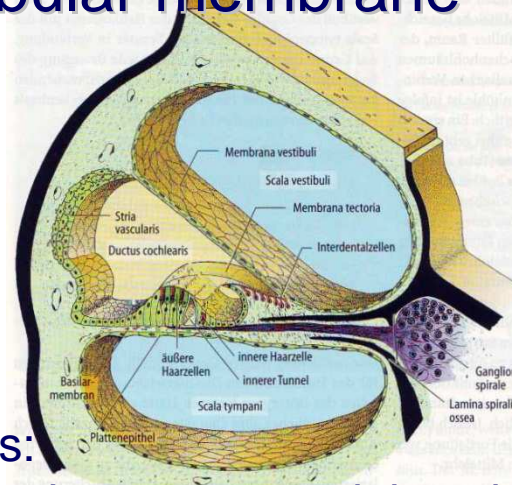
- ✓ basal lamina
- ✓ simple squamous epithelium

- *paries externus*:

- ✓ *lig. spirale cochleae*
- ✓ *stria vascularis*: three cell types: marginal, intermediate and basal – secrete endolymph

- *paries tympanicus* – basilar membrane (*membrana spiralis*):

- ✓ internal zone – *sulcus spiralis internus*, *limbus spiralis* (tympanic and vestibular lips ⇒ *membrana tectoria*),
- ✓ middle zone – spiral organ of *Corti*
- ✓ external zone – *sulcus spiralis externus*



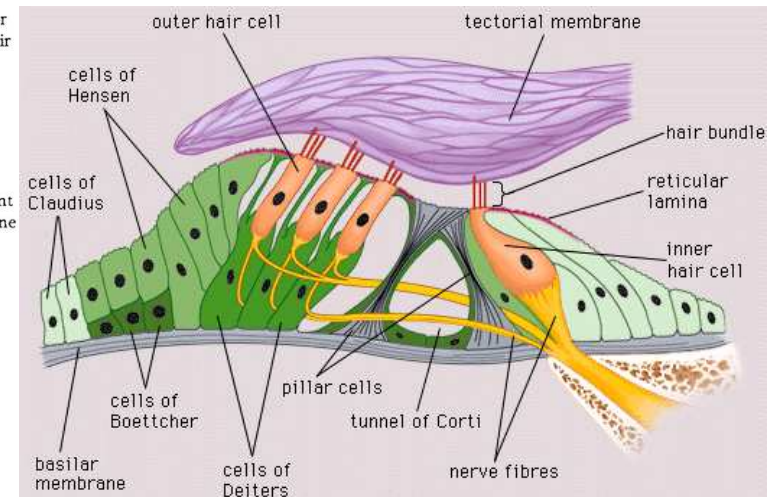
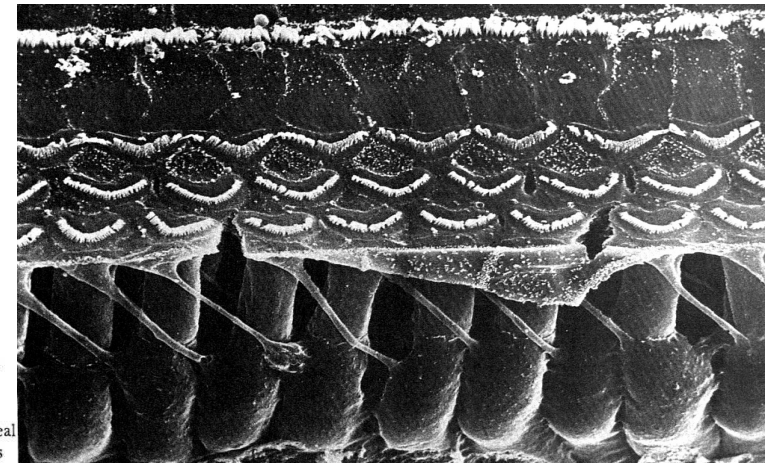
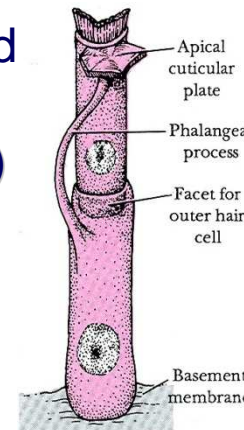


Alfonso Corti
(1822–1876)

Spiral organ of Corti, *organum spirale*

✓ located onto *basilar membrane*: 100 μm basal, 500 μm apical turns

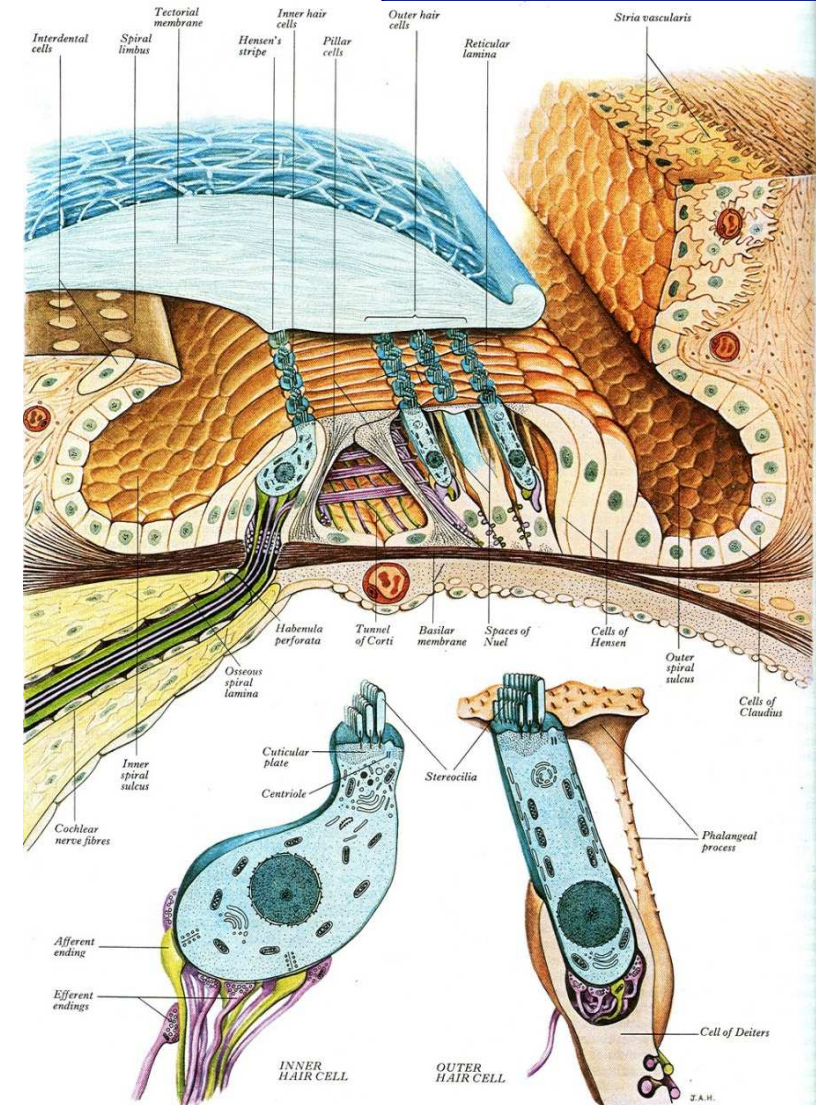
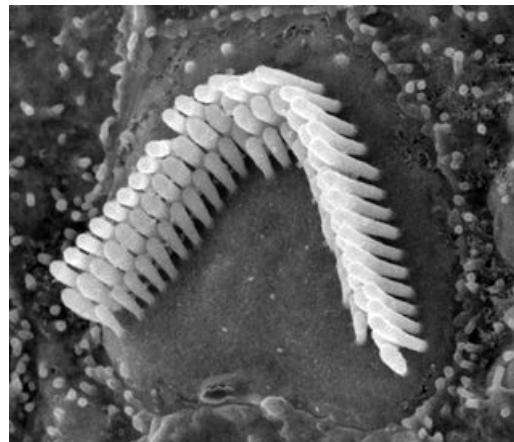
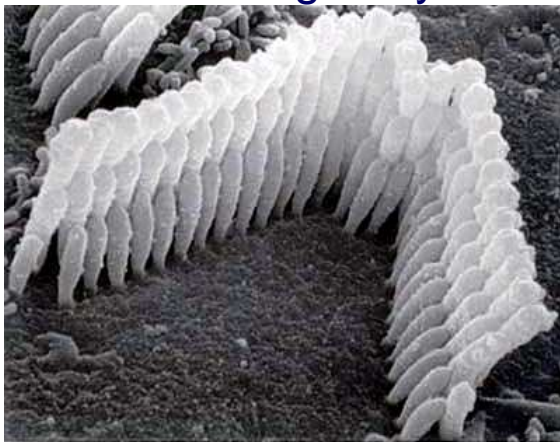
- receptor (sensory) and supporting cells:
 - ✓ internal and external rod (pillar) cells of Corti
 - ⇒ *cuniculus internus* (inner tunnel of Corti)
 - ⇒ *cuniculus medius* (space of Nuel)
 - ✓ internal phalangeal cells of *Deiters* – 1 row and external phalangeal cells of *Deiters* – 3 rows
 - ✓ internal (inner) hair cells – 1 row and external (outer) hair cells – 3 rows
 - ⇒ *cuniculus externus* (outer tunnel)
 - ✓ *epitheliocyti limitantes externi* (cells of *Hensen*) – 3-4 rows
 - ✓ *epitheliocyti sustentantes externi* (cells of *Claudius*)
 - ✓ supporting cells of *Boettcher* – beneath *Claudius* cells in the lower turn of the cochlea
 - ✓ *epitheliocyti limitantes interni* – 1-2 rows
 - ✓ *epitheliocyti sustentantes interni* – 2-3 rows





Hair cells, *epitheliocytii sensorii pilosi*

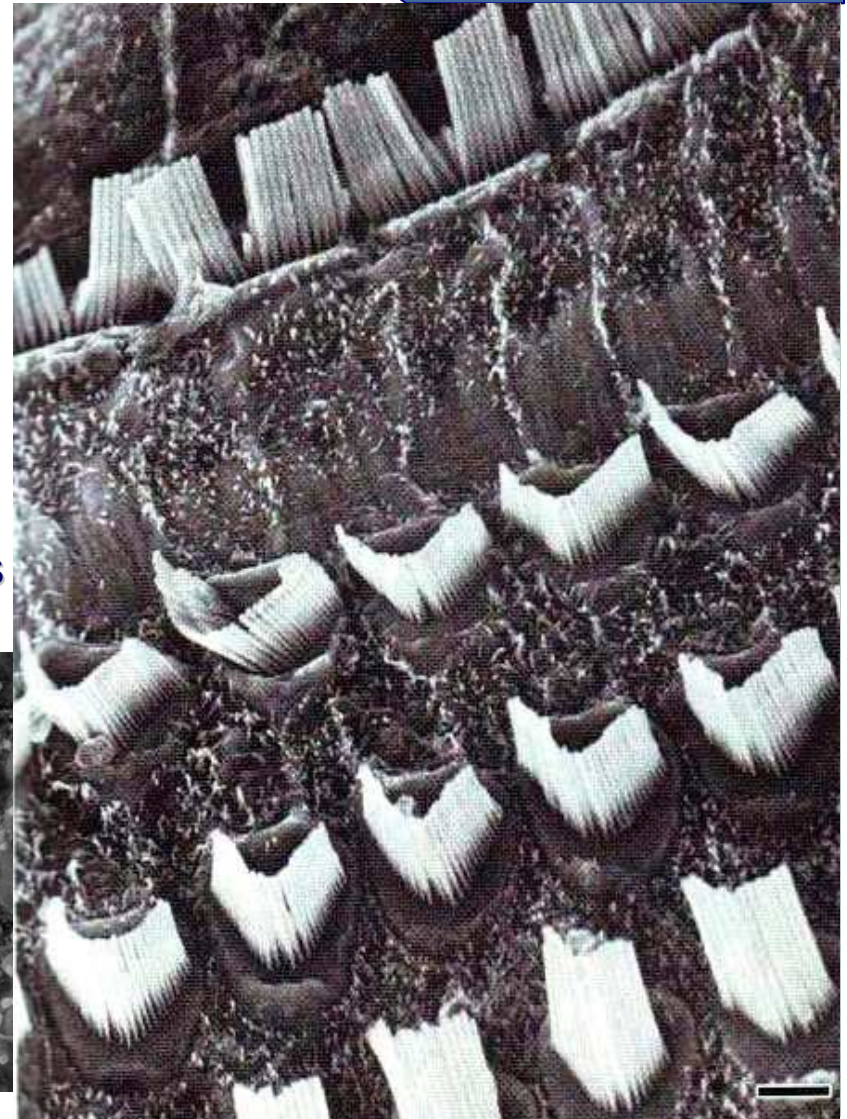
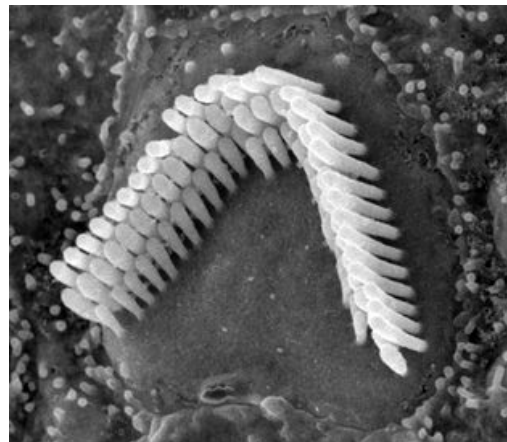
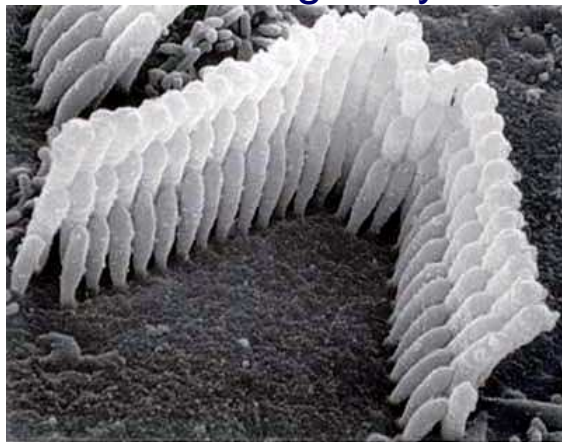
- inner (internal) hair cells:
 - ✓ ~ 3500 in number
 - ✓ arranged in a single row
 - ✓ carry 50-60 linear stereocilia
 - ✓ damaged by diuretics, ototoxic antibiotics (aminoglycosides)
- outer (external) hair cells:
 - ✓ longer cells, 12 000-20 000 in number
 - ✓ arranged in three rows (basally) and in 4-5 rows (apically)
 - ✓ carry stereocilia, arranged in V or W-forms
 - ✓ damaged by chinin derivatives





Hair cells, *epitheliocytii sensorii pilosi*

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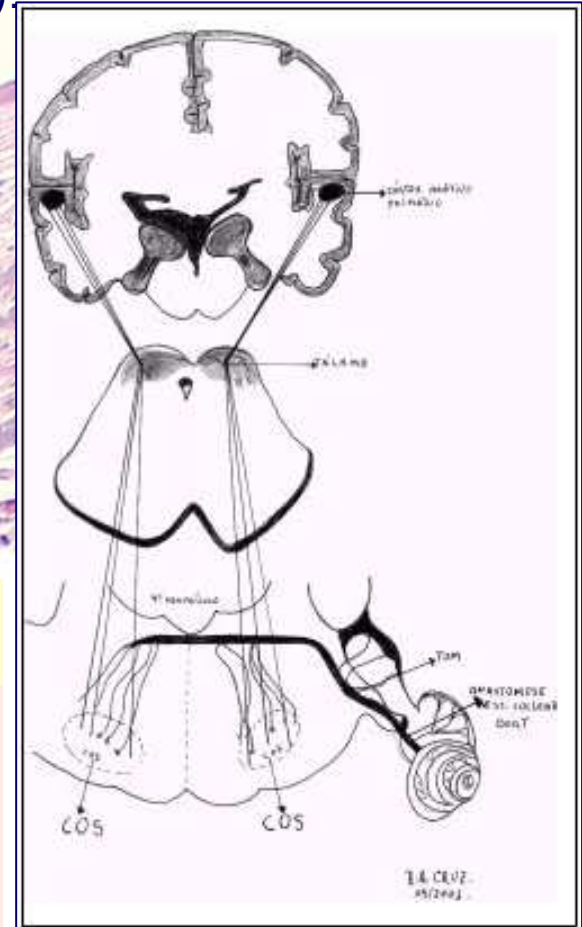
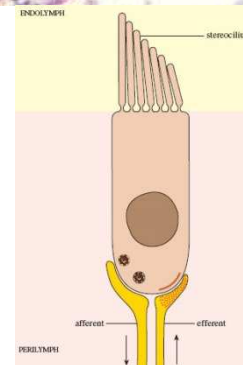
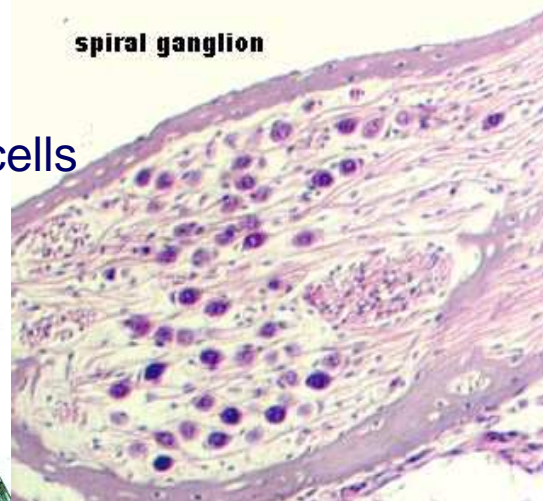
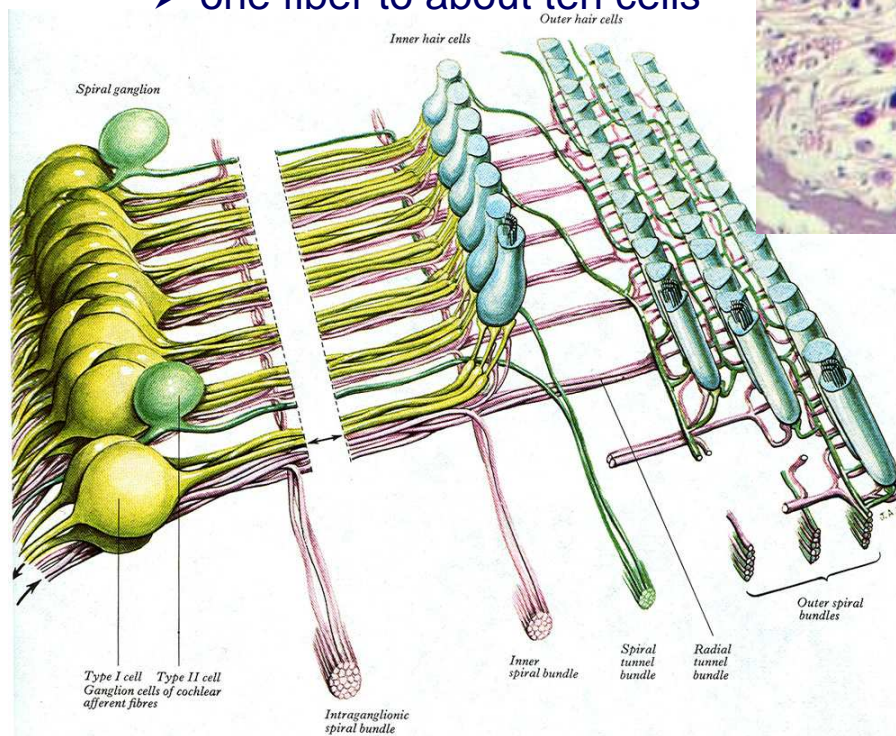




Cochlear innervation

- Afferent innervation – from spiral ganglion (in modiolus):

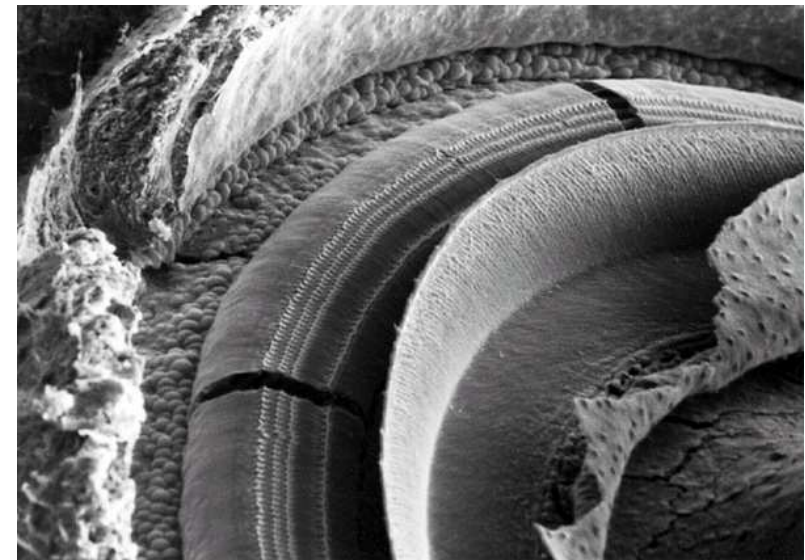
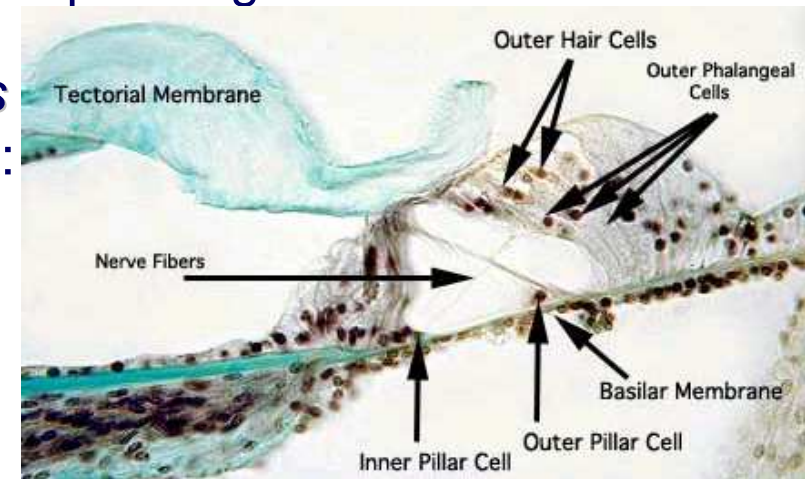
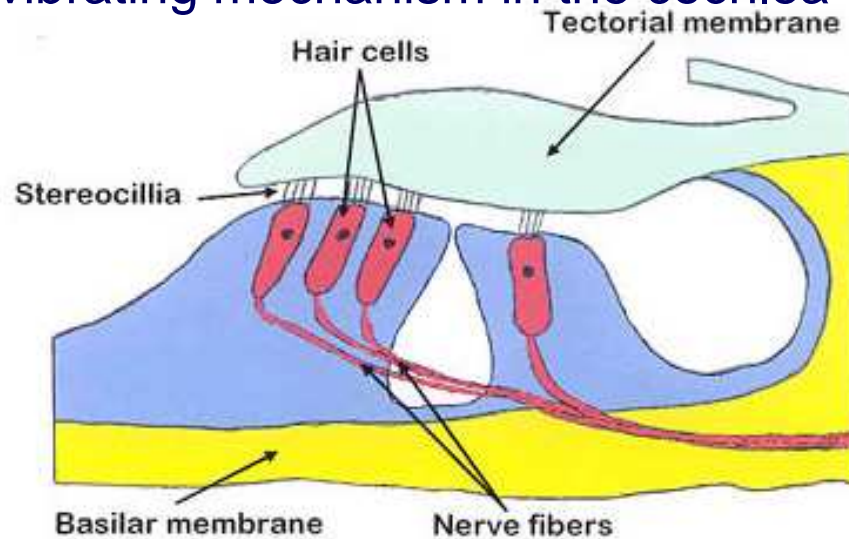
- ✓ large bipolar type I cells – ~ 95% of all afferent neurons
 - ⇒ inner hair cells
 - about ten fibers to each cell
- ✓ small pseudounipolar type II cells
 - ⇒ outer hair cells
 - one fiber to about ten cells



- Efferent innervation – *tractus olivocochlearis* (*Rasmussen's tract*)
 - ⇒ cholinergic inhibitory synapses

Tectorial membrane, *membrana tectoria (Cortii)*

- overlies the sulcus spiralis internus and the spiral organ of *Corti*
- secreted by the epithelial cells of the vestibular lip of the *limbus laminae spiralis*
- colorless fibers embedded in a jelly-like matrix:
 - ✓ 4 μm filaments of soft keratin
 - ✓ glycosaminoglycans
- covers the hair cells in organ of *Corti*, making contacts with their stereocilia
- the vibrating mechanism in the cochlea



Mechanism of the auditory reception

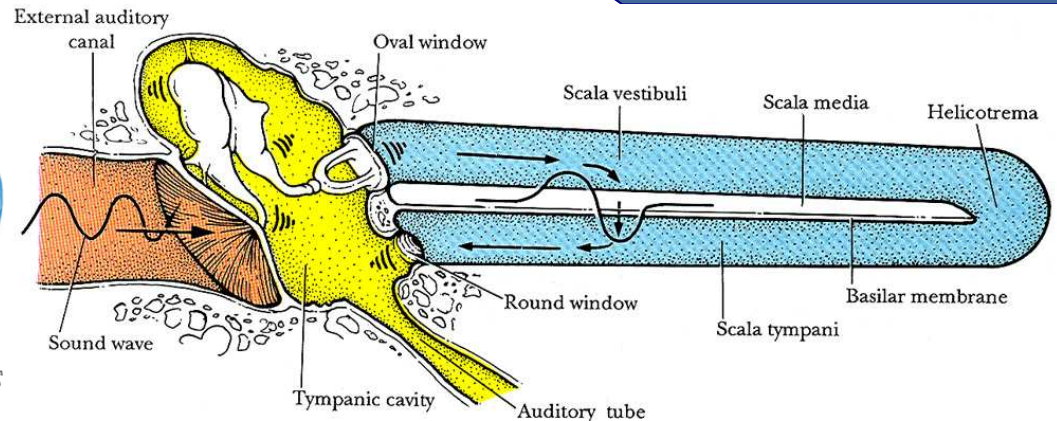
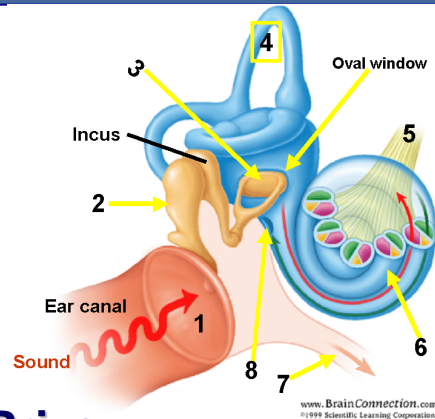


Georg von Békésy
(1899-1972)



**The Nobel Prize
in Physiology or Medicine 1961**
"for his discoveries of the physical
mechanism of stimulation within the cochlea"

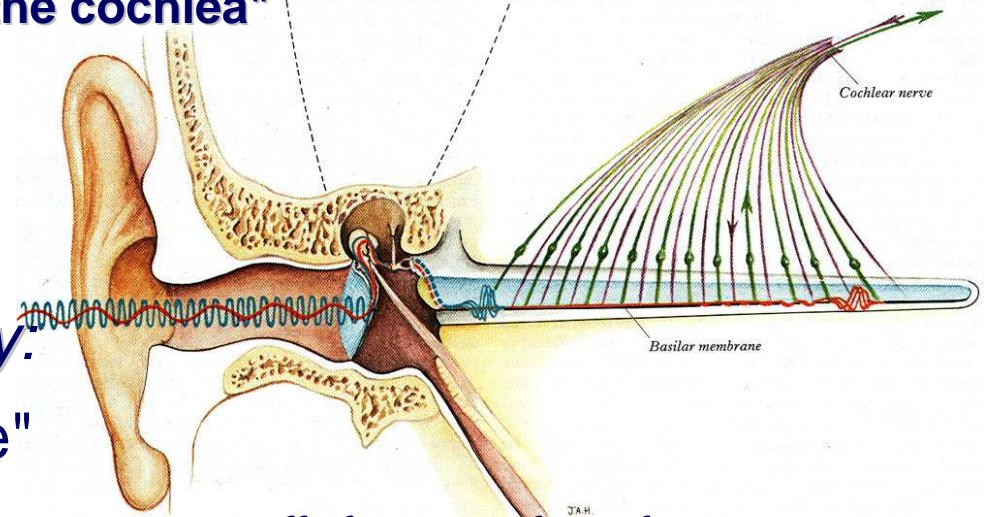
- *Helmholtz* resonance theory
- *Rutherford* telephone theory
- travelling wave theory of *Békésy*.
- ✓ basilar-membrane "resonance"



EXTERNAL EAR
Sound collection and amplification;
source location.

MIDDLE EAR
Amplification of signal (force
per unit area); impedance
matching between air and
water vibrations; neural
reflex and mechanical damping
of excessive vibration; pressure
equalizing through tympanic tube.

INNER EAR
Mechanical and neural filtering and
analysis of signals by spiral organ;
stimulus transduction by sensory
cells; action potential initiation
at synapses between cochlear nerve
fibres and sensory cells; central
control by centrifugal fibres.



NB: The human ear can nominally hear sounds in the range 12 Hz

Auditory pathways

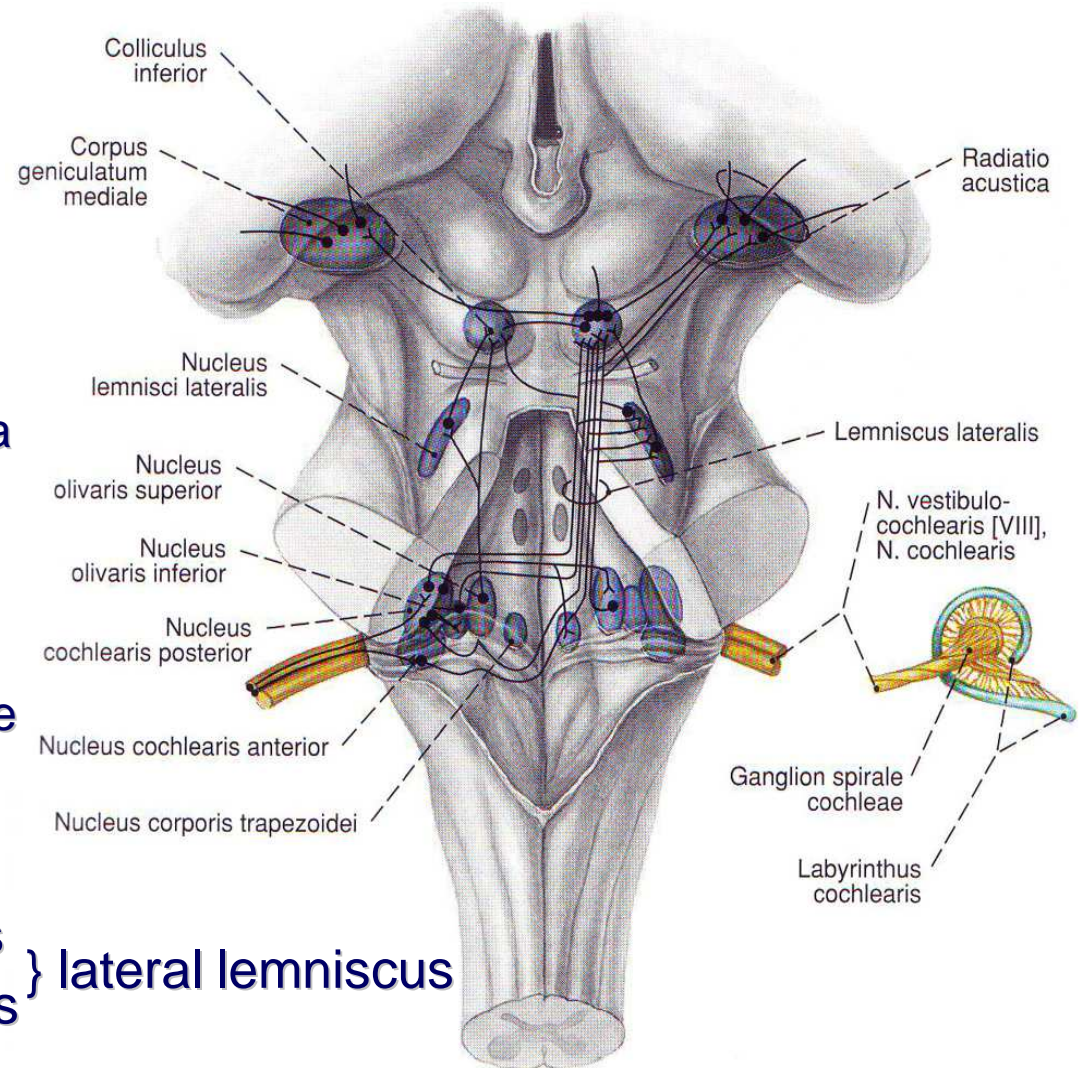


Ist neuron – spiral ganglion:

- ✓ true bipolar neurons – 30000-33000 cells
 - cell bodies in the spiral structure of the cochlea
 - peripheral processes ⇒ spiral organ of *Corti*
 - central processes ⇒ cochlear part of the vestibulocochlear nerve

IInd neuron – cochlear nuclei:

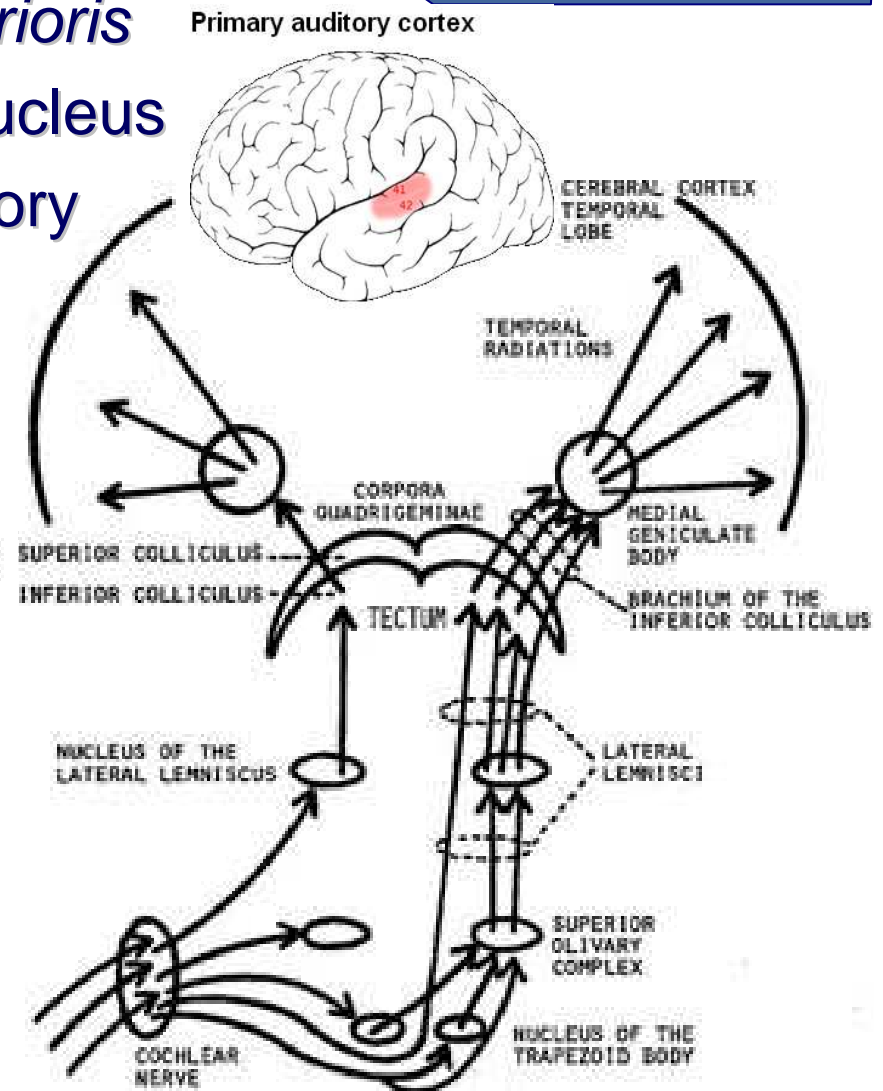
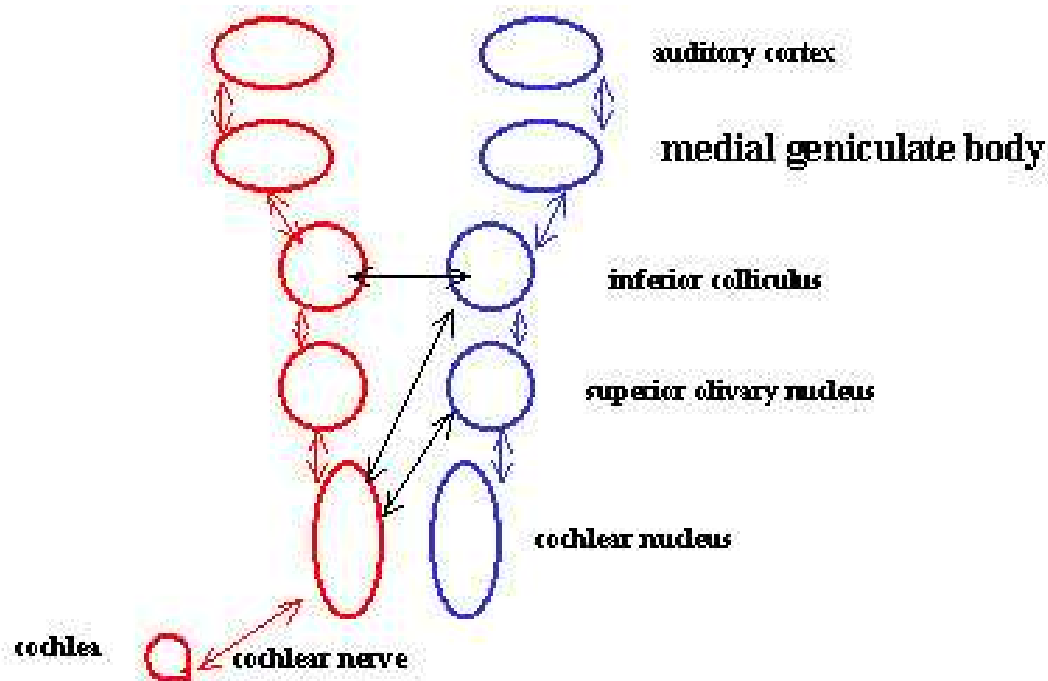
- ✓ dorsal cochlear nucleus
 - ✓ ventral cochlear nucleus
- } lateral lemniscus





Central auditory pathways

- IIIrd neuron – *nucleus colliculi inferioris*
- IVth neuron – medial geniculate nucleus
- ✓ *acoustic radiation* ⇒ primary auditory cortex (A-I) = *Brodmann's area 41* (upper part of *gyrus temporalis superior*)

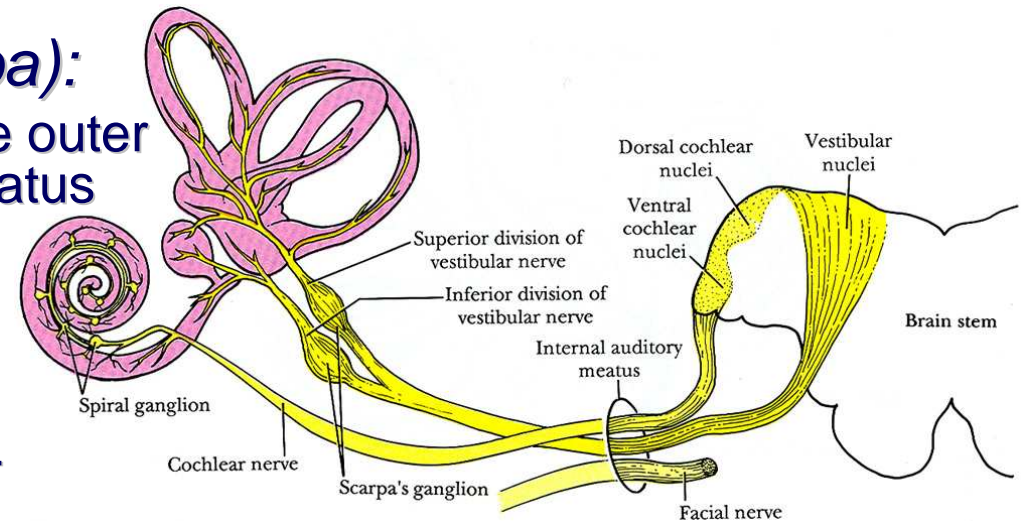




Vestibular pathways

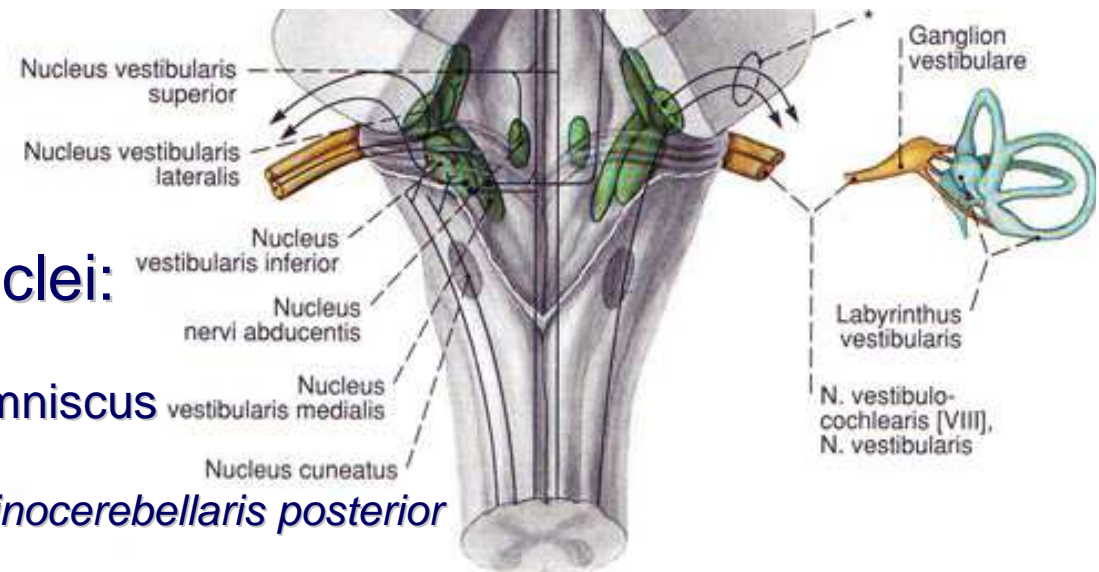
Ist neuron – vestibular ganglion (of Scarpa):

- ✓ situated in the upper part of the outer end of the internal auditory meatus
- ✓ true bipolar neurons – ~20000 cells
 - peripheral processes ⇨ statoreceptor spots in:
 - *maculae utriculi et sacculi* – linear acceleration
 - *semicircular ducts* – angular acceleration
 - central processes ⇨ vestibular part of the vestibulocochlear nerve



IInd neuron – vestibular nuclei:

- ✓ superior (Bechterew)
- ✓ inferior (Roller) } lateral lemniscus
- ✓ medialis (Schwalbe)
- ✓ lateralis (Deiters) ⇨ tractus spinocerebellaris posterior



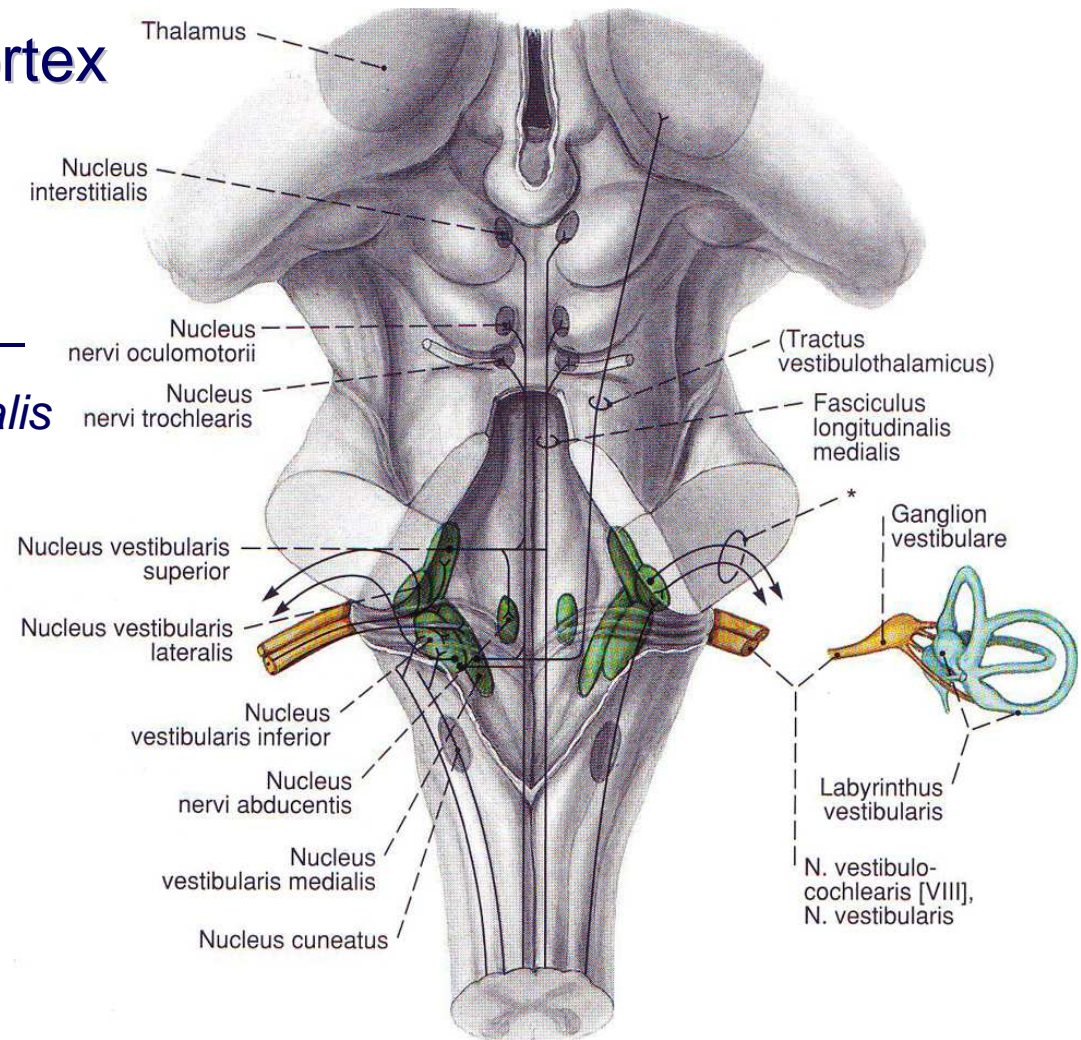


Central vestibular pathways

- IIIrd neuron – medial geniculate nucleus
- IVth neuron – vestibular cortex
 - ✓ rostral part of *gyrus temporalis superior*

- ✓ **tractus vestibulothalamicus** –
 - *nucleus ventralis posterolateralis*
 - *nucleus ventralis posterior inferior*

- ✓ **tractus thalamocorticalis** – *internal capsule* ⇒ vestibular area in *gyrus postcentralis (area 3a)* and around *sulcus intraparietalis*





Thank you...

