

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***

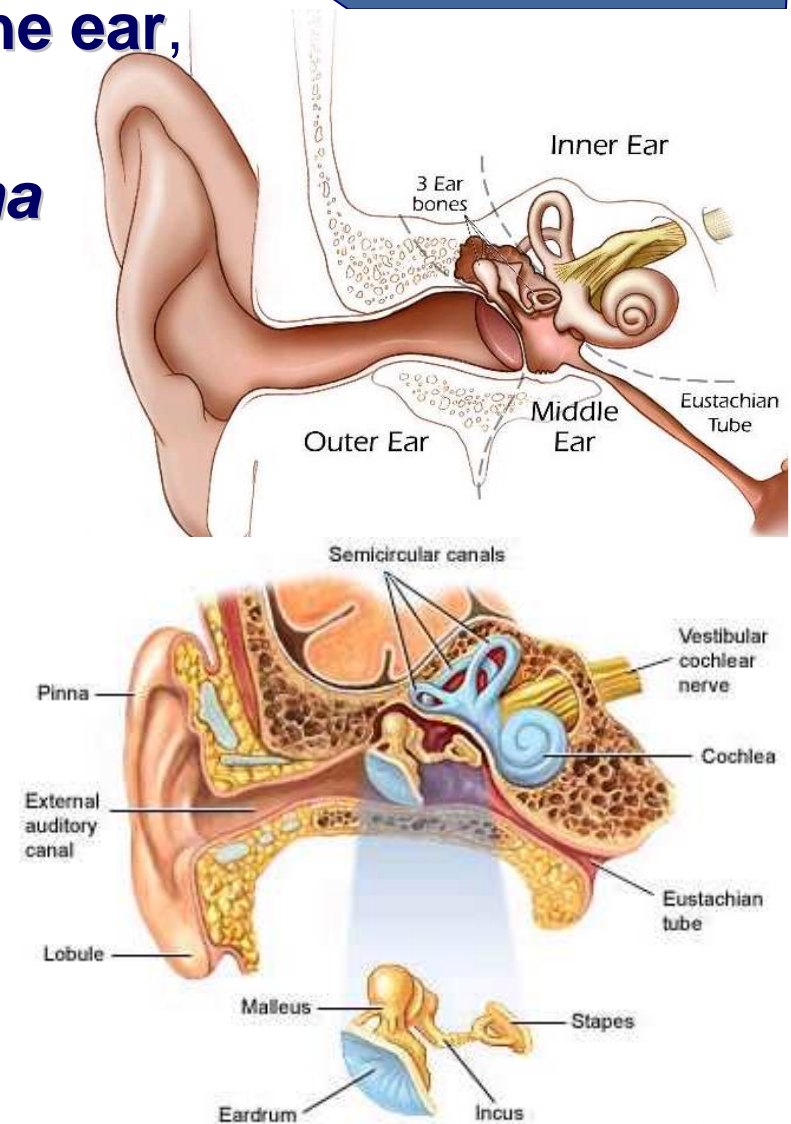
- auricle (pinna)
- external auditory meatus (ear canal)

- ✓ 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

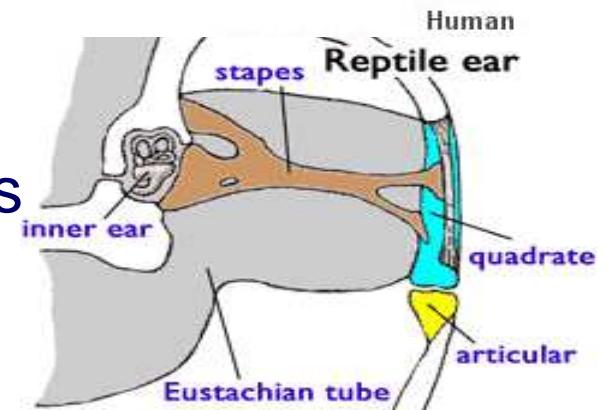
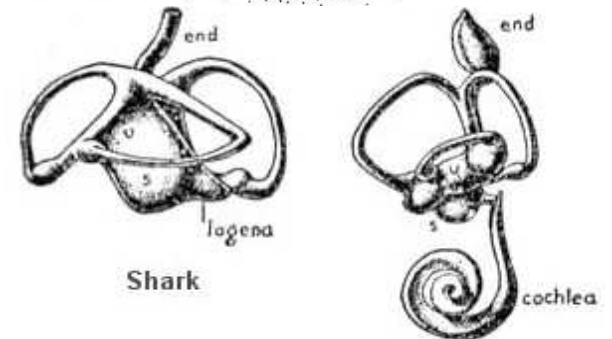
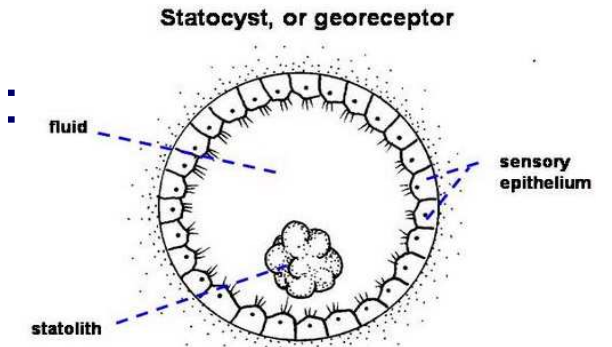
- The vestibular system – antedates the cochlear system:

- ✓ 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



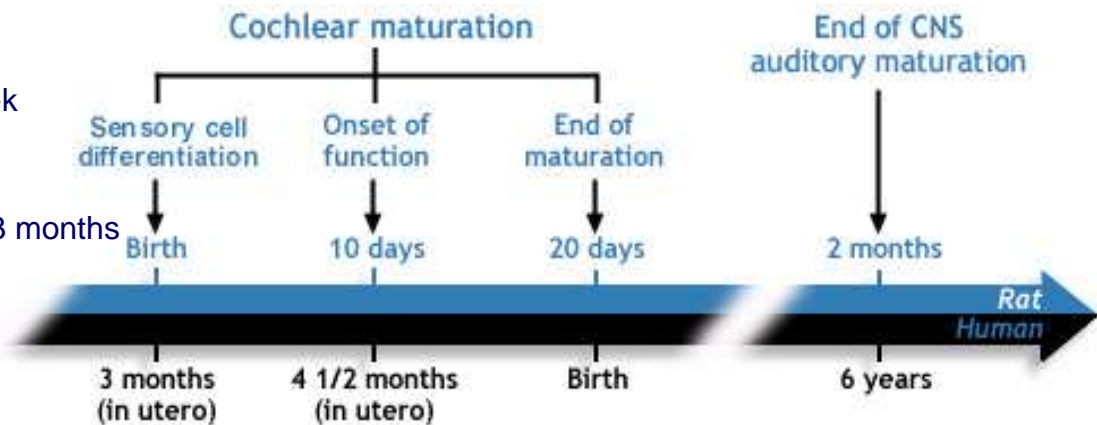


Ontogenesis of the ear

- 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



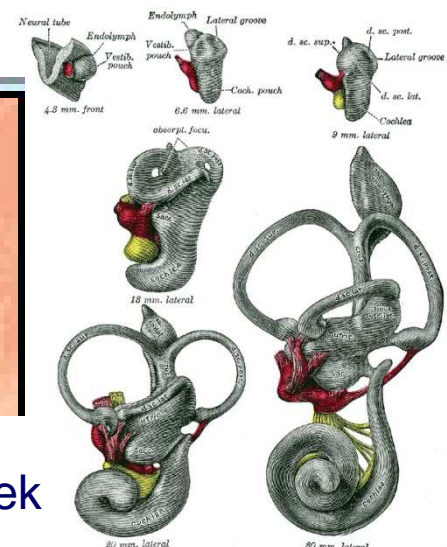
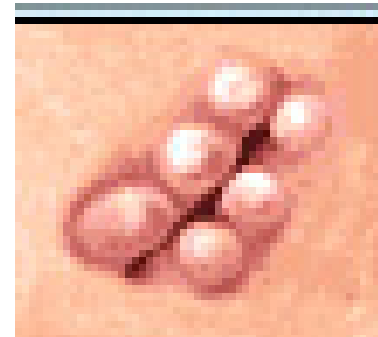
■ head mesenchyme:

✓ 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

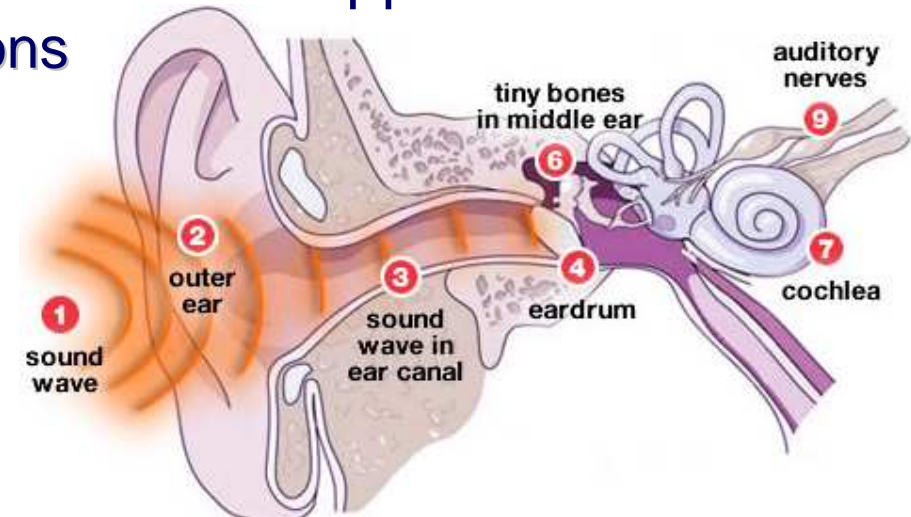
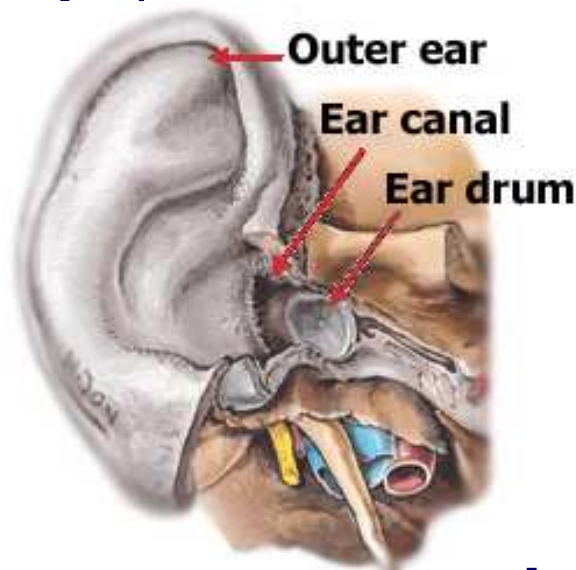
- auricle – six mesenchymal hillocks
- external acoustic meatus – begin of development: 8th week





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



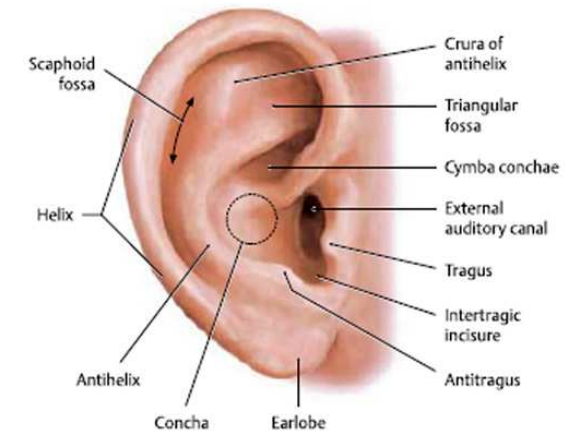
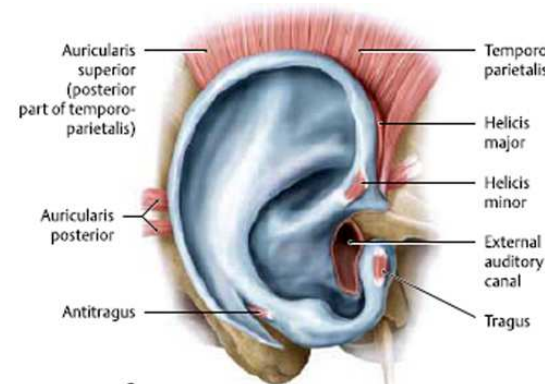
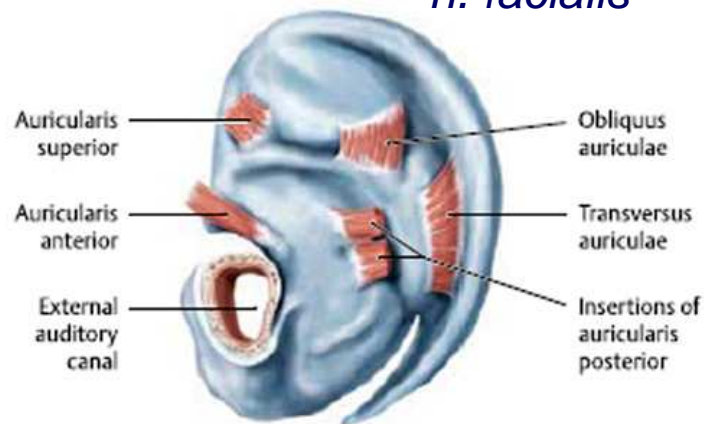
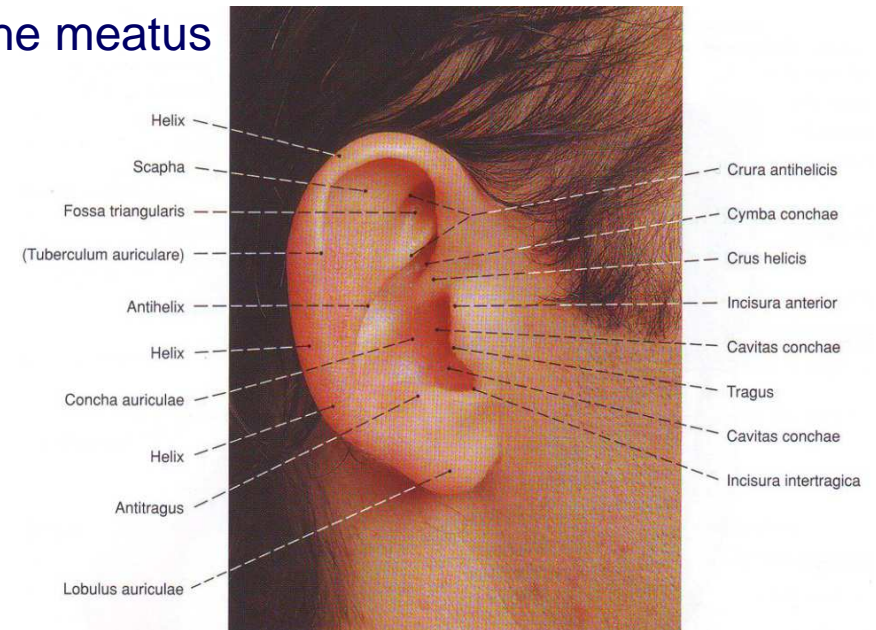
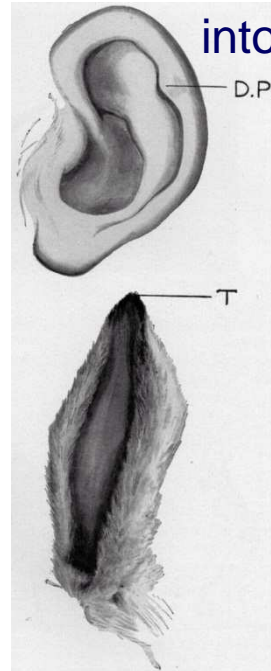
- ✓ auricle (pinna) – ***auricula***
- ✓ external acoustic meatus
(ear canal) – ***meatus acusticus externus***



Auricle, auricula

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

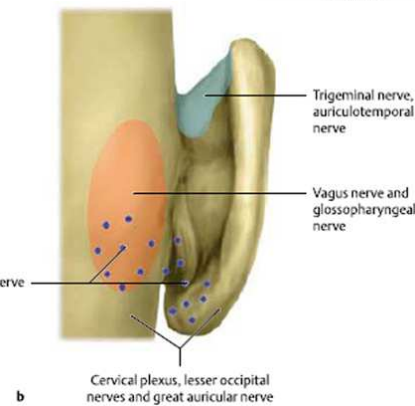
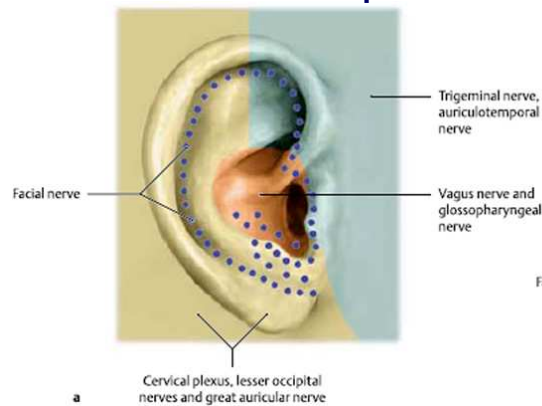
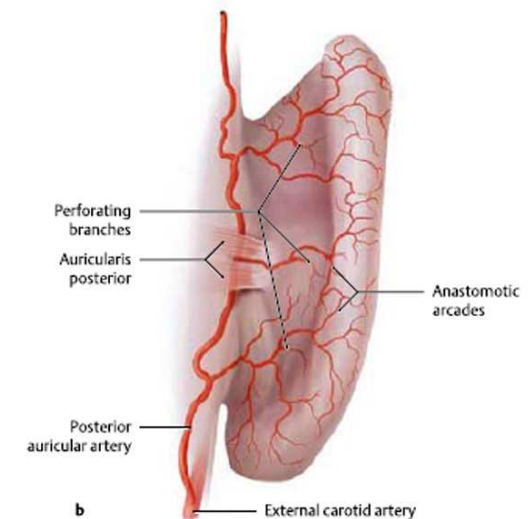
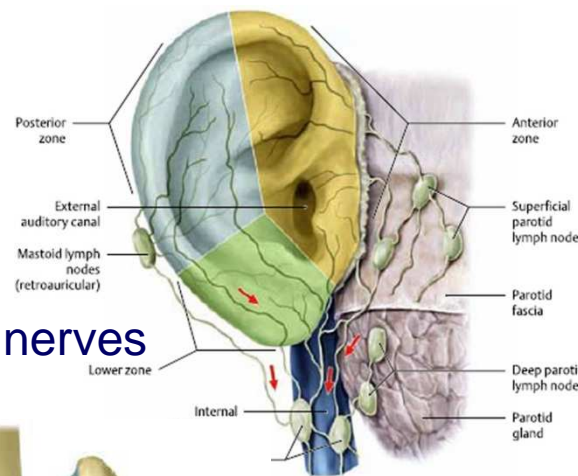
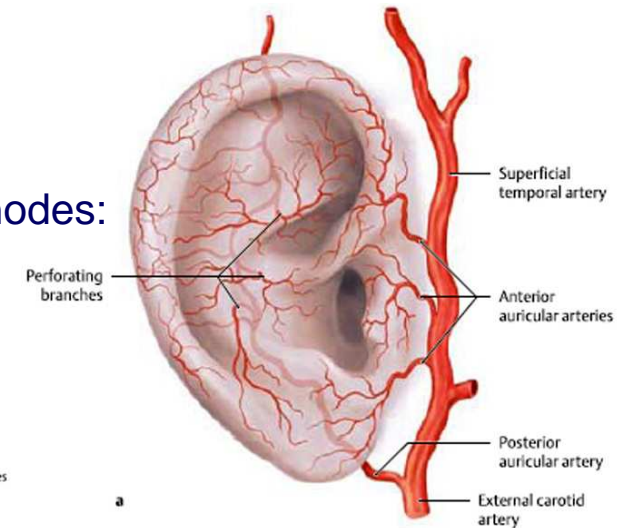
- ✓ thin skin with fine hairs
- ✓ elastic fibrocartilage
- ✓ lobule of auricle
- ✓ auricular tubercle (of Darwin)
- ✓ ligaments of auricle, extrinsic and intrinsic,
- ✓ auricular muscles – extrinsic and intrinsic, *n. facialis*





Auricle, auricula

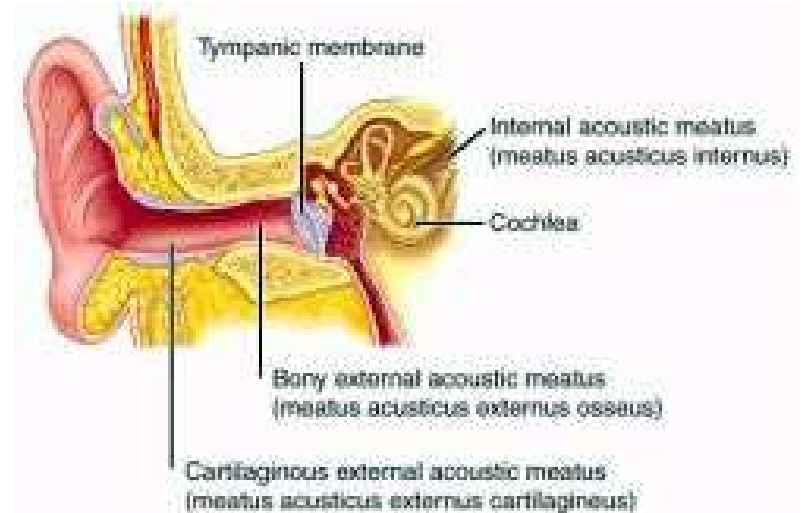
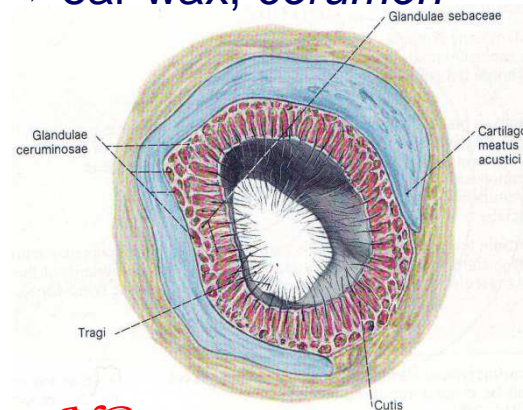
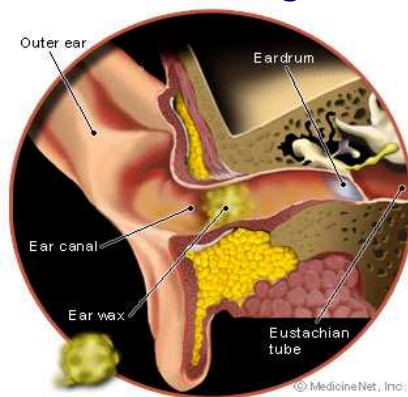
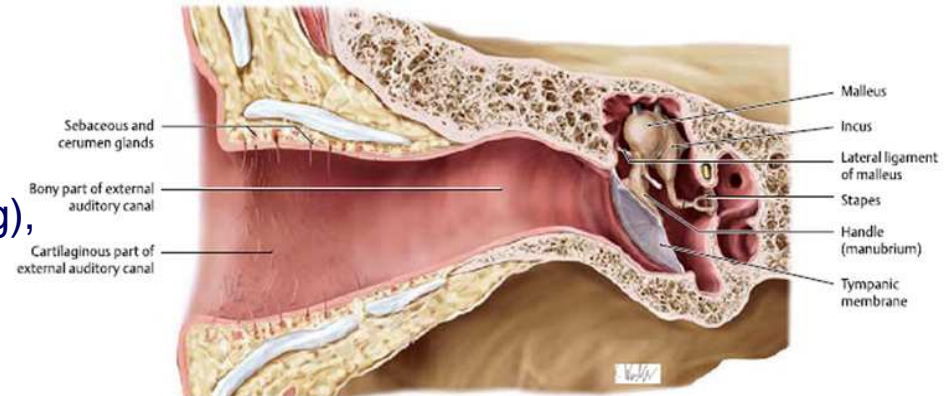
- Arterial supply of the auricle:
 - ✓ anterior auricular artery
 - ✓ posterior auricular artery
 - ✓ perforating branches
- Lymphatic drainage – three zones ⇒ deep cervical lymph nodes:
 - ✓ anterior zone
 - ✓ posterior zone
 - ✓ lower zone
- Sensory innervation:
 - ✓ trigeminal nerve
 - ✓ facial nerve
 - ✓ glossopharyngeal & vagus nerves
 - ✓ cervical plexus





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 $\frac{1}{3}$ (~8 mm long),
cartilago meatus acustici
 - ✓ osseous part – inner $\frac{2}{3}$ (~16 mm long),
meatus acusticus externus
 - ✓ thin skin; the thicker cerumen-producing ear canal skin has fine hairs, *tragi*
 - ✓ sebaceous glands \Rightarrow in the hair follicles
 - ✓ ceruminous glands \Rightarrow ear wax, *cerumen*

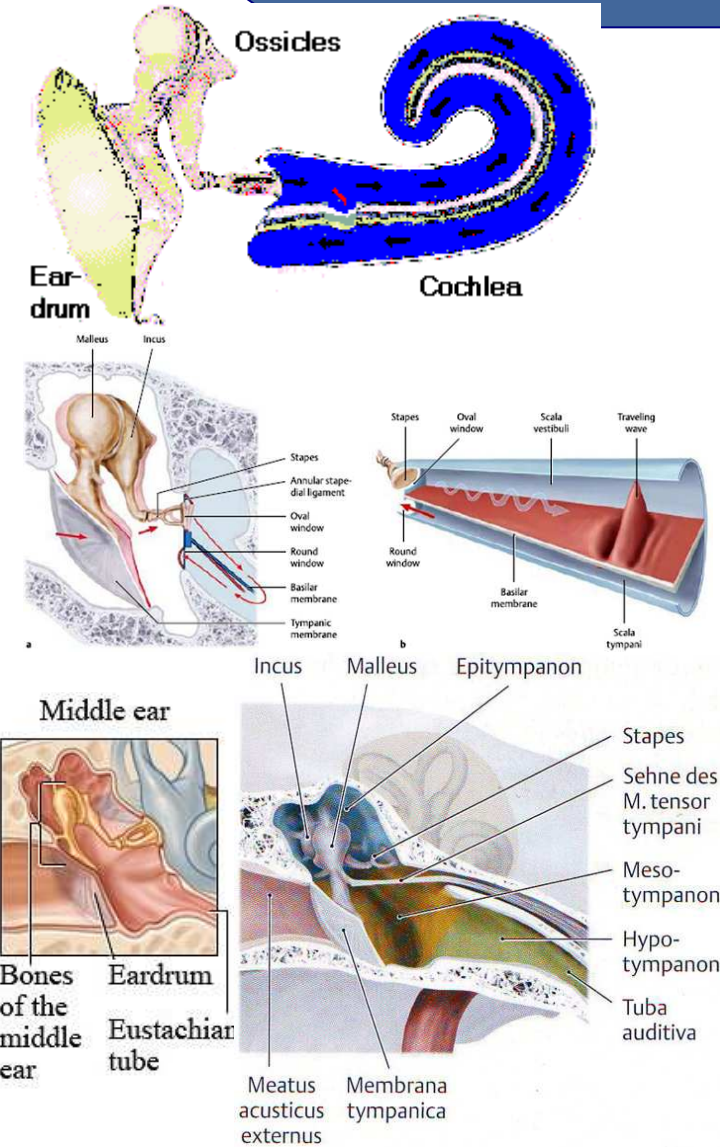
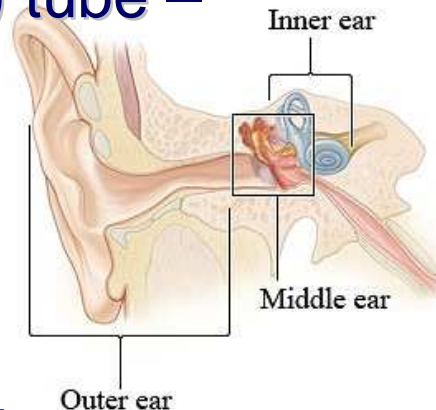


NB: The ear wax assists in cleaning and lubrication, and also



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*

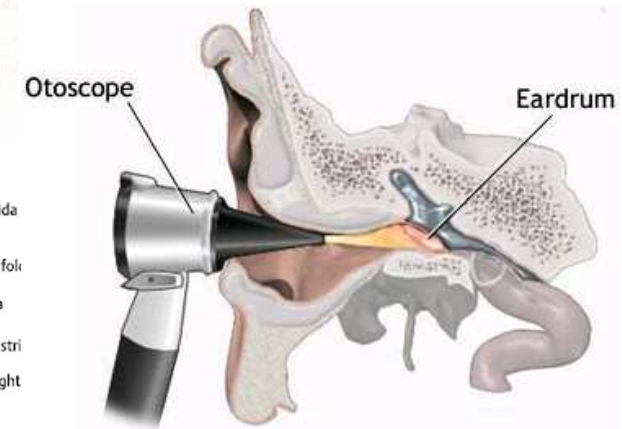
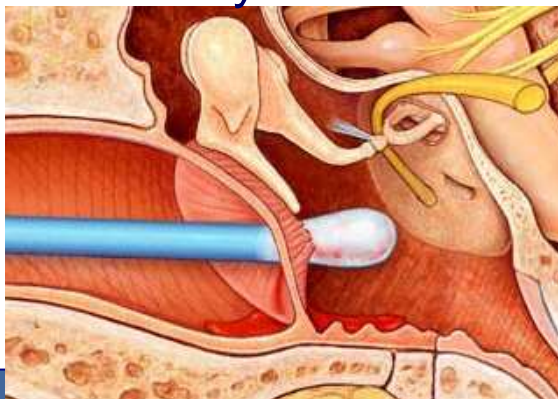
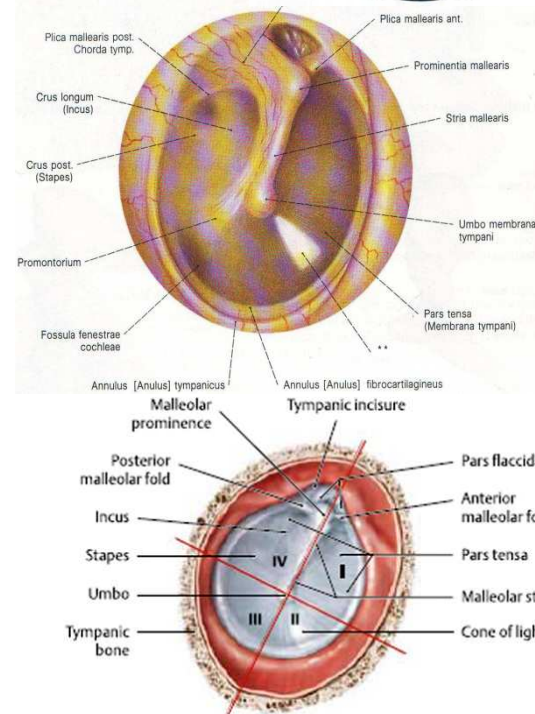
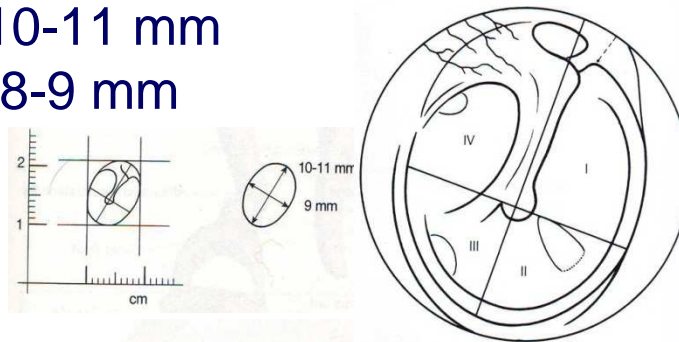
- **ear drum** – thin, semi-transparent, nearly oval in form:

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

- *pars flaccida* – Schrapnell's membrane

- *pars tensa* \Rightarrow *umbo*

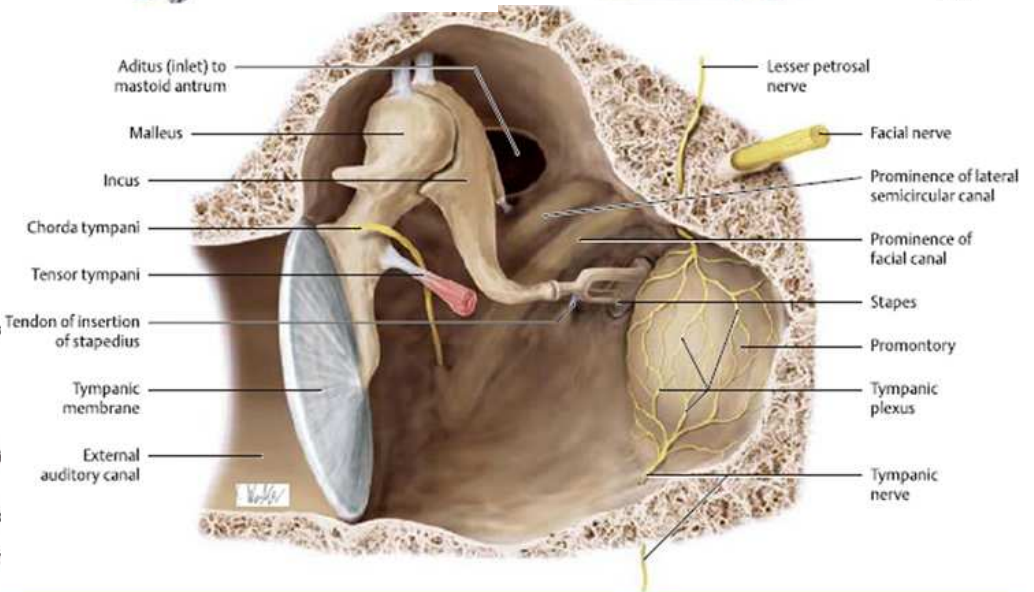
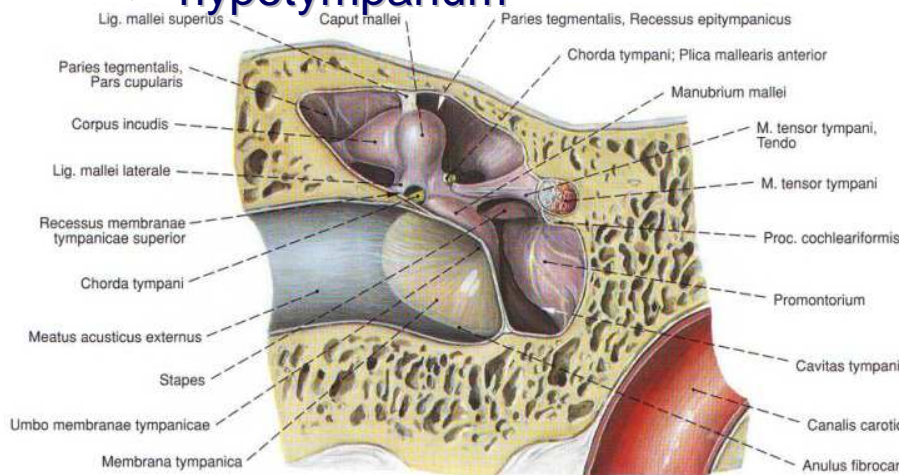
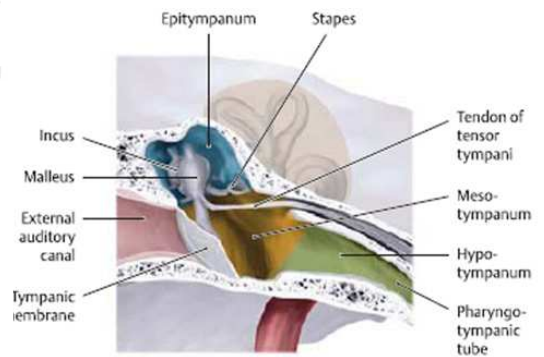
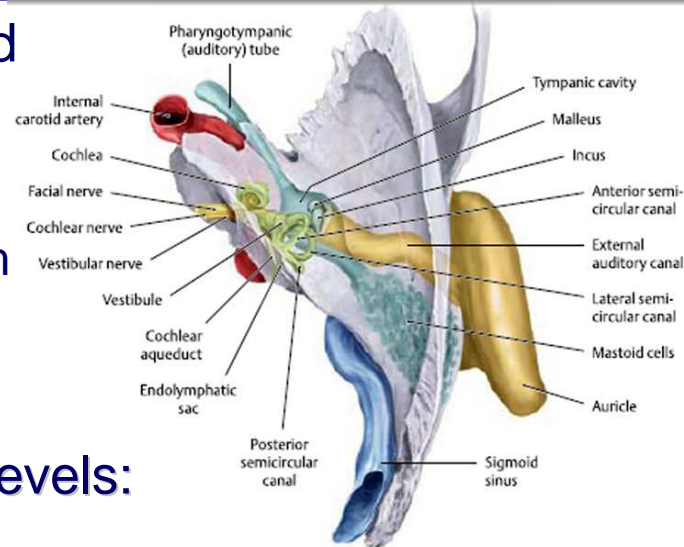
- ✓ cuticular layer
- ✓ fibrous layer – absent in *pars flaccida*:
 - radiate fibers
 - circular fibers
- ✓ mucous layer





Tympanic 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
- three clinically important levels:
 - ✓ epitympanum
 - ✓ mesotympanum
 - ✓ hypotympanum





Walls of the tympanic cavity

- six walls, lined with mucoperiosteum:

- ✓ lateral wall – ***paries membranaceus***:
membrana tympani et recessus epitympanicus

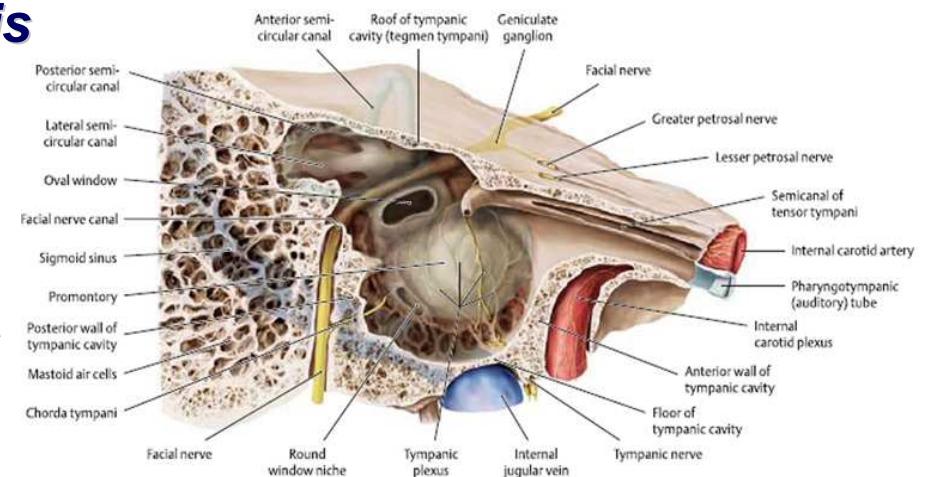
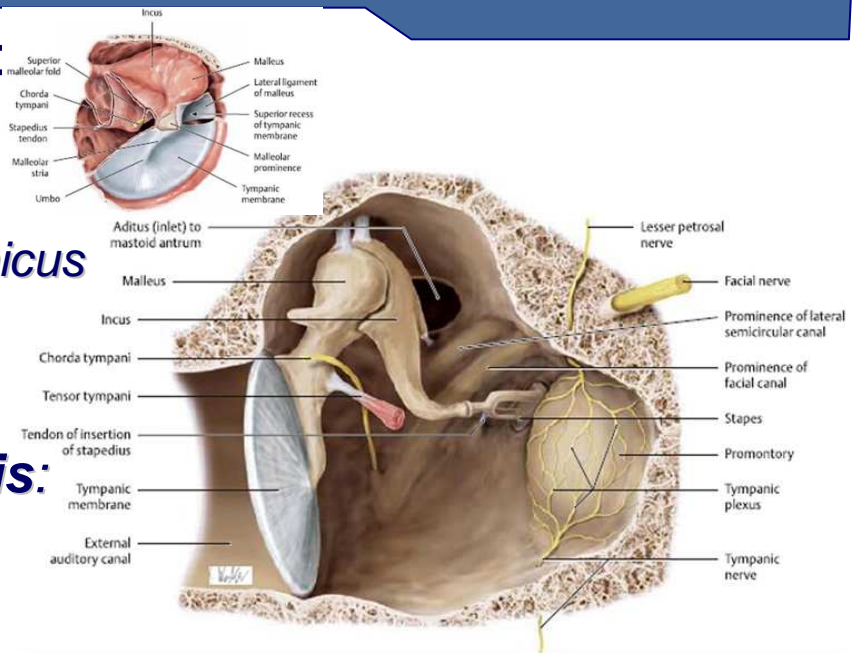
- ✓ medial wall – ***paries labyrinthicus***

- ✓ superior wall, roof – ***paries tegmentalis***:
tegmen tympani ⇒ otogenic meningitis

- ✓ inferior wall, floor – ***paries jugularis***
⇒ *canaliculus tympanicus*

- ✓ anterior wall – ***paries caroticus***

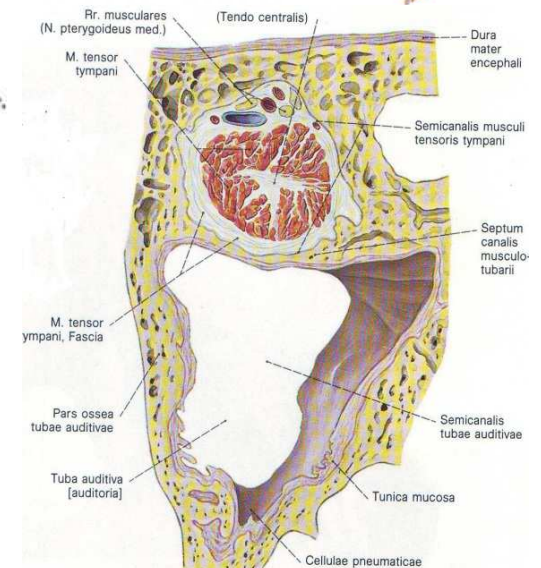
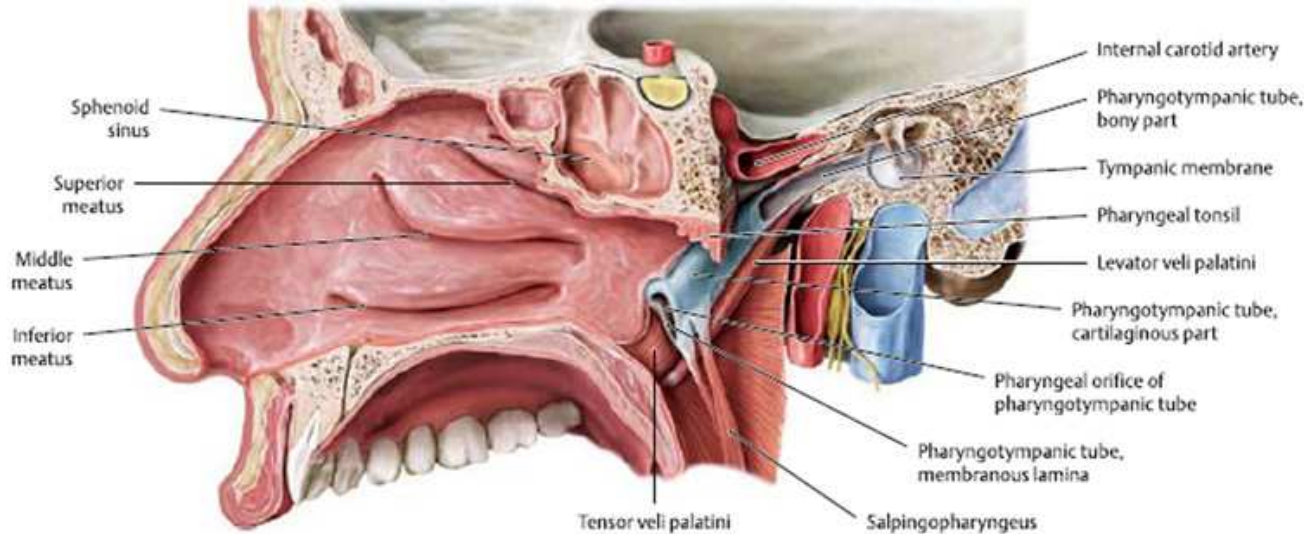
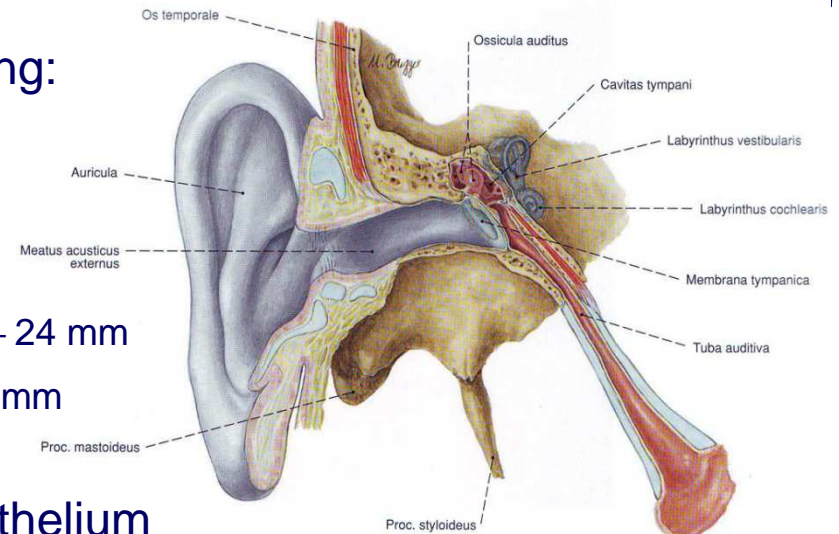
- ✓ posterior wall – ***paries mastoideus***
⇒ *antrum mastoideum*





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

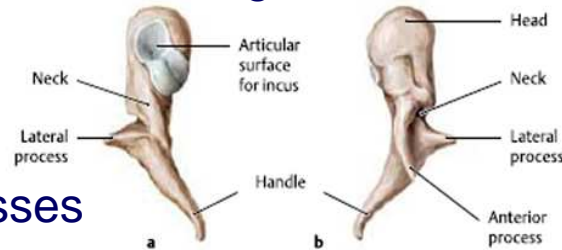




Auditory ossicles, *ossicula auditus*

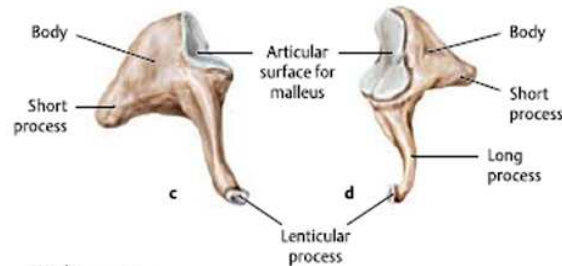
- **malleus** – Lat. = mallet, hammer; the largest, 8-9 mm long:

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



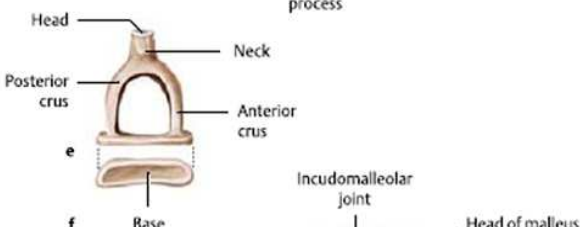
- **incus** – Lat. = anvil:

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



- **stapes** – Lat. = stirrup:

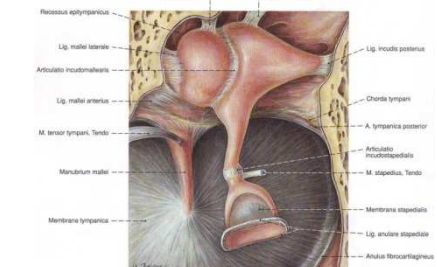
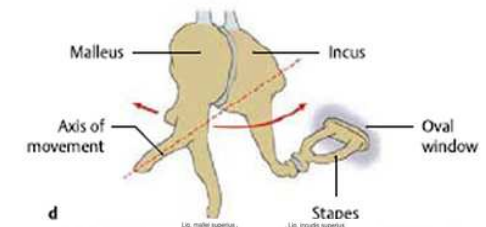
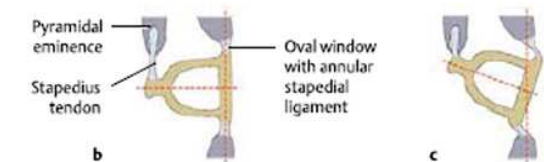
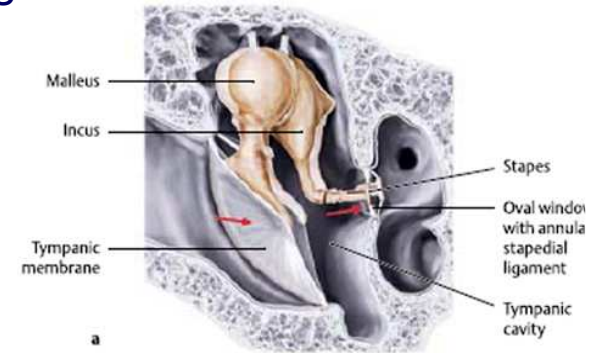
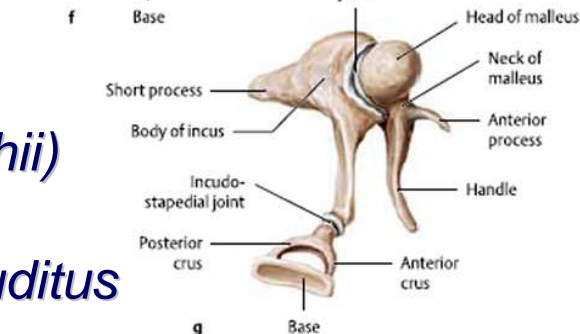
- ✓ head, *caput stapedis*
- ✓ limbs (*crura*)
 - *anterior*
 - *posterior*
- ✓ base, *basis stapedis*



- *m. tensor tympani (Eustachii)*

- *m. stapedius*

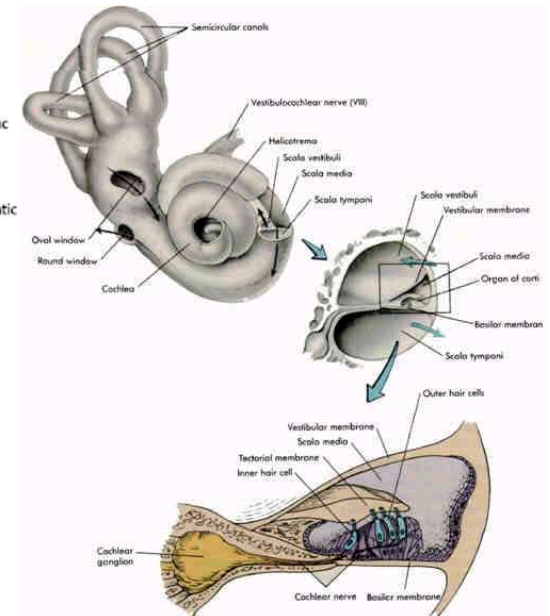
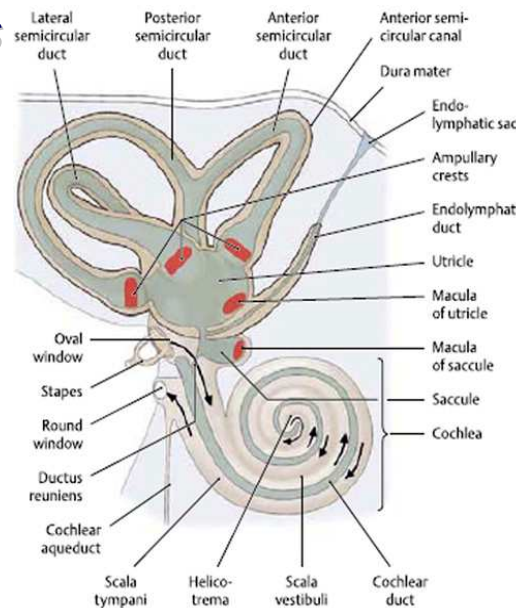
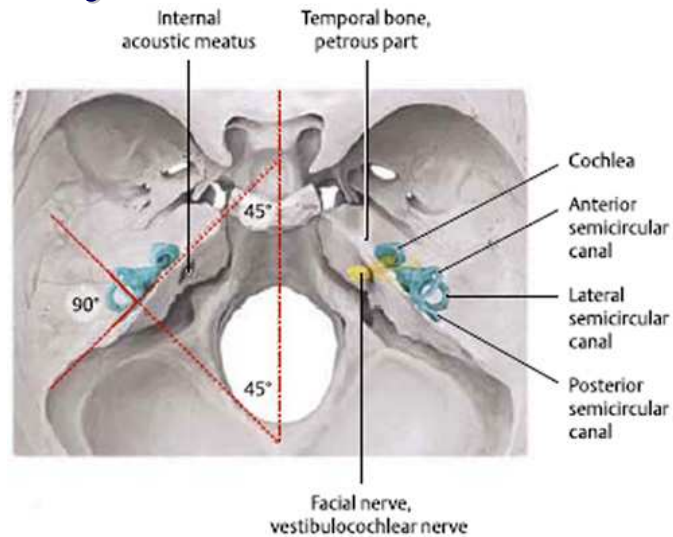
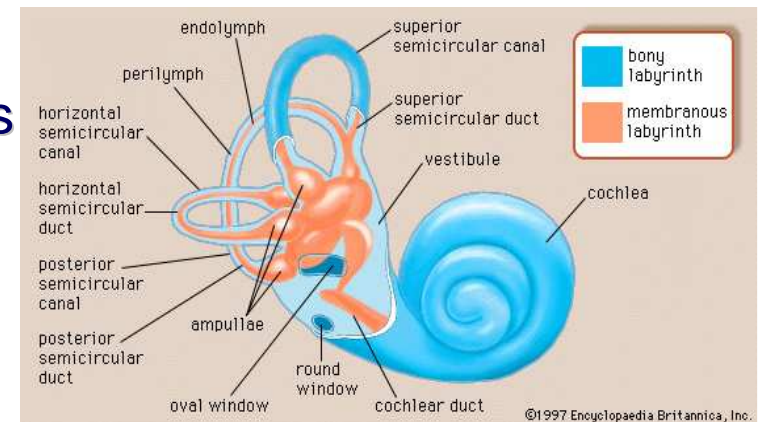
- *ligg. et artt. ossiculorum auditus*





Internal ear, *auris interna*

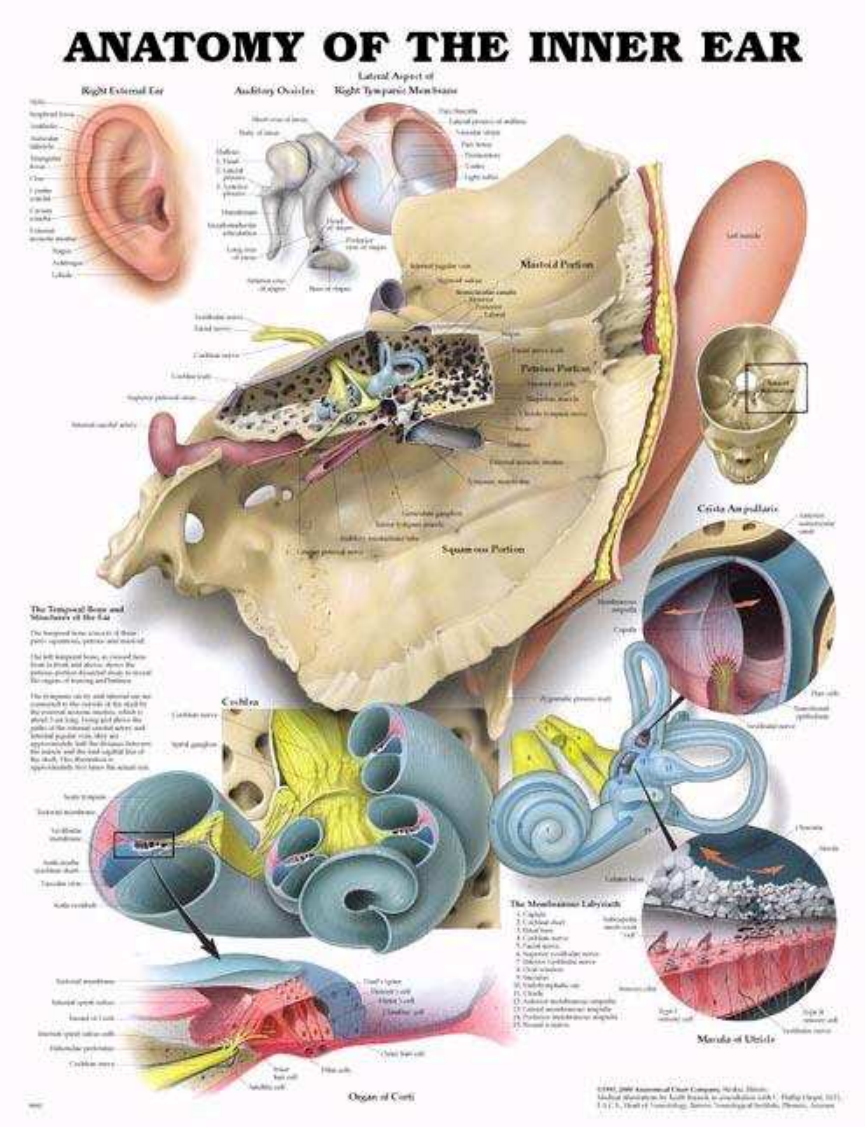
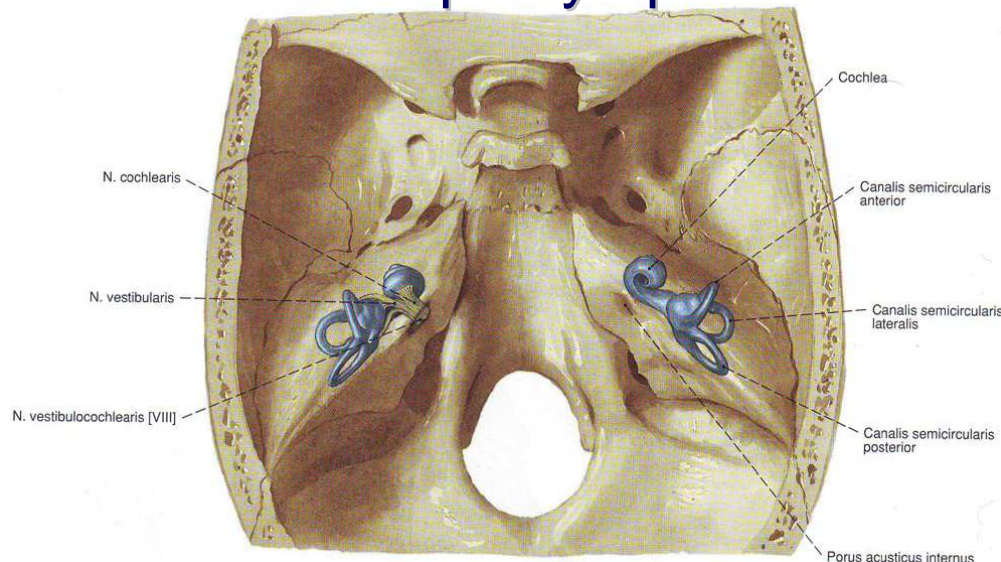
- location – in *pars petrosa ossis temporalis*
- main functions:
 - ✓ converts sound waves into nerve impulses
 - ✓ registers changes in equilibrium
- composition:
 - ✓ osseous labyrinth, ***labyrinthus osseus***
 - ✓ membranous labyrinth, ***labyrinthus membranaceus***





Osseous labyrinth, *labyrinthus osseus*

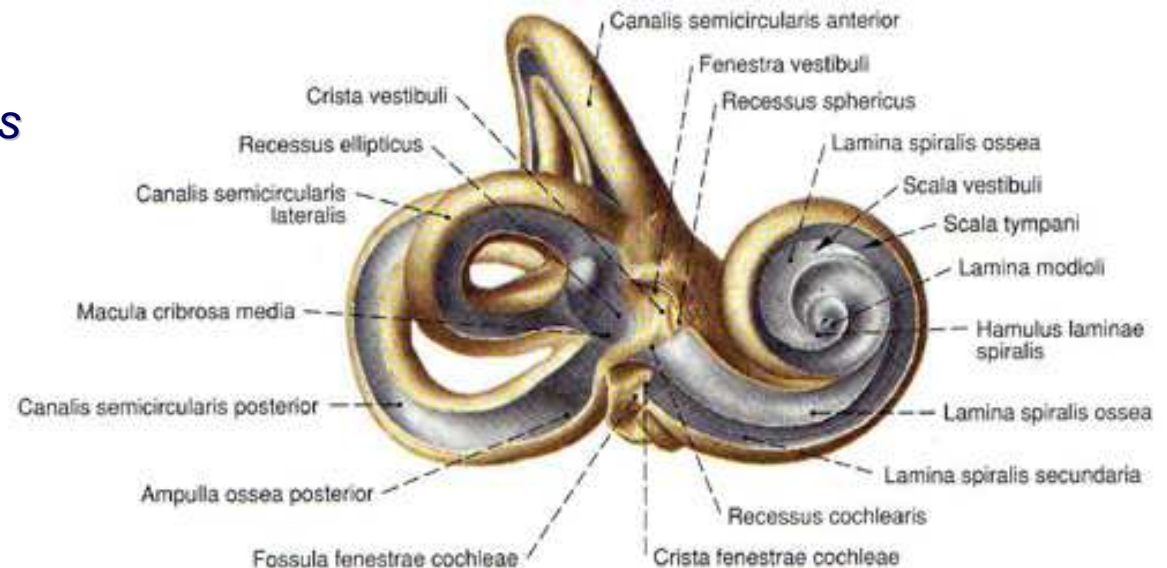
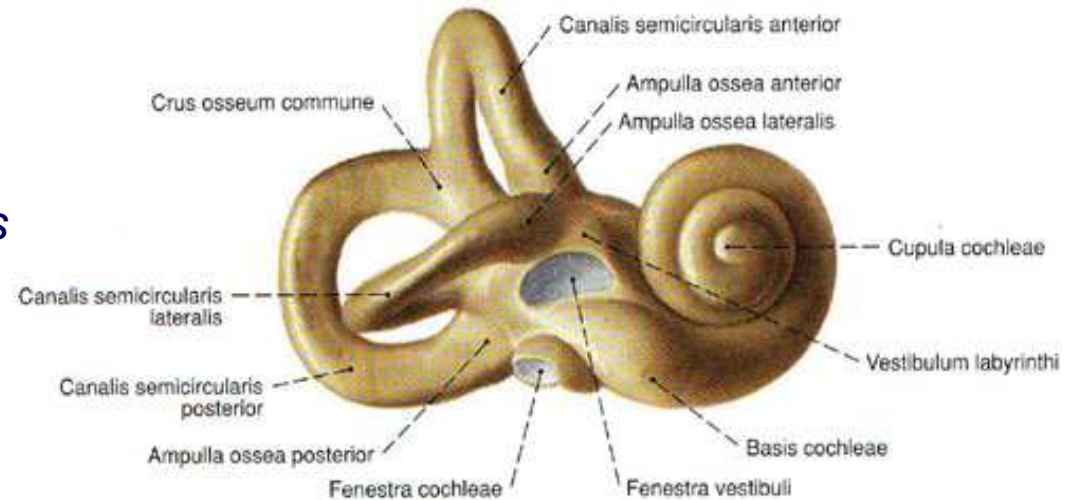
- vestibule, ***vestibulum***
- three semicircular canals, ***canales semicirculares***:
 - ✓ *canalis semicircularis lateralis*
 - ✓ *canalis semicircularis anterior*
 - ✓ *canalis semicircularis posterior*
- ***cochlea***
- filled with perilymph





Vestibule, vestibulum

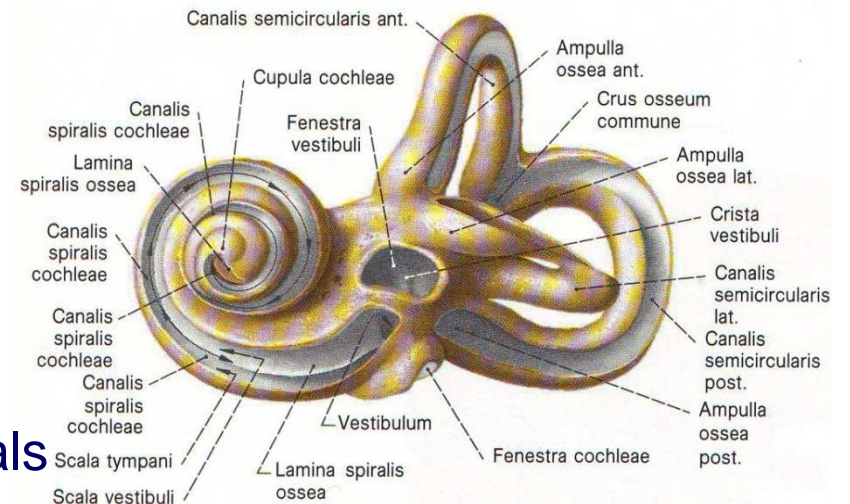
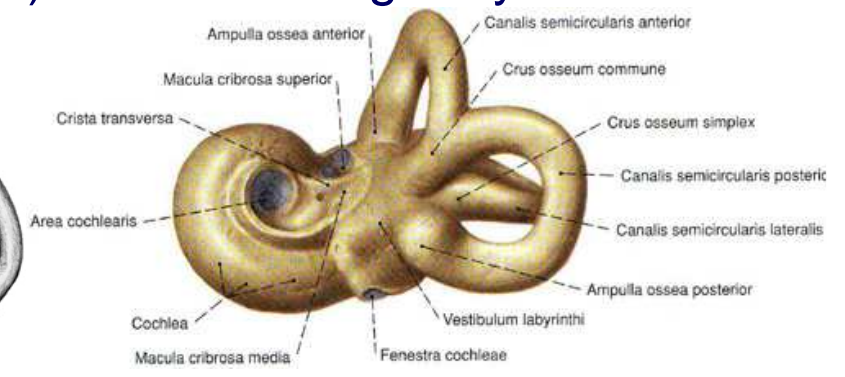
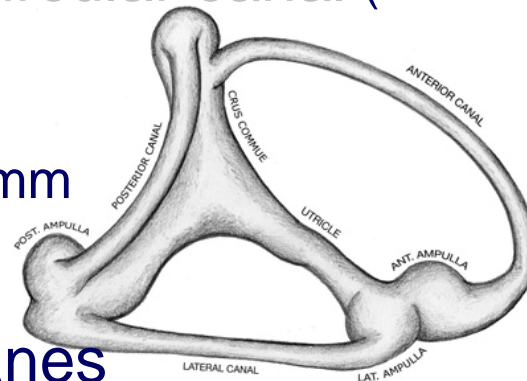
- lateral wall – *paries labyrinthicus*:
 - ✓ *fenestra vestibuli* ⇨ closed by *basis stapedis*, fixed with *lig. annulare stapedis*
 - ✓ *fenestra cochleae* ⇨ *membrana tympani secundaria*
- medial wall:
 - ✓ elliptical recess ⇨ *utricleus*
 - ✓ vestibular crest ⇨ aqueduct of the vestibule
 - ✓ spheroid 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

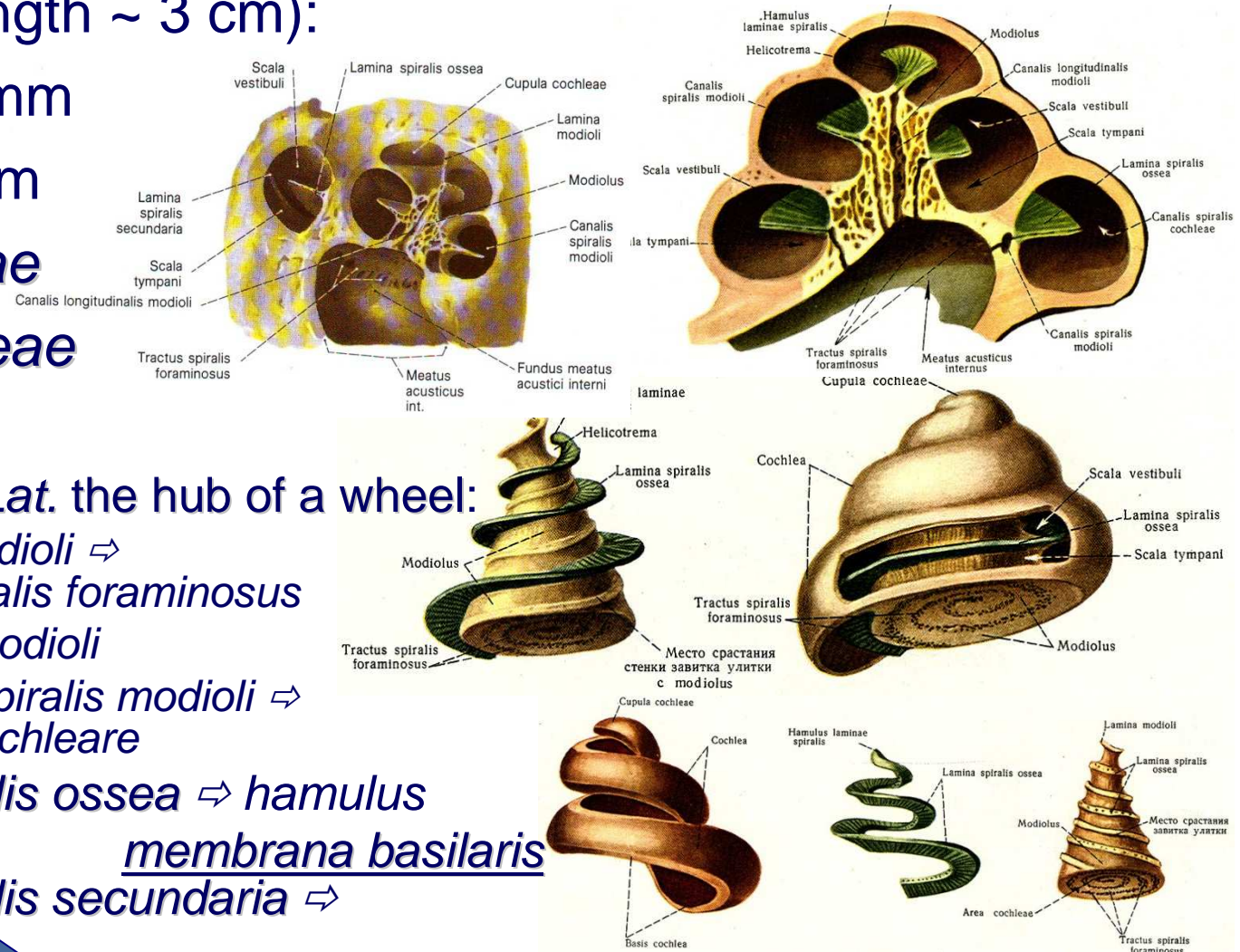
- spiral canal, *canalis spiralis cochleae* – 2½-2¾ turns (length ~ 3 cm):

- ✓ 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*

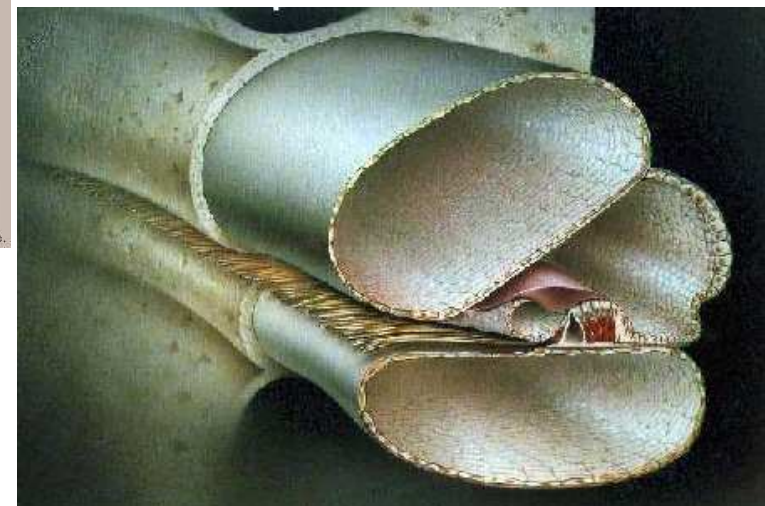
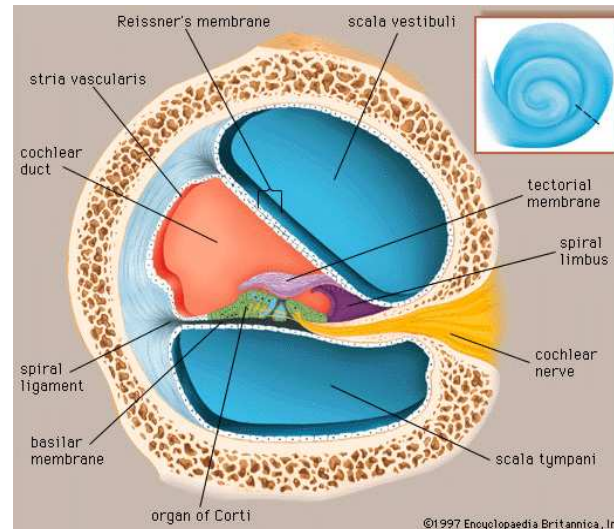
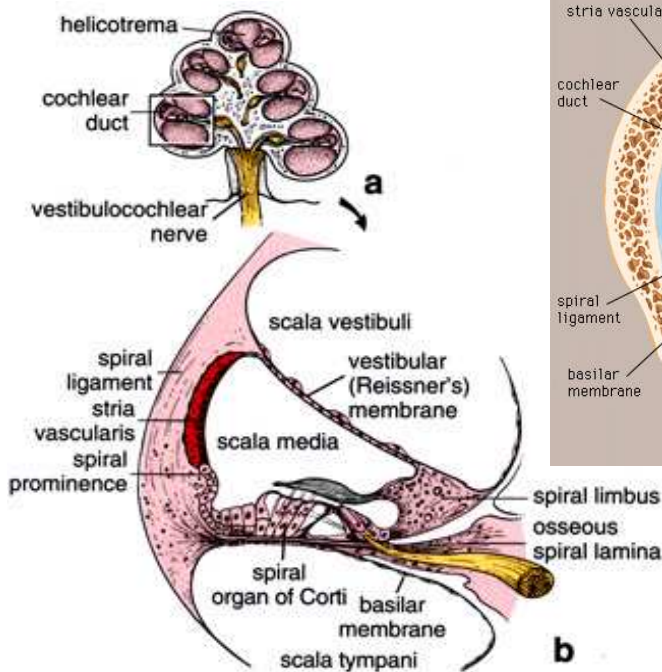
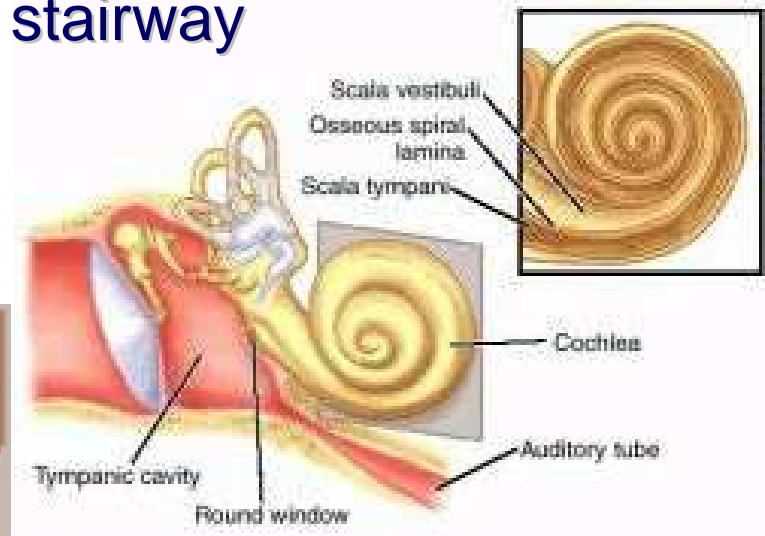
Lat. *cochlea*, snail shell





Cochlear canal, *canalis cochlearis*

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





Membranous labyrinth, *labyrinthus membranaceus*

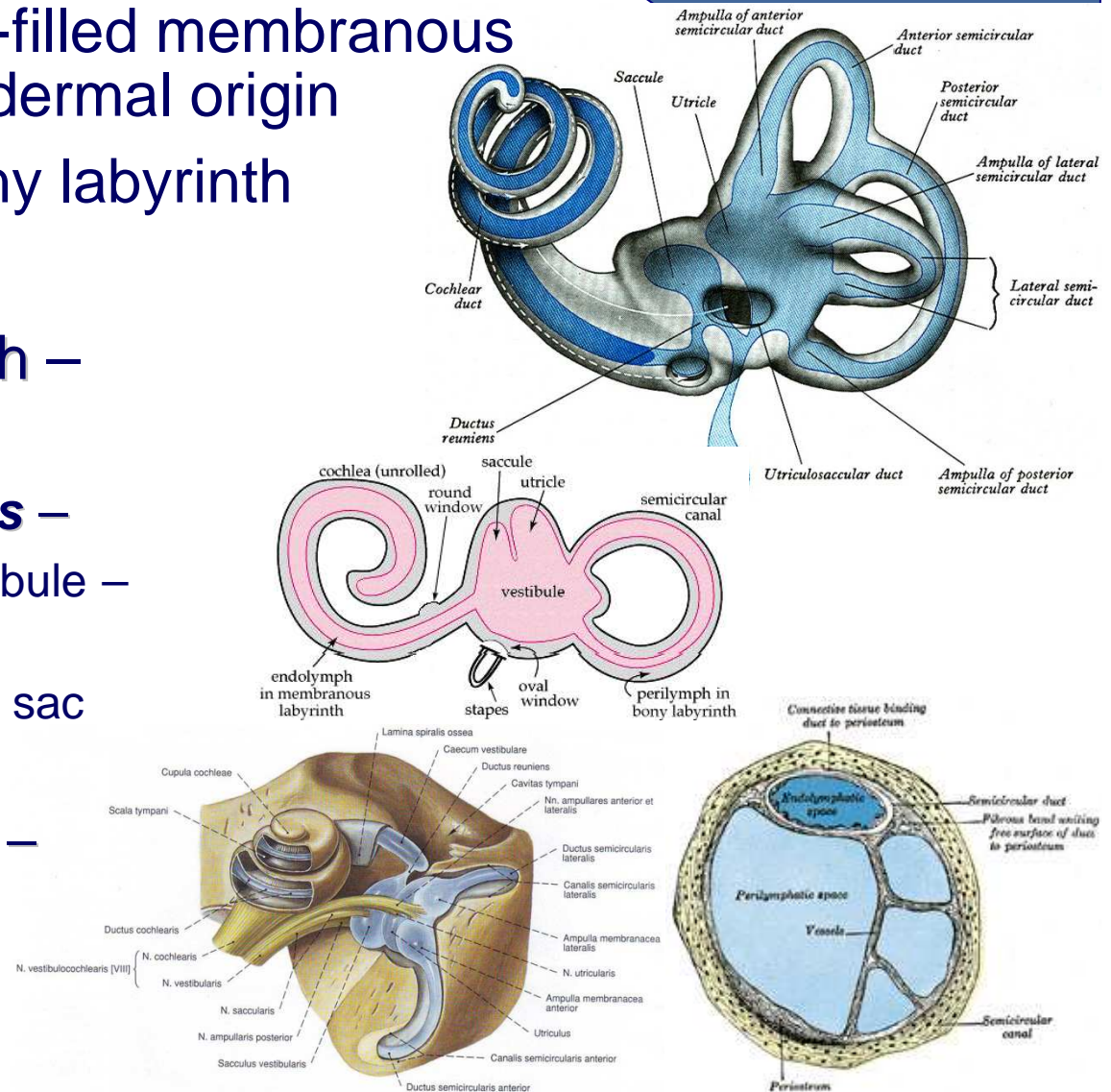
- a closed system of fluid-filled membranous channels (sacs) of ectodermal origin
- location – within the bony labyrinth
- filled with endolymph
- surrounded by perilymph – perilymphatic space

✓ *labyrinthus vestibularis* –

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

✓ *labyrinthus cochlearis* –

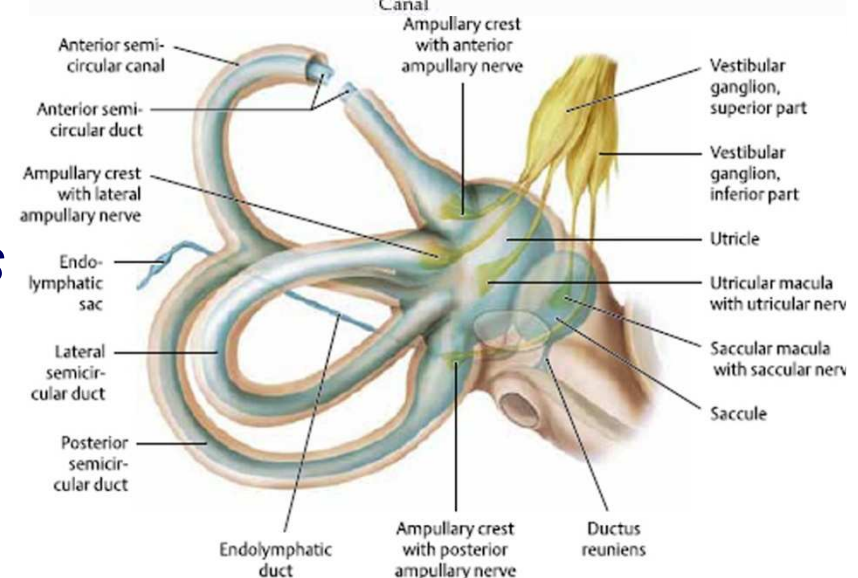
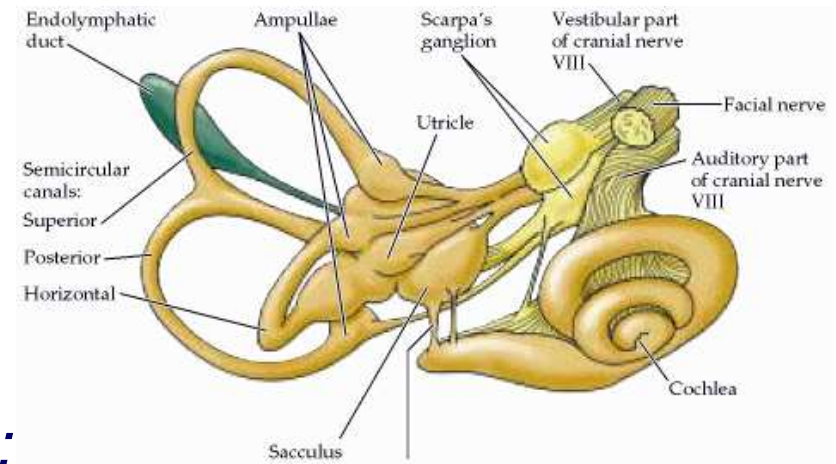
- membranous cochlea (cochlear duct)
- spiral organ of Corti





Vestibular labyrinth, *labyrinthus vestibularis*

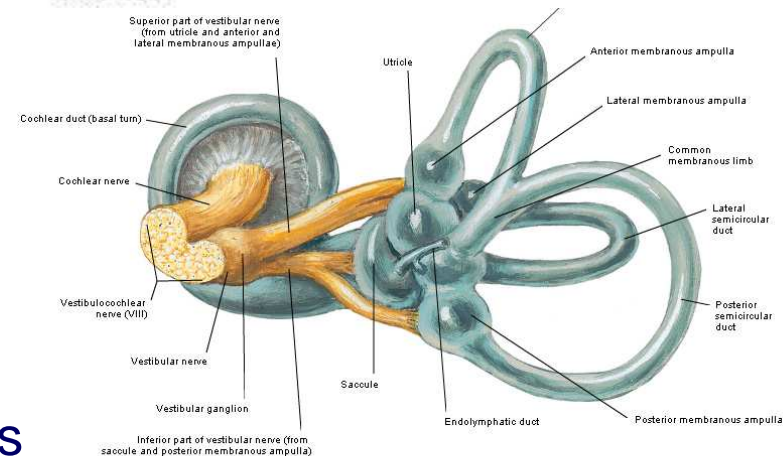
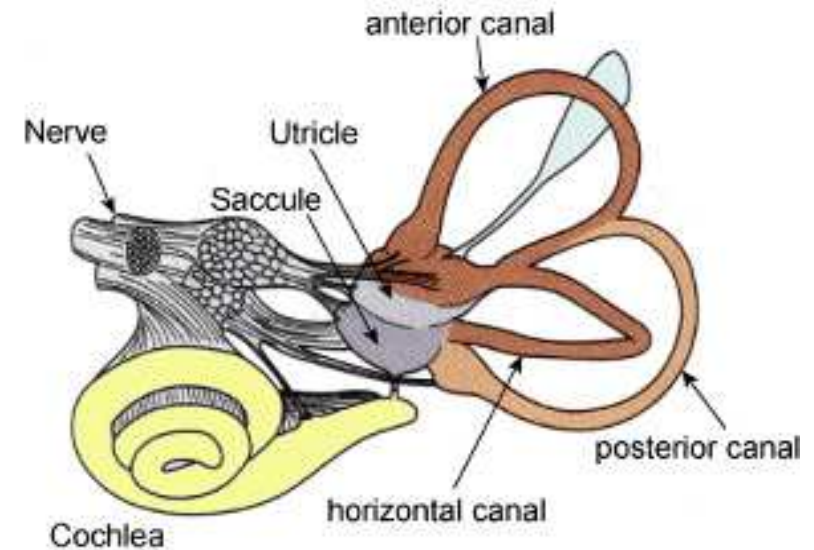
- *utricle* – in *recessus ellipticus*:
 - ✓ *ductus utriculosaccularis*
 - ✓ *macula utriculi* – $\frac{2}{3}$ mm: *pars utricularis n. vestibulocochlearis*
- *sacculus* – in *recessus sphericus*:
 - ✓ *ductus reuniens* \Rightarrow *ductus cochlearis*
 - ✓ *macula sacculi* – *pars saccularis n. vestibulocochlearis*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





Vestibular labyrinth, *labyrinthus vestibularis*

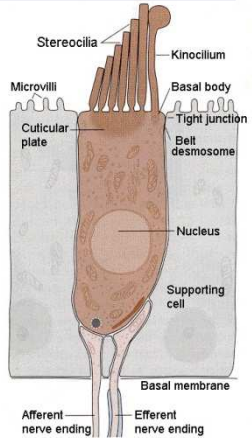
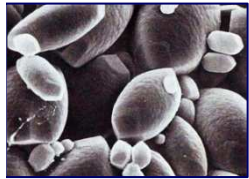
- semicircular ducts:
 - ✓ *ductus semicircularis lateralis*
 - ✓ *ductus semicircularis anterior*
 - ✓ *ductus semicircularis posterior*
- ¼ of the semicircular canals
- *ampulla membranacea*
- *crus membranaceus*:
 - ✓ *simplex* – for lateral duct
 - ✓ *commune* – anterior&posterior ducts
- wall –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



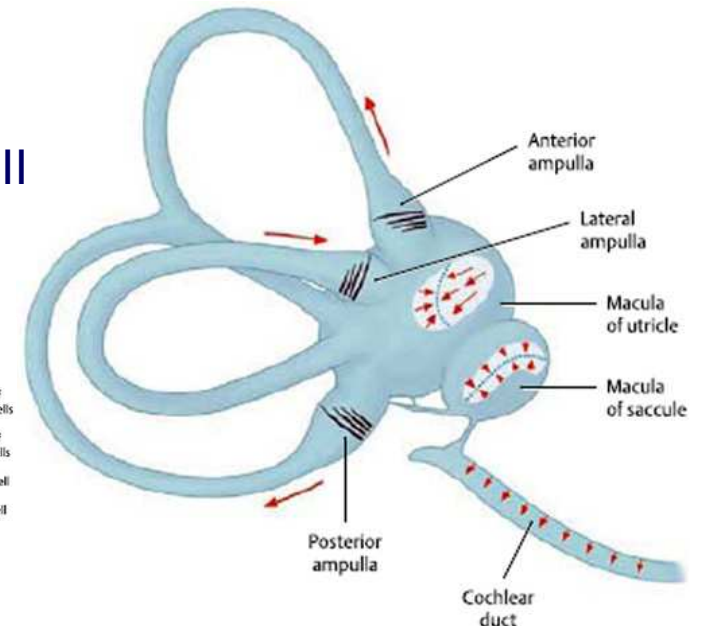
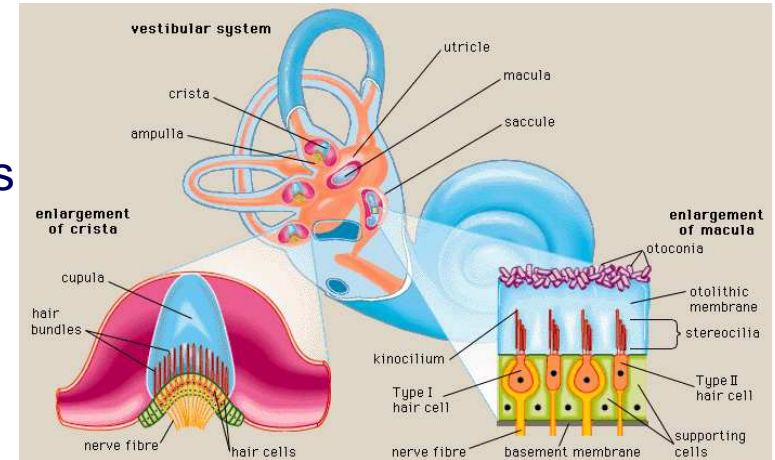
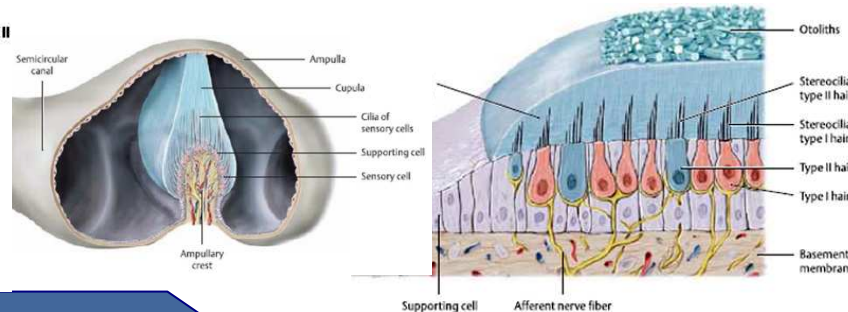
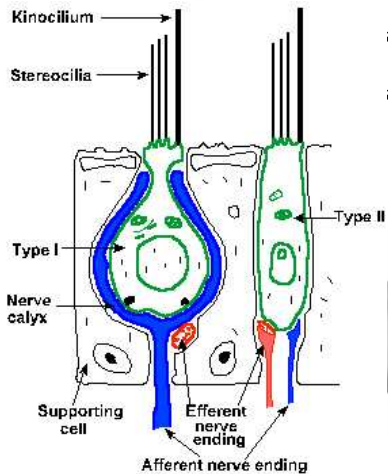


Vestibular system

- 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

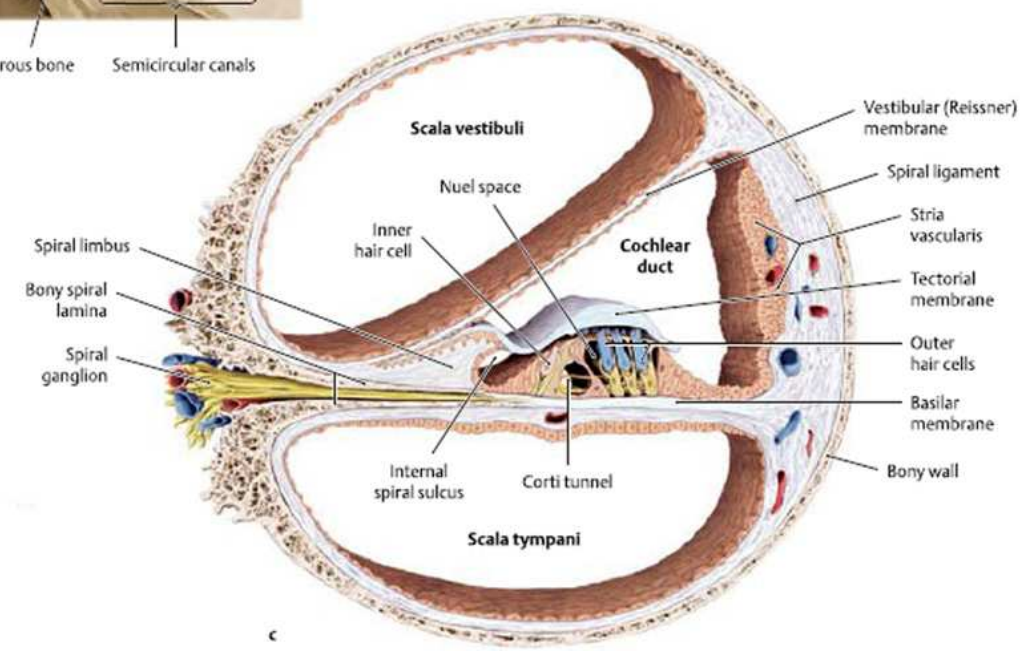
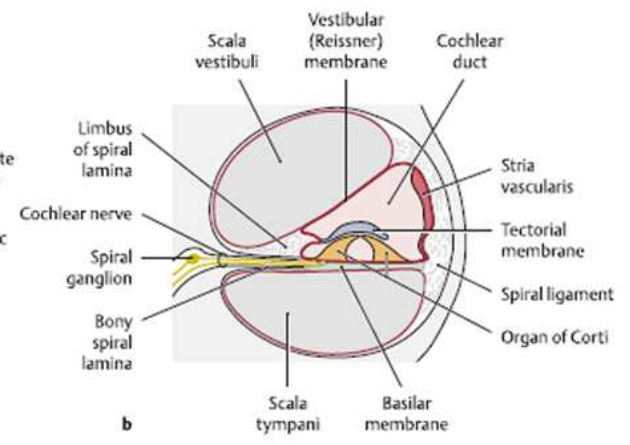
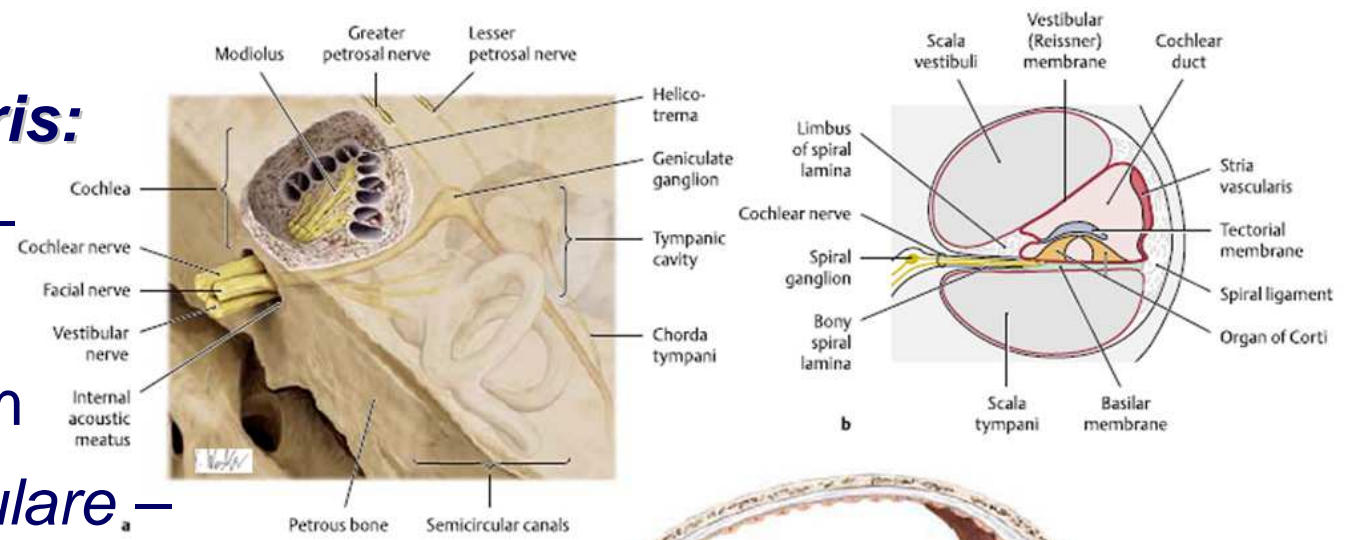




Cochlear labyrinth, *labyrinthus cochlearis*

■ 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:

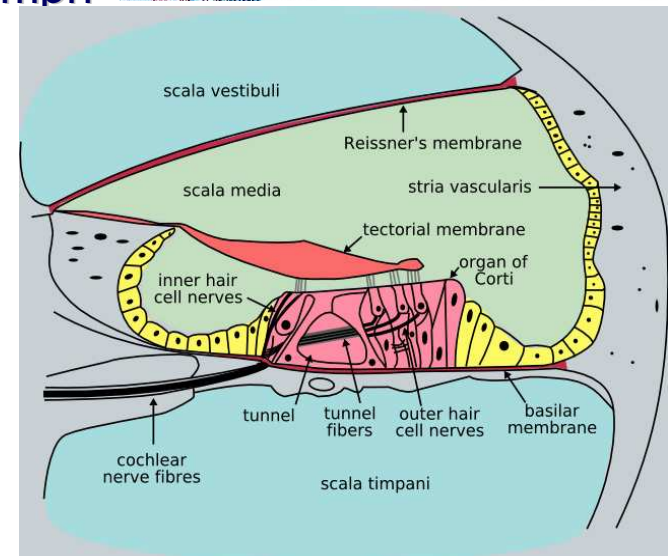
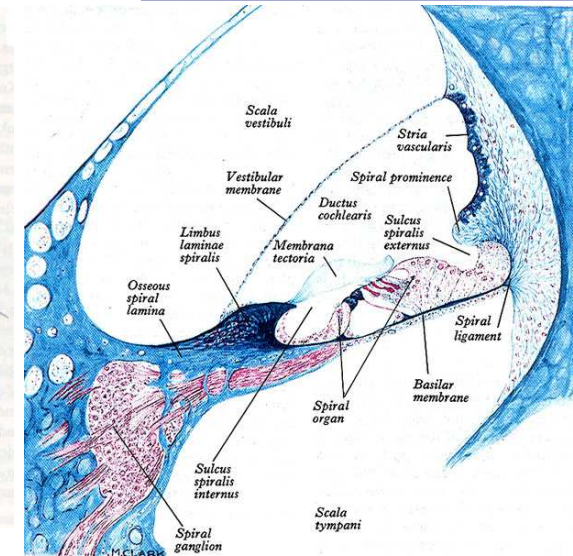
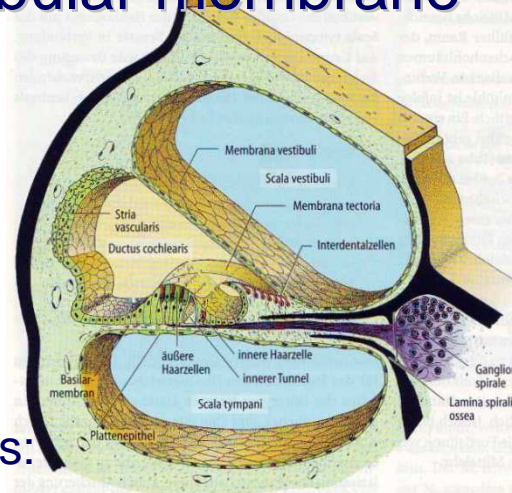
- ✓ basal lamina
- ✓ simple squamous epithelium

- *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*



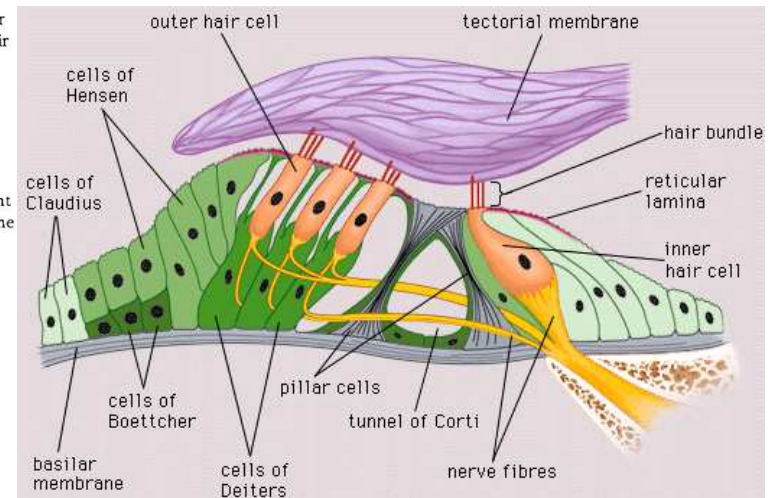
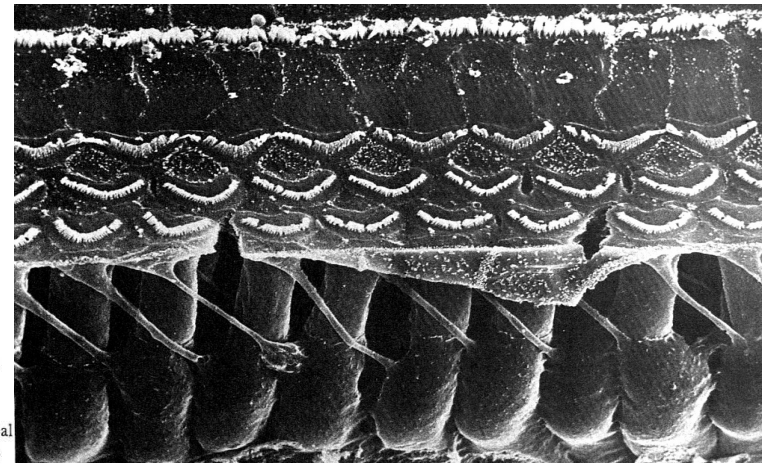
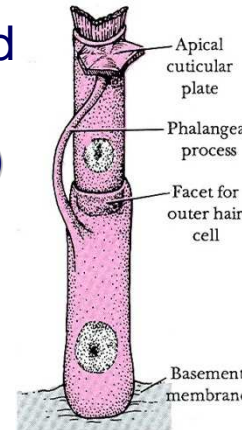


Alfonso Corti
(1822–1876)

Spiral organ of Corti, *organum spirale*

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

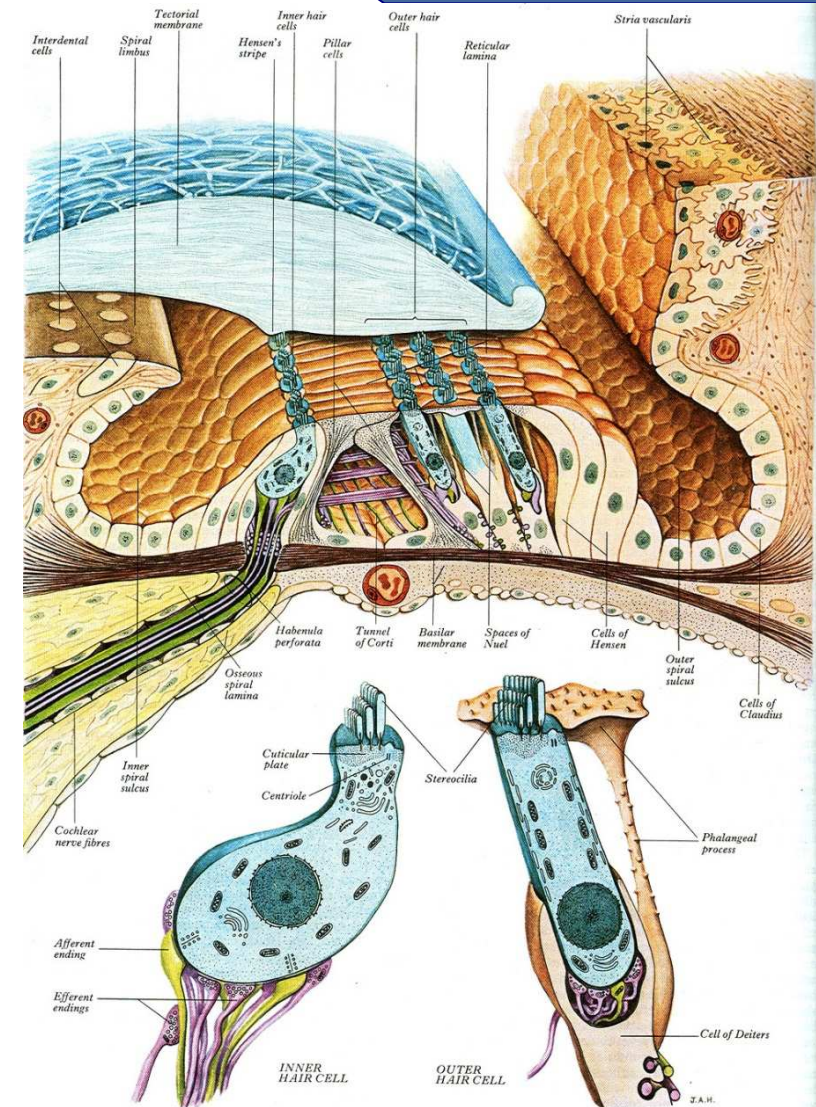
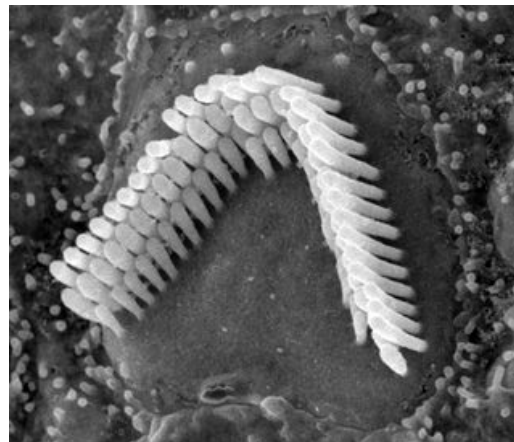
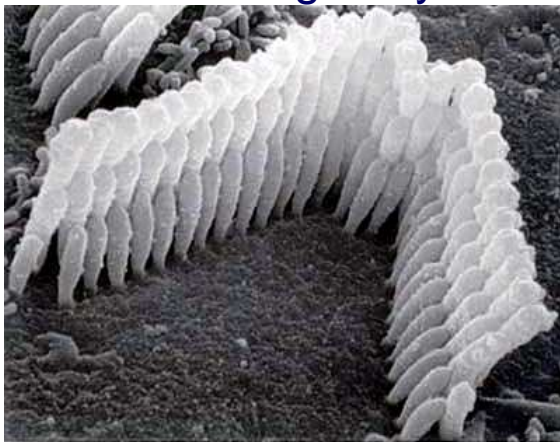
- receptor (sensory) and supporting cells:
 - ✓ internal and external rod (pillar) cells of Corti
 - ⇒ *cuniculus internus* (inner tunnel of Corti)
 - ⇒ *cuniculus medius* (space of Nuel)
 - ✓ internal phalangeal cells of *Deiters* – 1 row and external phalangeal cells of *Deiters* – 3 rows
 - ✓ internal (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

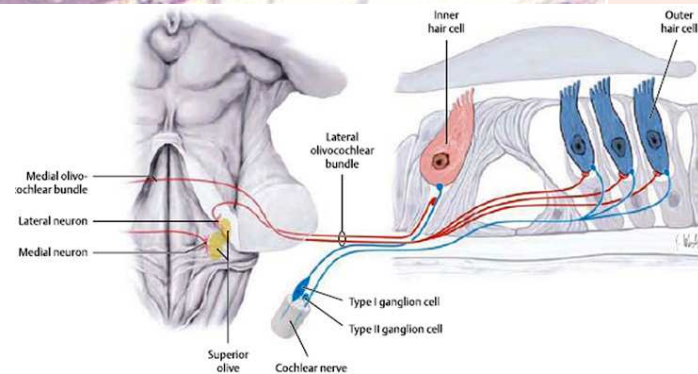
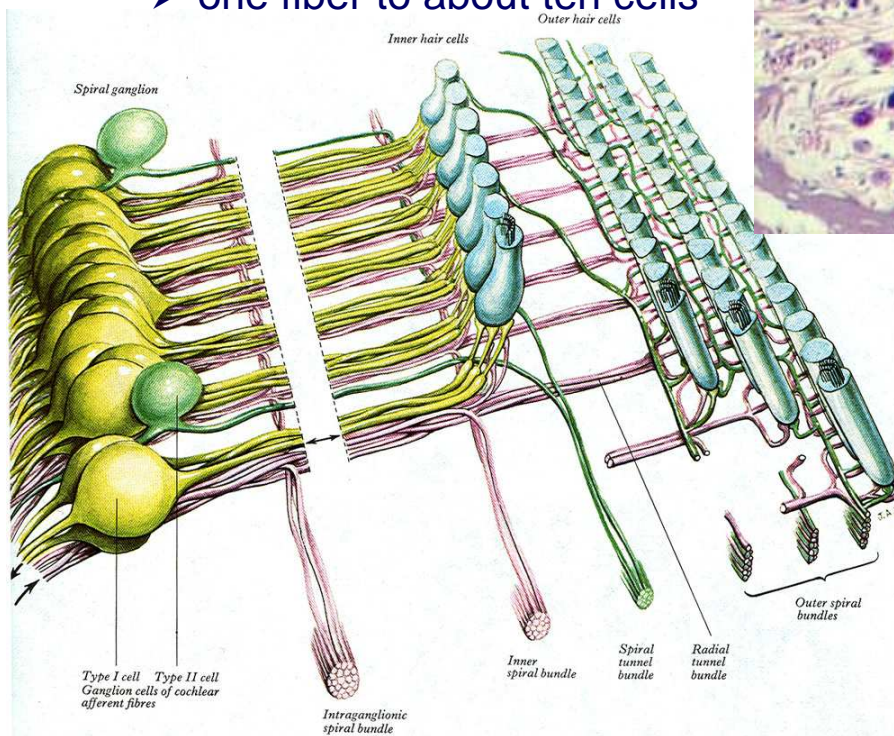
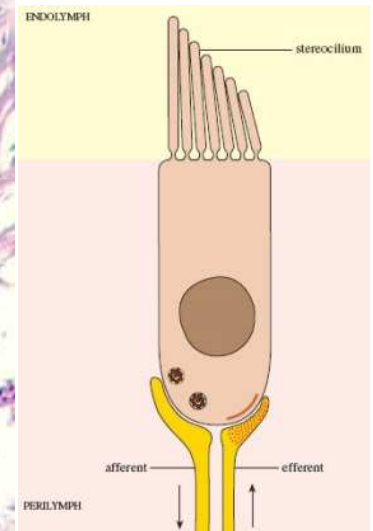




Cochlear innervation

- 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

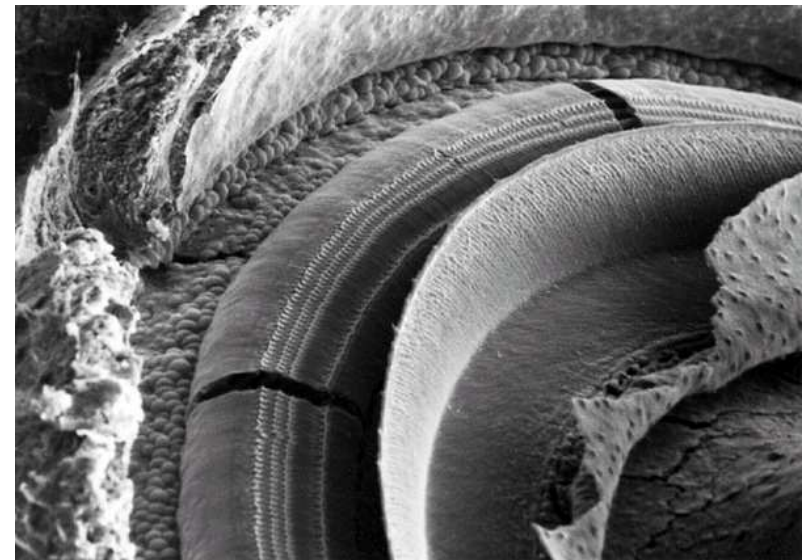
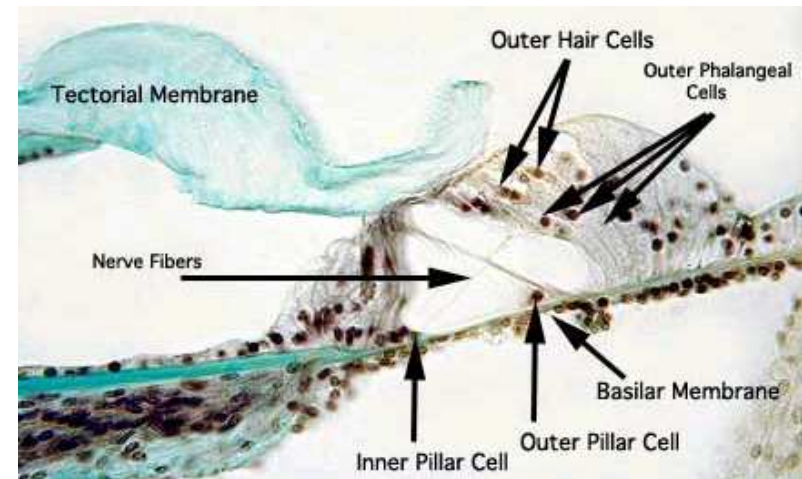
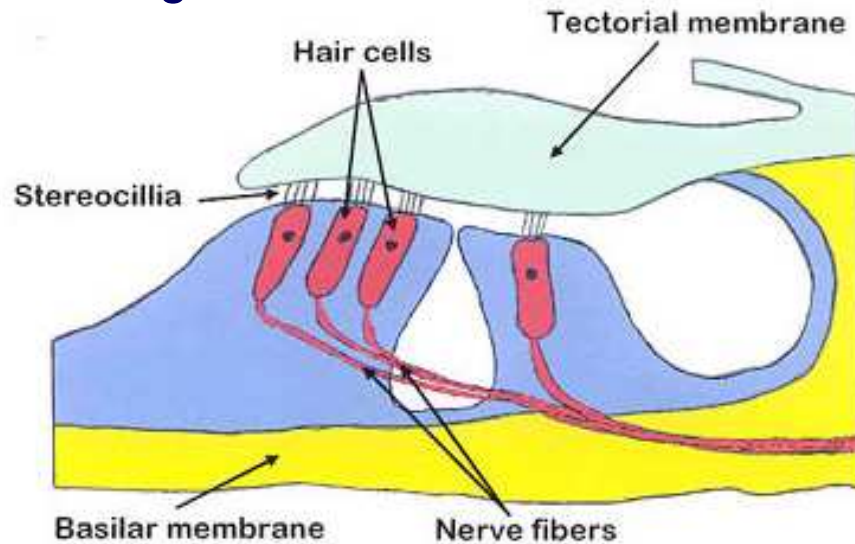


- Efferent innervation – *tractus olivocochlearis* (*Rasmussen's tract*)
 - ⇒ cholinergic inhibitory synapses



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

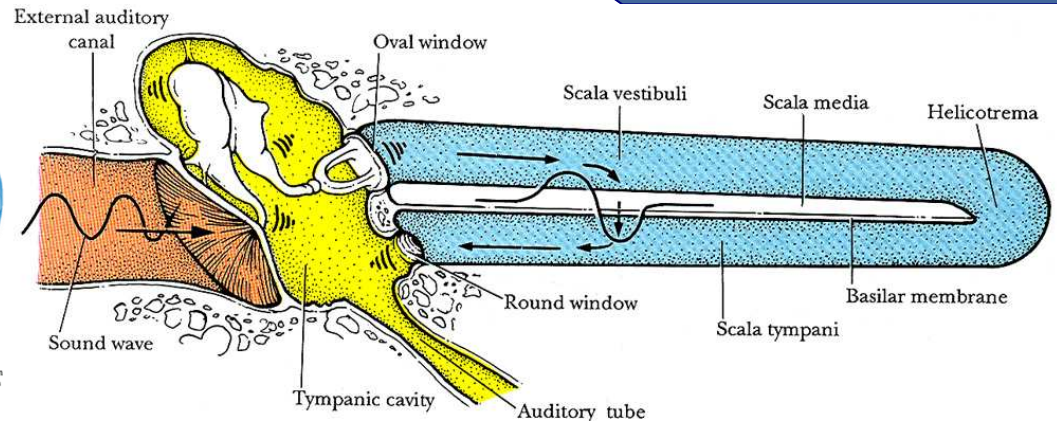
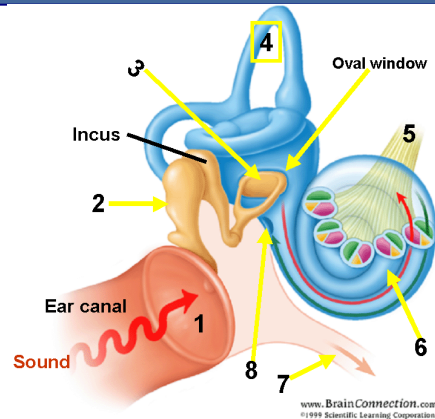


Georg von Békésy (1899-1972)



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

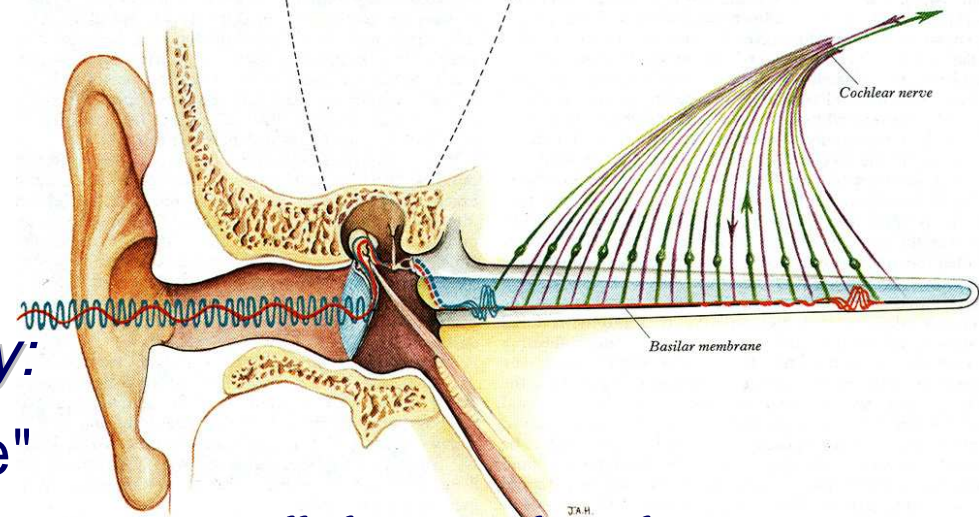
- Helmholtz resonance theory
- Rutherford telephone theory
- travelling wave theory of *Békésy*:
- ✓ basilar-membrane "resonance"



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

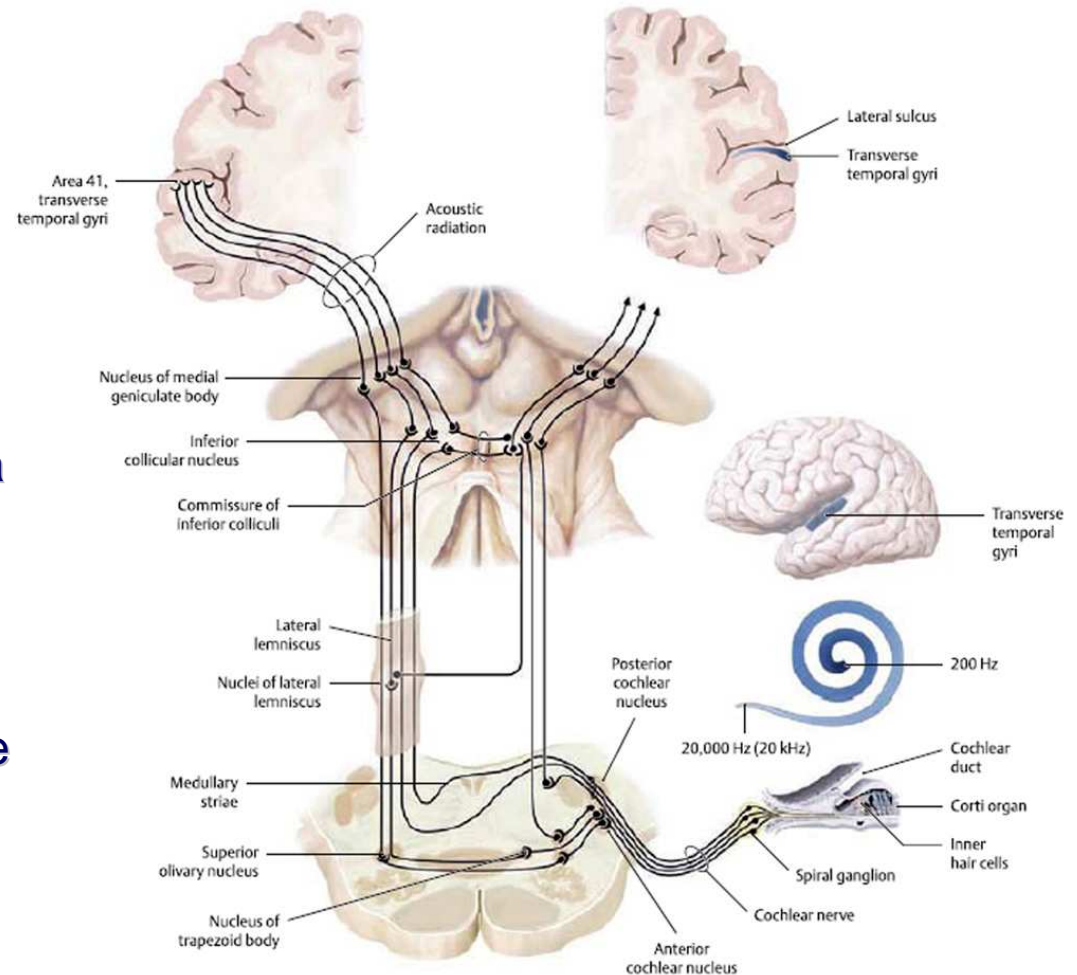


Ist neuron –
spiral ganglion:

- ✓ 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:

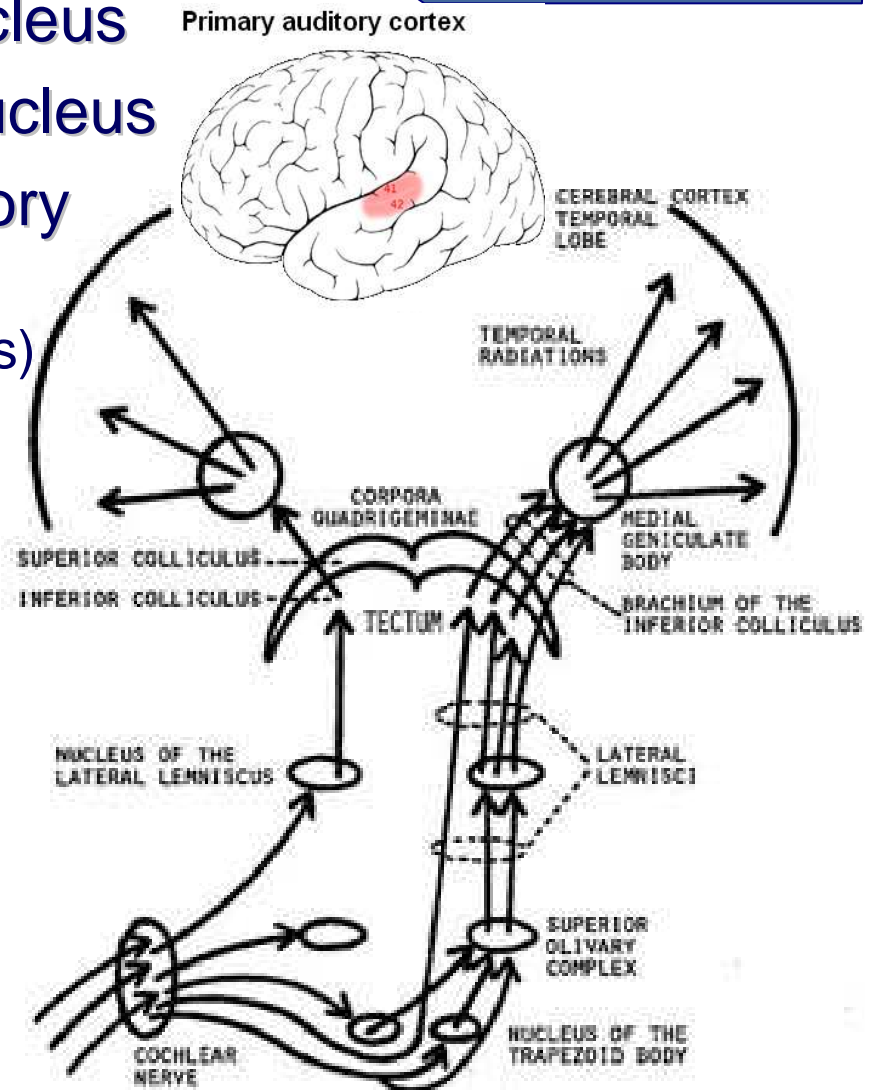
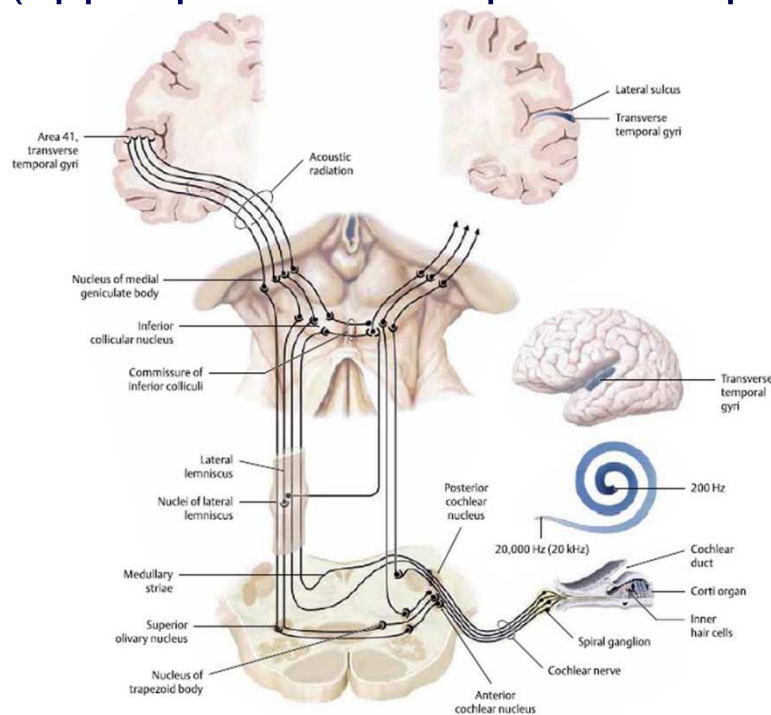
- ✓ dorsal cochlear nucleus
 - ✓ ventral cochlear nucleus
- } lateral lemniscus





Central auditory pathways

- IIIrd neuron – inferior colliculus nucleus
- IVth neuron – medial geniculate nucleus
- ✓ acoustic radiation \Rightarrow primary auditory cortex (A-I) = *Brodmann's area 41* (upper part of the superior temporal gyrus)

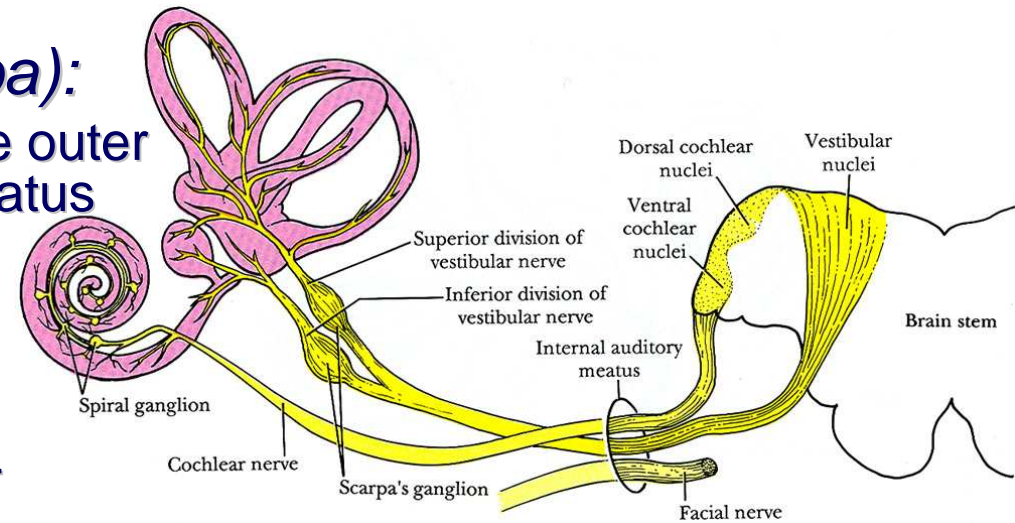




Vestibular pathways

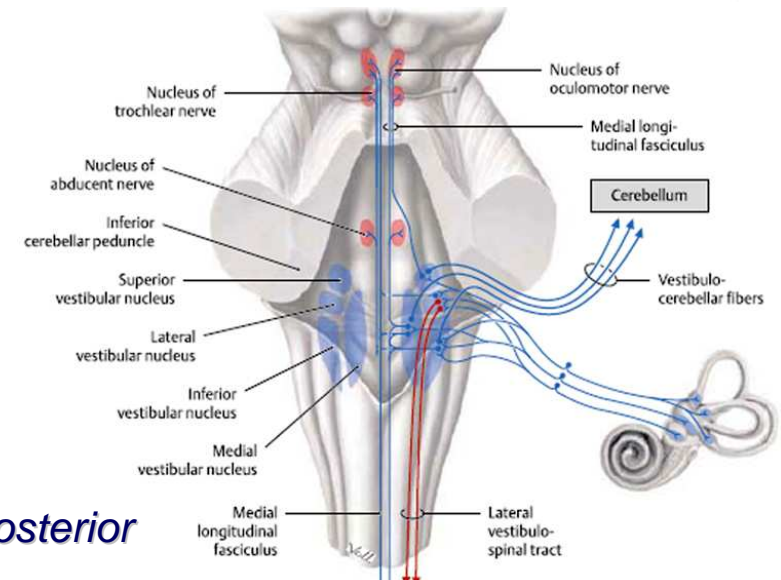
■ 1st neuron – vestibular ganglion (of Scarpa):

- ✓ 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



■ 1¹nd neuron – vestibular nuclei:

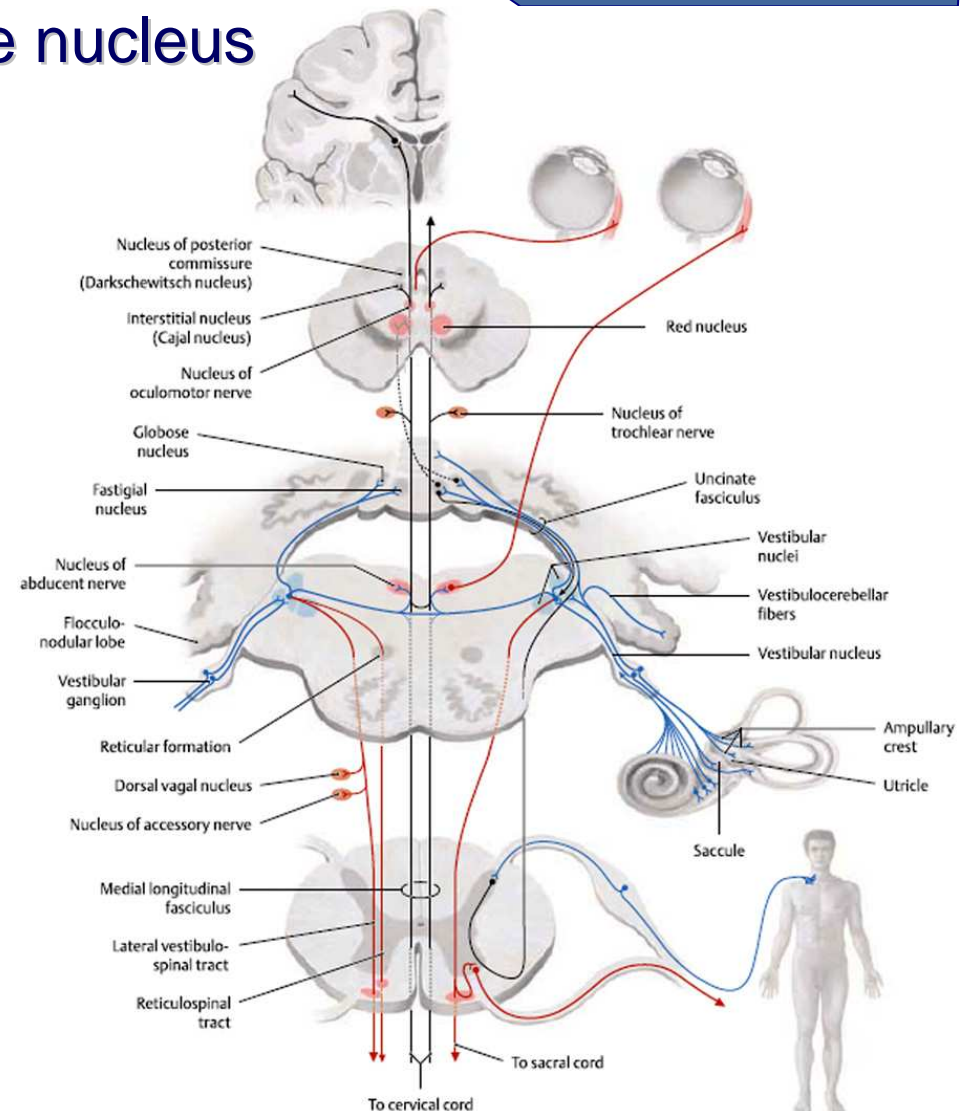
- ✓ superior (*Bechterew*)
- ✓ inferior (*Roller*) } lateral lemniscus
- ✓ medial (*Schwalbe*)
- ✓ lateral (*Deiters*) ⇔ *tractus spinocerebellaris posterior*





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...

