# ANATOMY of the HUMAN TEMPORAL BONE

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# INTRODUCTION

The temporal bone contains the organs for hearing (i.e., organ of Corti) and the detection of gravity, linear and rotational motion (i.e., maculae of the utricule and saccule, cristae of the superior, lateral and posterior semicircular canals).

The senses of hearing and balance involve the peripheral auditory and vestibular structures and the central nervous system. This atlas covers the anatomy of the peripheral auditory and vestibular systems only. The peripheral auditory system consists of the external, middle and inner ears (p 3). The peripheral vestibular system consists of five separate sensory organs (pp 47-49). A portion of the external ear and all of the middle and inner ears as well as the vestibular sense organs are housed within the temporal bone. The vestibulocochlear nerve ($8^{th}$ cranial) traverses the internal auditory meatus (pp 4, 7,15, 42) to synapse on sensory cells. The central processes of the vestibulocochlear neurons synapse in the central nervous system.

The end organ for hearing consists of the coiled organ of Corti (p 50) that averages about 32 mm in length. Sensory (hair) cells are located in the organ of Corti (p 31). There are approximately 100 inner hair cells and 400 outer hair cells per mm length of the organ of Corti. Primary auditory neurons, called spiral ganglion neurons, are located in Rosenthal's canal (pp 29, 30), a spiral channel at the periphery of the modiolus. The bipolar SGNs send their peripheral processes to synapse on the hair cells in the sensory epithelia while their central processes traverse the modiolus, exit the temporal bone via the internal auditory meatus and synapse in the cochlear nuclei of the brainstem.

Hearing is a very important sense for oral communication, language acquisition, employment and the enjoyment of some of life's greatest pleasures such as music, the sounds of nature and the voices of loved ones. A variety of conditions and disease processes in the peripheral auditory system result in mild to profound hearing loss. Some hearing losses are treatable or correctable to a variable degree with medication, surgery, a cochlear implant or a hearing aid; other losses are permanent.

Disease entities of the external ear include: absence of the pinna or external auditory meatus, infections, earwax accumulation in the external auditory canal, or tumors. Disease entities of the middle ear include: tympanic membrane perforation, damage to or loss of one of the middle ear ossicles, otosclerosis, fluid or infection in the middle ear space, or malfunction of the Eustachian tube. Disease entities of the inner ear include: congenital malformations, loss of sensory cells and nerve fibers (i.e., sensorineural hearing loss), cochlear otosclerosis, Meniere's disease, acoustic neuroma, or sudden hearing loss. Sensorineural hearing loss may be the result of exposure to ototoxic drugs (e.g., aminoglycoside antibiotics, platinum compounds, diuretics), noise, or radiation, the process of aging (presbycusis) or viral infections.

The end organs for gravity and motion detection consist of five separate sensory organs: the macula of the utricule (pp 47 and 50) and macula of the saccule, both housed in the vestibule and three cristae, one in the ampullated end of the superior, lateral (or horizontal) and posterior semicircular canals (pp 48-50). Detection of motion and the position of the head in space depend upon the peripheral vestibular organs and central vestibular pathways.

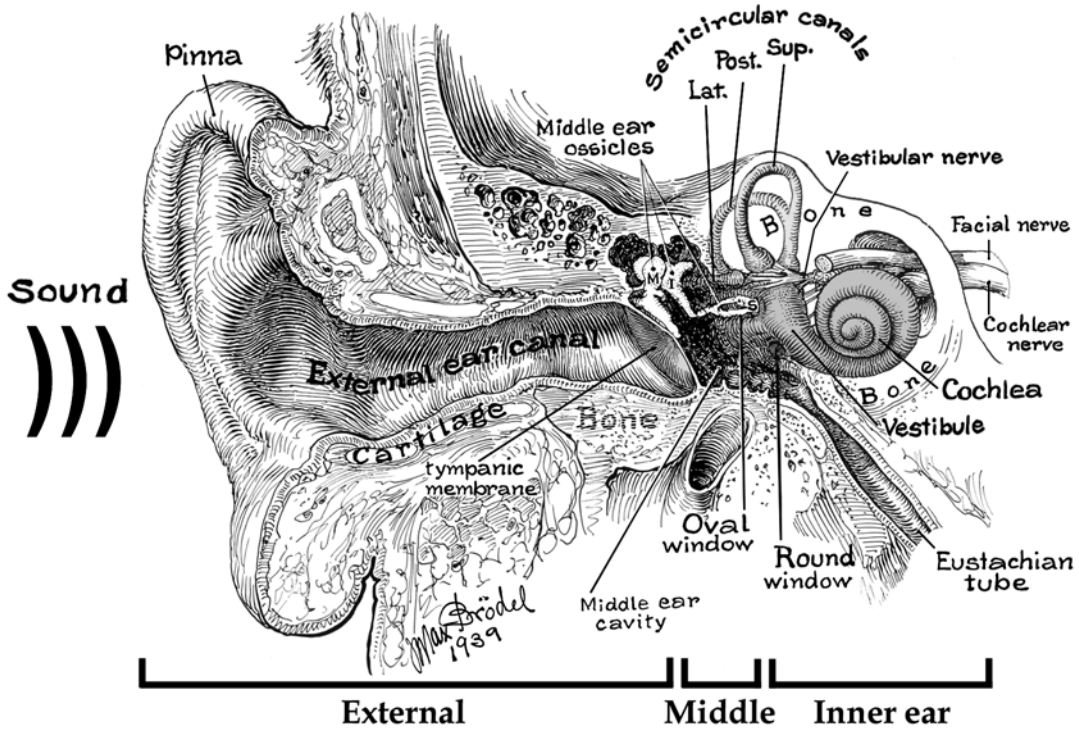
The maculae (p 47) consist of flat plates of sensory (hair) and supporting cells. Nerve fibers enter the maculae from beneath the epithelium to innervate the hair cells. The maculae are covered by an extracellular otolithic membrane in which are embedded a number of

microscopic stones composed of calcium carbonate and protein (i.e., otoconia). These organs are sensitive to linear acceleration and give one the sense of head position in space.

The cristae (pp 48-49) are crests of connective tissue covered with a single layer of sensory and supporting cells. Nerve fibers enter the cristae through the connective tissue to innervate the hair cells. Stereocilia on the hair cells project into an extracellular gelatinous material called the cupula. Motion of endolymph in response to angular acceleration deflects the cupula and stimulates the hair cells.

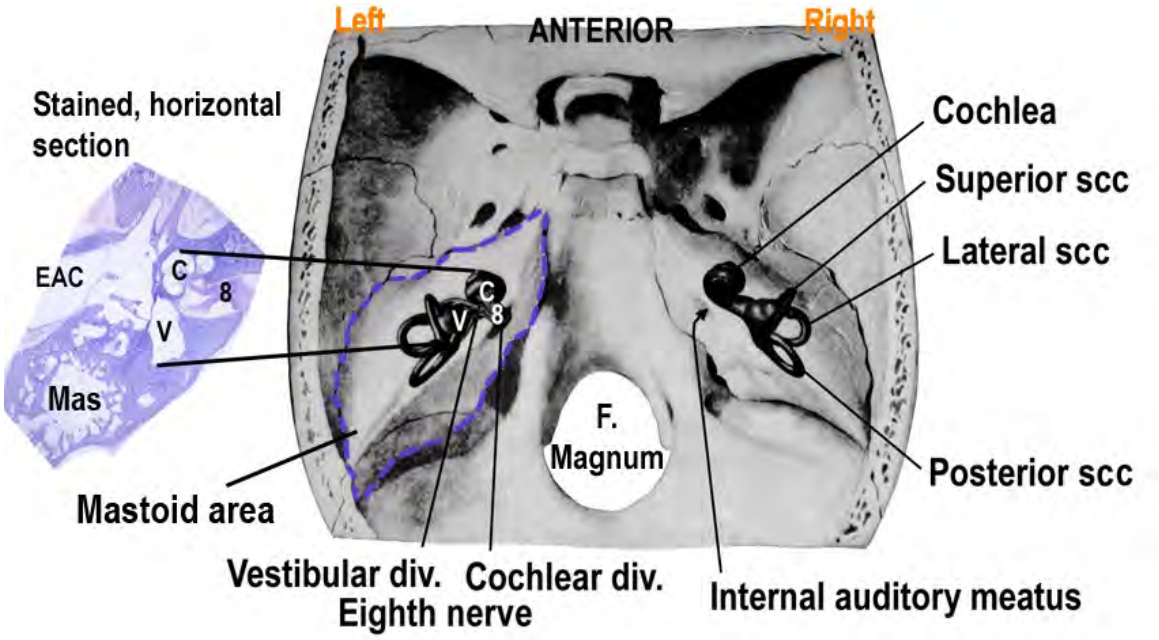
Most of the photomicrographs in this atlas were taken with a dissection microscope at low magnification in order to demonstrate the gross anatomy of the auditory and vestibular systems and their relation to one another. Higher magnifications are needed to identify individual cells in the sensory end organs in these systems.

**SCHEMATIC VIEW of EXTERNAL, MIDDLE and INNER EARS**



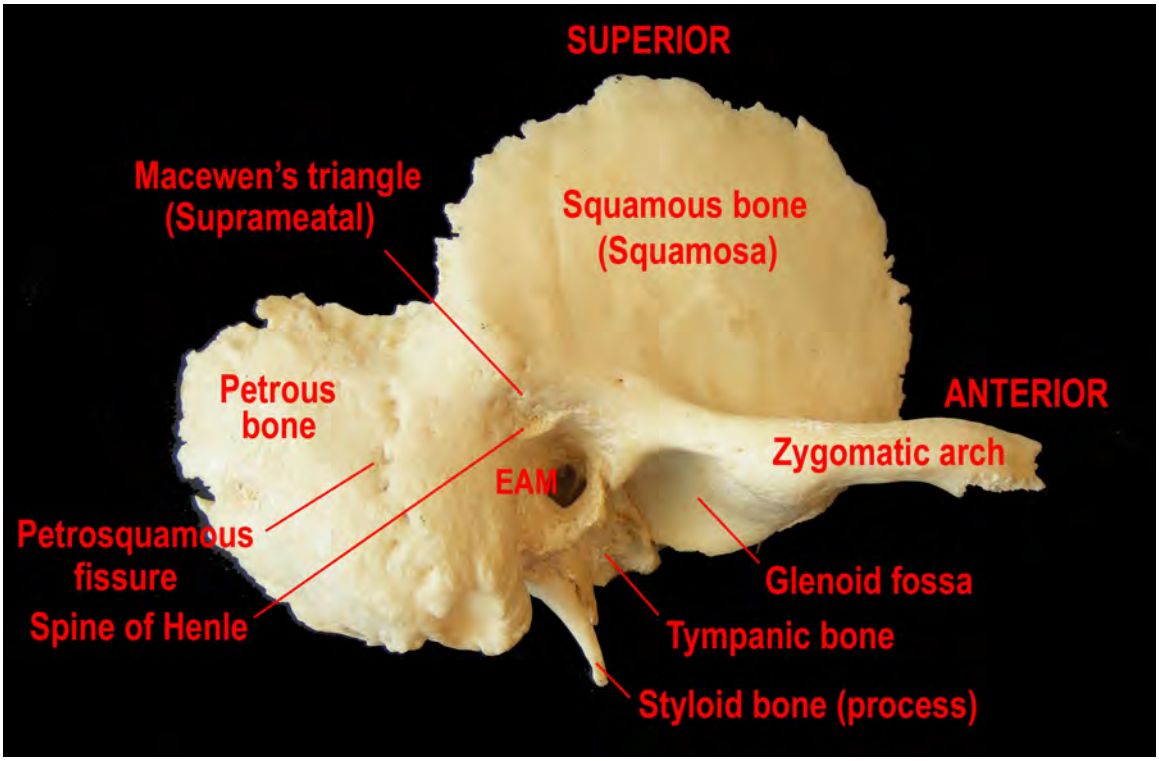

This drawing shows a frontal section through the head of the right peripheral auditory system. The system can be divided into the external, middle and inner ears. The external ear consists of the pinna and the external auditory canal. A transparent membrane called the tympanic membrane or eardrum separates the external and middle ears. The middle ear contains three bones (ossicles) called the malleus (M; pp 33, 36), incus (I; pp 34, 36) and stapes (S; pp 35, 36). These bones articulate with one another by synovial joints and form the ossicular chain. Within the middle ear are two muscles (i.e., tensor tympani; p 16-19; and stapedius; pp 21-22 and 26), openings from the middle ear space into the mastoid (via aditus ad antrum; p 10), nasopharynx (via Eustachian tube; p 17-21) and inner ear (via oval window; pp 18-20; and round window; pp 24-25) and nerves (e.g., chorda tympani; pp 14-20 and 44) The inner ear consists of the coiled cochlea (pp 18, 28, 50), the vestibule and three semicircular canals (i.e., Lat - lateral; Post - posterior; Sup - superior; pp 45, 46, 50). Sound waves enter the external canal and vibrate the tympanic membrane. These vibrations are transmitted by the ossicular chain. Vibration of the ossicular chain results in piston-like motion of stapes that is tightly held in the oval window by the annular ligament. Motion of the stapes displaces cochlear fluids and the organ of Corti where hair cells release neurotransmitter packets in response to motion. The neurotransmitter stimulates nerve endings applied to the hair cell bases and these fibers carry auditory information to the brain where it is perceived as sound. (Drawing adapted from Brodel, 1946).

## BASE of SKULL with MEMBRANOUS LABYRINTHS SUPERIMPOSED



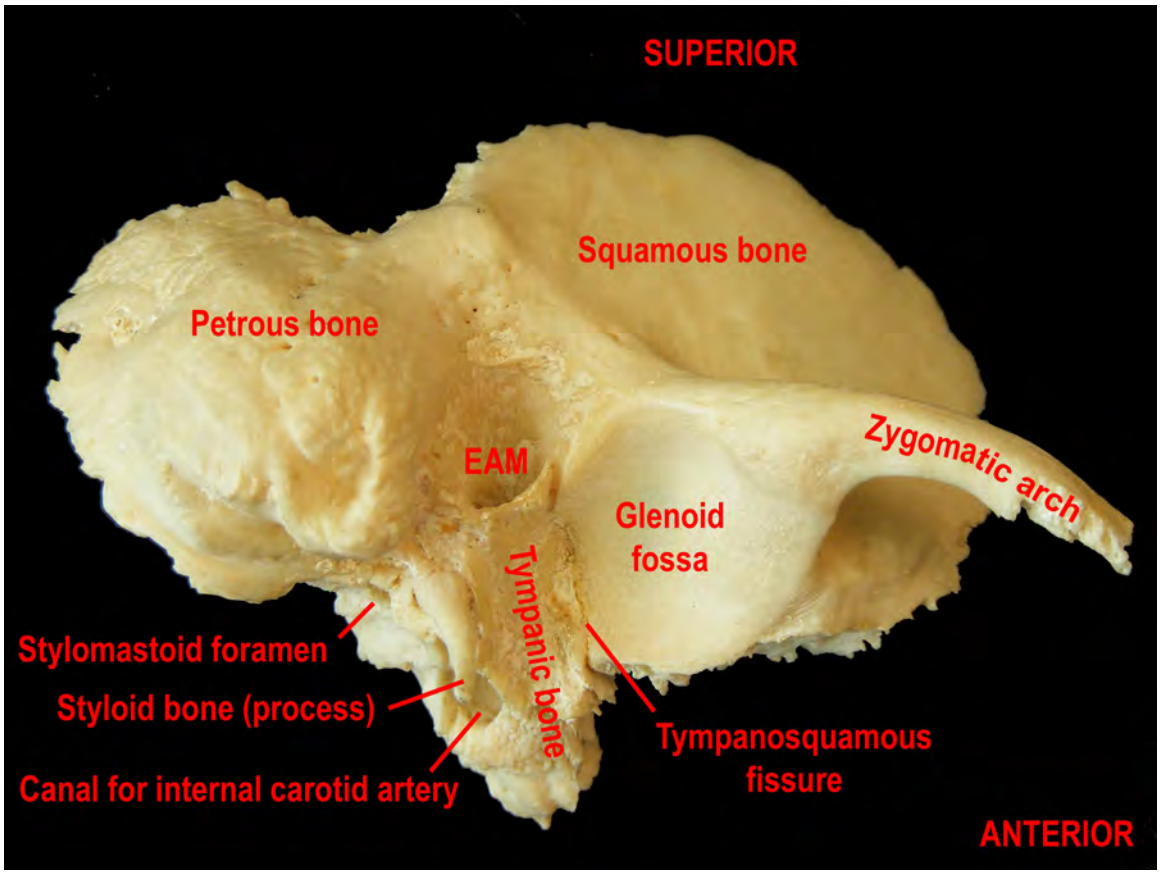

This photograph shows the base of the skull after removal of the calvarium and brain. The petrous portion of the right and left (outlined in purple) temporal bones make prominent projections into the middle cranial fossa on either side of the foramen magnum (**F. magnum**). Schematic drawings of the right and left membranous labyrinths are superimposed on the temporal bones. The cochlea ( **C**), vestibule (**V**) and vestibulocochlear nerve (**8**) in the internal auditory meatus are visible. A horizontal section through the middle of the left temporal bone is also shown. Note that the cochlea is anterior to the vestibule and its apex points in a anterior-inferior direction. The three semicircular canals (i.e., lateral scc; posterior scc; superior scc) are oriented at right angles to one another. The left superior semicircular canal is parallel to the right posterior semicircular canal and the right superior semicircular canal is parallel to the left posterior semicircular canal. The left and right lateral canals are parallel to each other. **EAC** - external auditory canal; **MAS** - mastoid. (Illustration adapted from Chapter 8 by Bohne and Harding in Clark and Ohlemiller, 2008).

**TEMPORAL BONE (LATERAL SURFACE)**



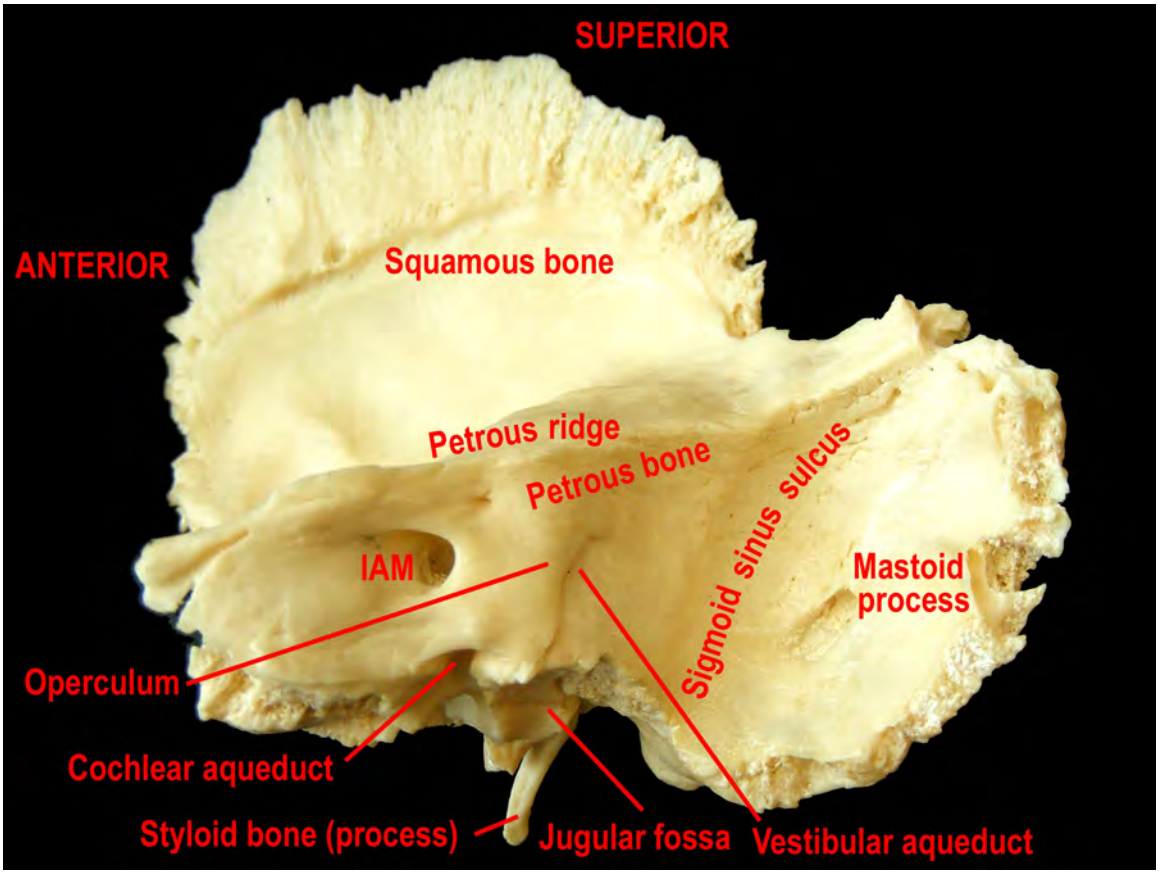

This is a dried right temporal bone viewed from its lateral surface. The four parts of the temporal bone are visible here: 1) squamous bone - flattened region that forms the lateral portion of the skull and is the origin for the temporalis muscle. The zygomatic arch extends anteriorly from the squamous bone; 2) tympanic bone - forms the floor and anterior wall of the bony portion of the external auditory canal; 3) petrous bone - houses the middle and inner ears; and 4) styloid bone - a slender process of variable length that extends in an anterior-inferior direction and serves as the attachment for the stylohyoid, styloglossus and stylopharyngeus muscles. Immediately in front of the external auditory meatus (**EAM**) is the glenoid (mandibular) fossa where the condyle of the mandible articulates. Also visible on the lateral side of the temporal bone are Macewen's (suprameatal) triangle (i.e., a shallow depression posterior-superior to the EAM that marks the position of the mastoid antrum) and the spine of Henle. (Photograph by V. Militchin).

**TEMPORAL BONE (INFERIOR SURFACE)**



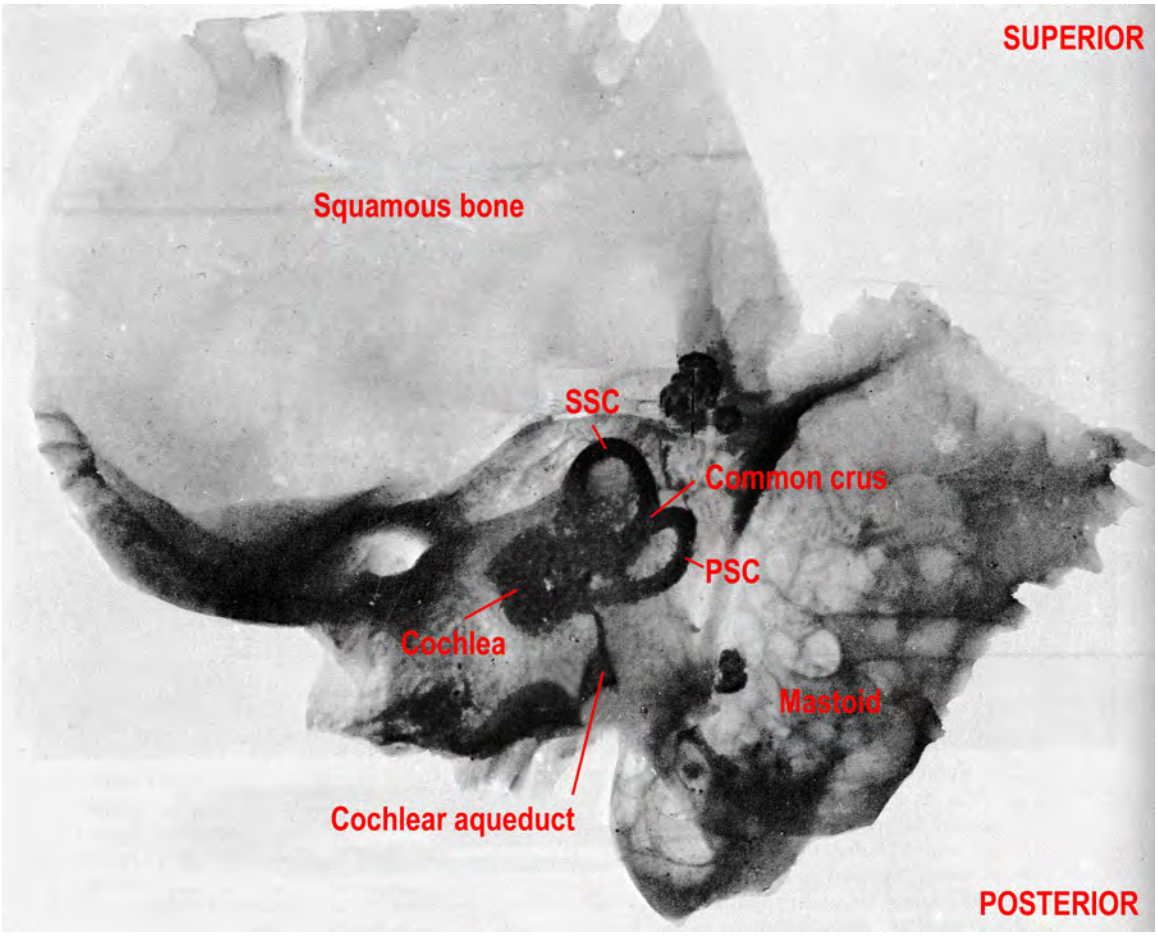

When viewed from its inferior surface, the entire tympanic portion of the right temporal bone is visible, as is the inferior opening of the canal for the internal carotid artery, the stylomastoid foramen where the VII$^{th}$ nerve exits from the skull and the glenoid (mandibular) fossa. The mastoid process, located posterior to EAM, develops after birth from the petrous portion of the temporal bone. The mastoid is filled with air spaces and communicates with the middle ear space via the aditus ad antrum. The sternocleidomastoid, splenius capitus, and longissimus capitus muscles are attached here. (Photograph by V. Militchin).

**TEMPORAL BONE (MEDIAL SURFACE)**




This is the medial surface of a dried right temporal bone. The petrous portion of the temporal bone houses part of the middle ear (e.g., ossicles) and inner ear (i.e., cochlear and vestibular end organs). The following landmarks are visible on the medial surface: 1) cochlear aqueduct - a fine canal that connects scala tympani in the basal turn to the cerebrospinal fluid (CSF) space around the brain; 2) vestibular aqueduct - a bony passage that runs from the vestibule to the subarachnoid space. It transmits the endolymphatic duct; 3) internal auditory meatus (IAM) - a bony opening through which the 7$^{th}$ (i.e., facial) and 8$^{th}$ (i.e., vestibulocochlear) cranial nerves enter the petrous part of the temporal bone; 4) mastoid process; 5) sigmoid sinus sulcus - an 's'-shaped depression on the medial side of the temporal bone that is located posterior to the operculum and vestibular aqueduct. The sigmoid sinus is continuous with the transverse sinus and empties into the internal jugular vein; 6) styloid process. The jugular fossa marks the location of the jugular bulb. The temporal bone contains the air space of the middle ear and air cells in the mastoid, petrosa, perilabyrinthine and accessory areas (Photograph by V. Militchin).

**TEMPORAL BONE with MEMBRANOUS LABYRINTH INJECTED**




This is the medial surface of a dried and cleared (i.e., made transparent) right temporal bone in which the perilymphatic spaces of the inner ear were injected with contrast medium. The cochlea, superior (SSC) and posterior (PSC) semicircular canals appear black, as does the common crus (i.e., joined region of the non-ampullated ends of the superior and posterior canals). The cochlear aqueduct connects scala tympani to the subarachnoid space near the bulb of the internal jugular vein. The mastoid air cells, a pneumatized portion of the squamous and petrous bones is clearly visible. (Photograph scanned and adapted from Wolff et al, 1971).

## HORIZONTAL SERIES of SECTIONS through HUMAN TEMPORAL BONE

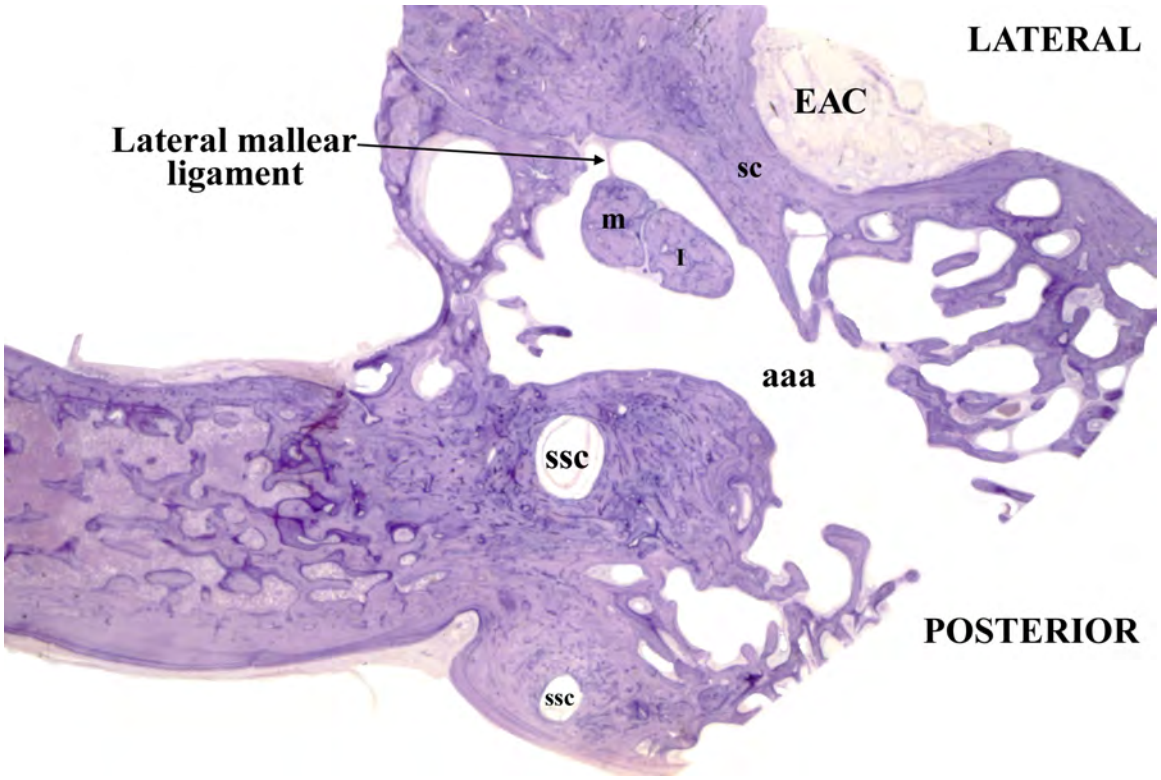
Detailed knowledge of the microscopic anatomy of the human temporal bone is very useful for understanding surgical relationships and for interpreting radiological images of the temporal bone in patients with otologic problems. Preparation of the human temporal bone for microscopic study generally involves fixation, decalcification, embedding in a supporting medium such as celloidin and sectioning parallel to the long axis of the specimen at a thickness of 20 µm. Initially every tenth section is stained with hematoxylin and eosin and mounted for microscopic examination. The intervening sections are saved in 80% ethanol for future studies (e.g., immunocytochemical staining, DNA analysis, scanning electron microscopy). The following photomicrographs were taken of a series of horizontal sections through the human temporal bone, from its superior surface to its inferior surface.

Some key structures are labeled where they appear most prominently but not in all sections. The facial nerve, however, is labeled in every section in which it appears so it can serve as a landmark. In order to identify an unlabeled structure, the viewer should follow it through the sections until it becomes more prominent.

Dr. Gershon J. Spector supplied the excellent slides from which the following images were photographed. The slides were acquired by Dr. Spector when he was a resident with Dr. Harold F. Schuknecht (Schucknecht, 1993) at the Massachusetts Eye and Ear Infirmary.

We are grateful for the critical review of this portion of the Atlas and the many helpful suggestions, especially surgical perspectives, provided by Dr. J. Gail Neely.

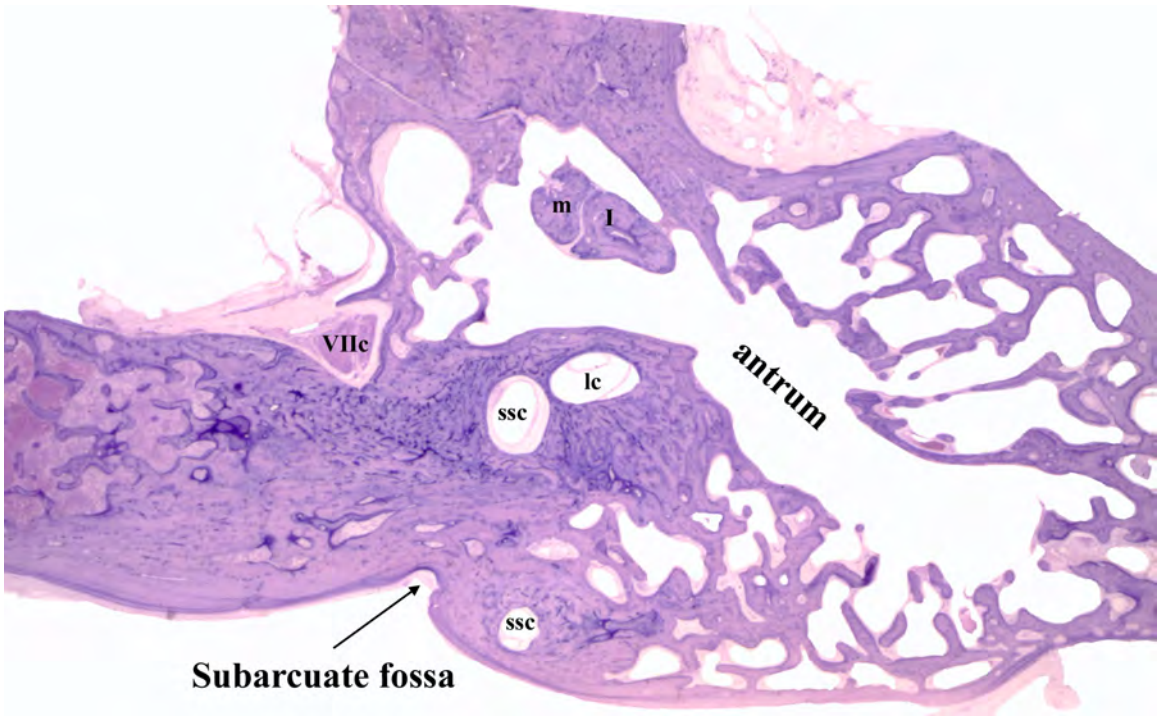
**EPITYMPANIC RECESS**




**Section 1**: This section, just inferior to the tegmen tympani (i.e., roof of middle ear space), passes through the epitympanic recess where the head of the malleus (**m**) and body (**I**) of the incus are located. Note the lateral mallear ligament's attachment from the malleus to the lateral wall of the middle ear space. The superior semicircular canal (**ssc**) has been cut in two places. **EAC** - external auditory canal.

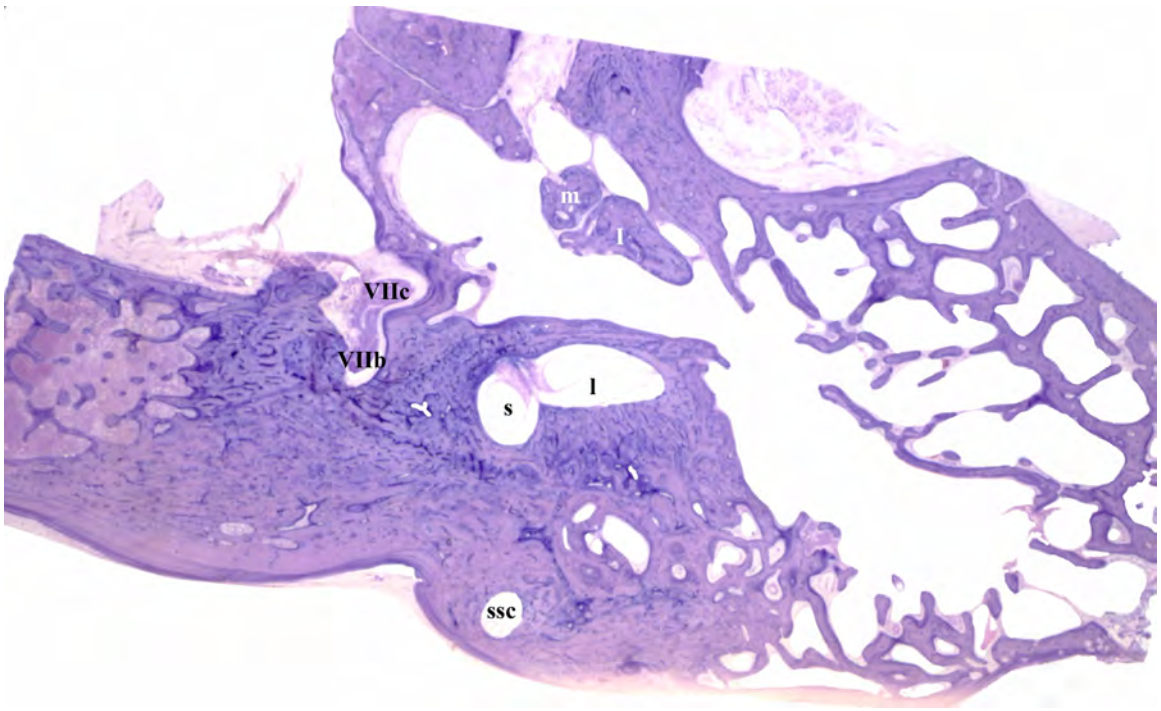
The scutum (**sc**) is the lateral wall of the epitympanum and is a "shield"-like contribution of the squamous portion of the temporal bone to the osseous external auditory canal (**EAC**). The aditis ad antrum (**aaa**) is the passageway from the epitympanum to the mastoid antrum and is just inferior to the tegmen.

## SUPERIOR and LATERAL SEMICIRCULAR CANALS



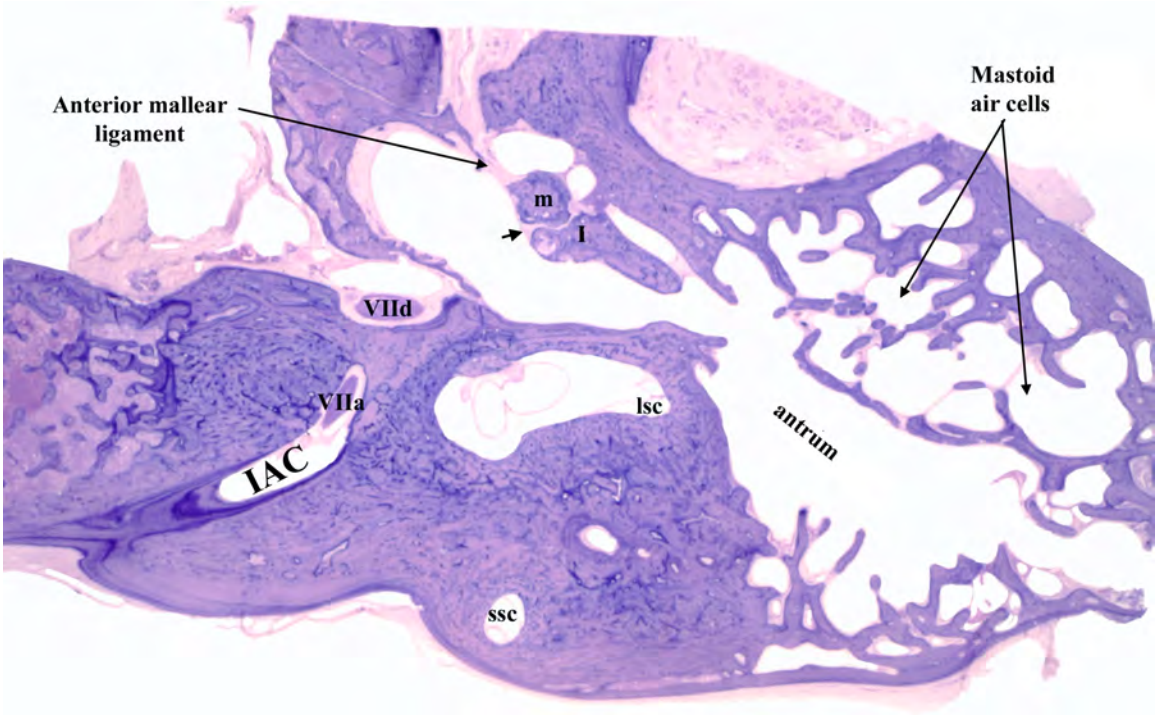

**Section 21**: The superior semicircular canal (**ssc**) is in two parts while one cut through the lateral (**lc**) semicircular canal is now visible. The geniculate ganglion (**VIIc**) of the facial nerve has appeared anterior to the superior and lateral semicircular canals. The antrum is the connection between the mastoid air cells and the epitympanum. **I** - incus; **m** - malleus.

**AMPULLAE of SUPERIOR and LATERAL SEMICIRCULAR CANALS**



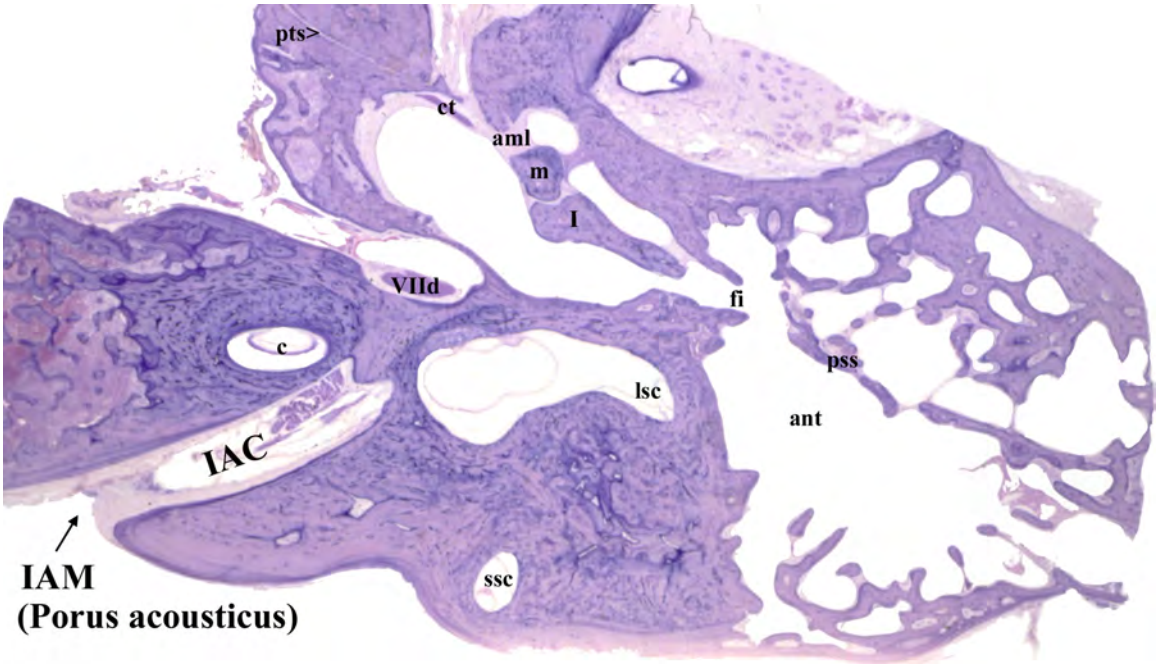

**Section 41**: This section is still within the epitympanic space where the head of the malleus (**m**) and body of the incus (**I**) are visible. The labyrinthine segment (**VIIb**) and the geniculate ganglion (**VIIc**) of the facial nerve can be seen along with the ampullae of the superior (**s**) and lateral (l) semicircular canals.

## MALLEUS and INCUS in EPITYMPANIC SPACE



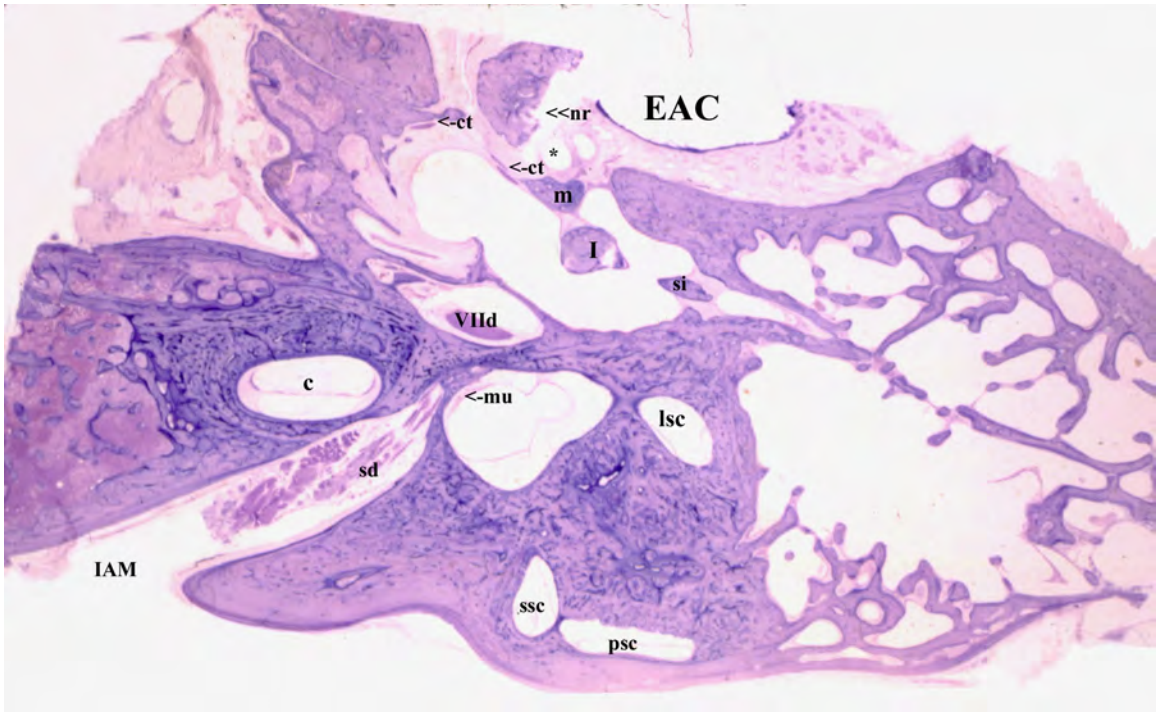

**Section 61**: The incudomalleal joint (arrow) between the malleus (**m**) and incus (**I**) can be seen. The anterior mallear ligament attaches the neck of the malleus to the anterior wall of the middle ear space. The facial nerve is in two parts: **VIIa** - within the internal auditory canal and the beginning of the labyrinthine segment; **VIId** - beginning of its tympanic segment. The lateral canal (**lsc**) and the non-sensory portion of the superior canal (**ssc**) can be seen. **IAC** - internal auditory canal.

## CHORDA TYMPANI




**Section 81**: The chorda tympani (**ct**) can be seen near the petrotympanic suture (**pts**) at the anterior end of the middle ear space. The anterior mallear ligament (**aml**) is visible anteriorly; this is the most important stabilizing structure for the malleus (**m**). The antrum (**ant**) is surgically defined as the large air cell lateral to the lateral semicircular canal (**lsc**). The lateral wall of the antrum is the petrosquamous suture **(pss**) (Körner's septum) internally. The basal turn of the cochlea (**c**) is just becoming visible. **fi** - fossa incudis; **I** - incus; **IAC** - internal auditory canal; **IAM** - internal auditory meatus or porus acousticus.

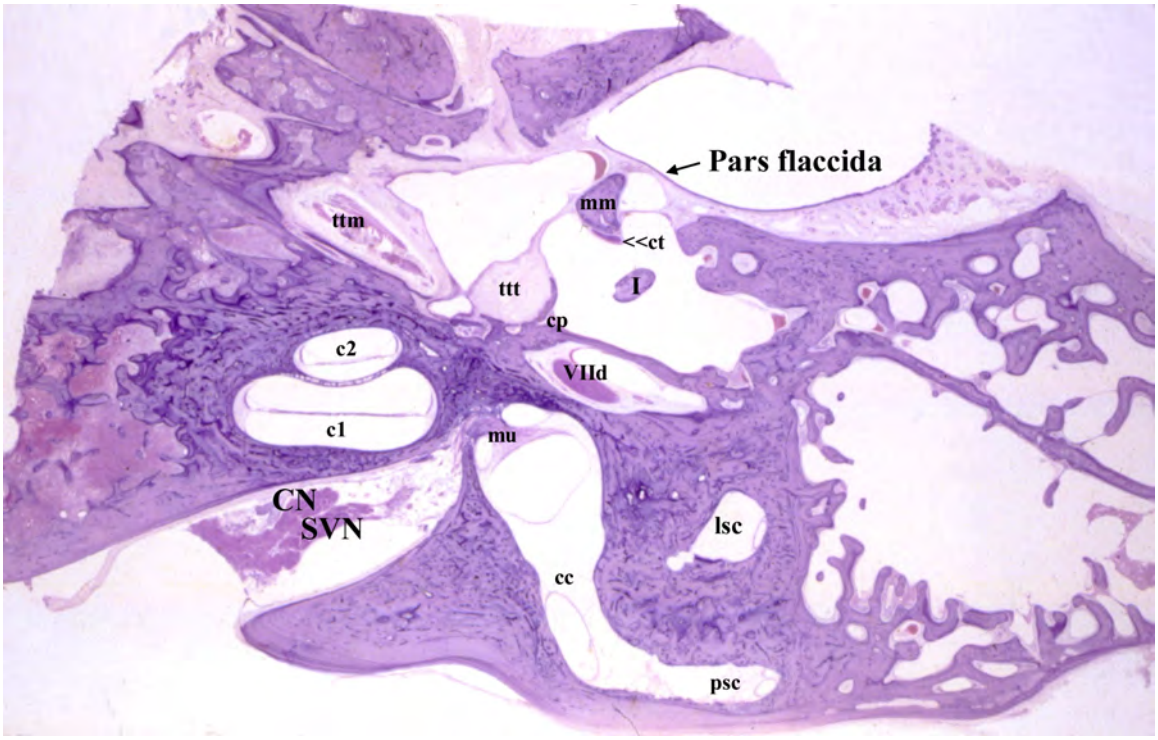
## INTERNAL AUDITORY MEATUS




**Section 101**: The chorda tympani (**ct**) appears in two parts. This section is inferior to the bulk of the short process of the incus (**si**). The internal auditory meatus (**IAM**) is the opening from the middle cranial fossa into the temporal bone. The superior vestibular division (**sd**) of the vestibulocochlear nerve (VIII CN) is present in the internal auditory canal. The macula of the utricle (**mu**), one of two gravity receptors, is visible in the center, along with cuts through the non-sensory portions of the lateral (**lsc**), posterior (**psc**) and superior (**ssc**) semicircular canals.***** - Prussak's space; **c** - cochlea; **EAC** - external auditory canal; **I** - incus; **m** - malleus; **nr**- notch of Rivinus (i.e., incisura tympanica). **VIId** - Tympanic segment of facial nerve.

**Surgical perspective** - Note that the superior vestibular division (**sd**) of the VIII nerve enters the end organs (i.e., lateral and superior cristae and utricular macula) from an anterolateral direction.

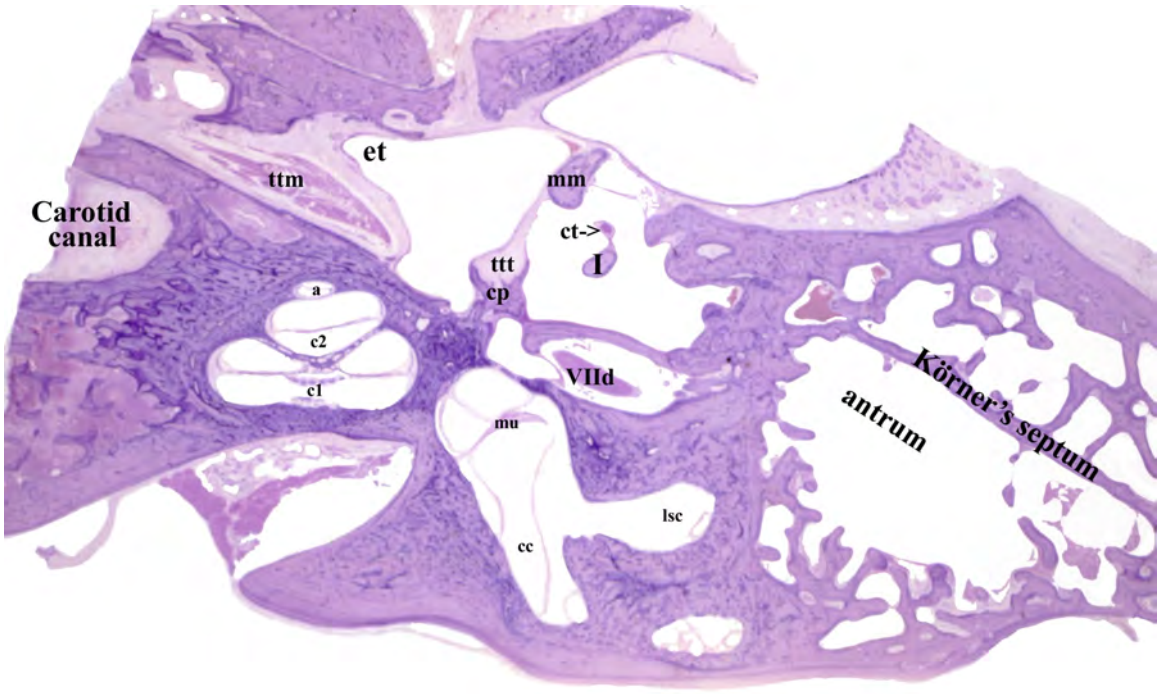
**INSERTION of TENSOR TYMPANI TENDON into MANUBRIUM**




**Section 141**: The chorda tympani (**ct**) crosses the middle ear space, medial to the manubrium of the malleus (**mm**) and lateral the long process of the incus (**I**). The tendon of the tensor tympani (**ttt**) runs in a medial-lateral direction to insert into the medial side of the manubrium. Note that the tendon makes a 90° angle with the tensor tympani muscle (**ttm**). The macula of the utricle (**mu**) is still visible along with much of the non-sensory portion of the posterior semicircular canal. Two turns of the cochlear spiral (**c1**, **c2**) are seen medial to the tensor tympani. **cc** - common crus; **CN** - cochlear division of VIII$^{th}$ CN; **lsc** - lateral semicircular canal; **psc** - posterior semicircular canal; **SVN** - superior vestibular division of VIII$^{th}$ CN; **VIId** - Tympanic segment of facial nerve.

**Surgical perspective** - The tympanic segment of the facial nerve anterior to the cochleariform process (**cp**) is in the epitympanum while posterior to the process, the tympanic segment is at the border of the epitympanum and mesotympanum.

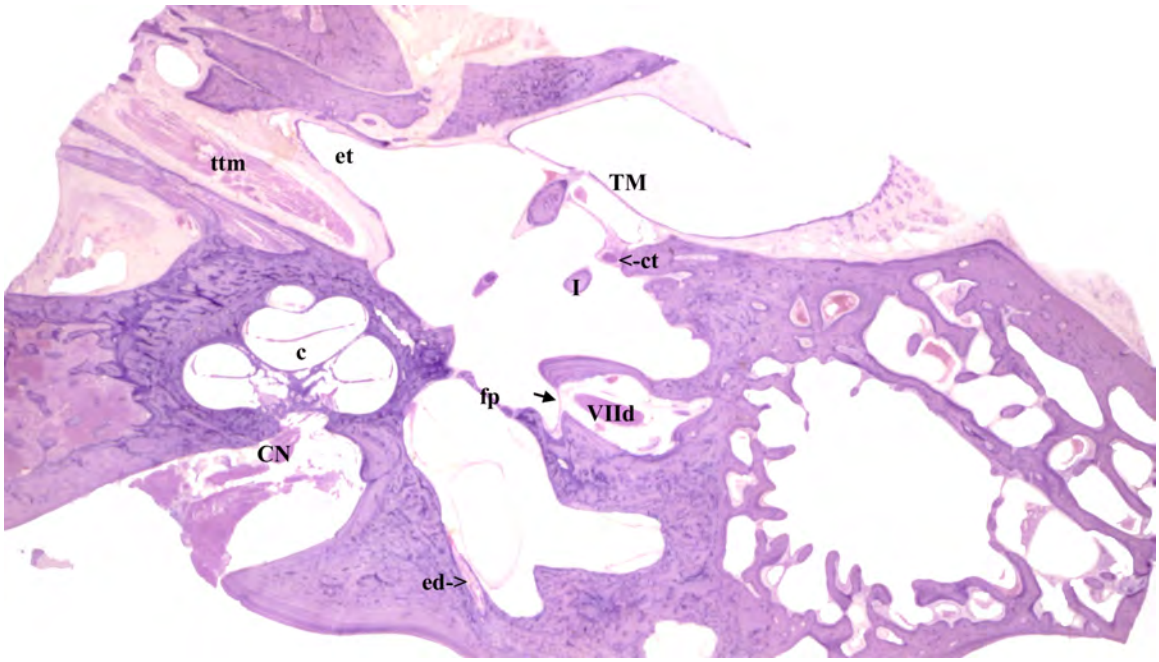
**TENSOR TYMPANI MUSCLE and TENDON**




**Section 161**: The chorda tympani (**ct**) is still visible in the middle ear space medial to the manubrium of the malleus (**mm**) and lateral to the long process of the incus (**I**). The tendon of the tensor tympani (**ttt**) hooks around a bony prominence (cochleariform process - **cp**) on the medial wall of the middle ear in order to run in a medial-lateral direction. The macula of the utricle (**mu**) is still visible along with the entrance into the vestibule of the non-ampullated portion of the lateral canal (**lsc**) and common crus (**cc**). Three turns of the cochlear spiral (**c1**, **c2**, **a**) are seen pointing anterolaterally, medial to the tensor tympani muscle (**ttm**). **VIId** - Tympanic segment of facial nerve.

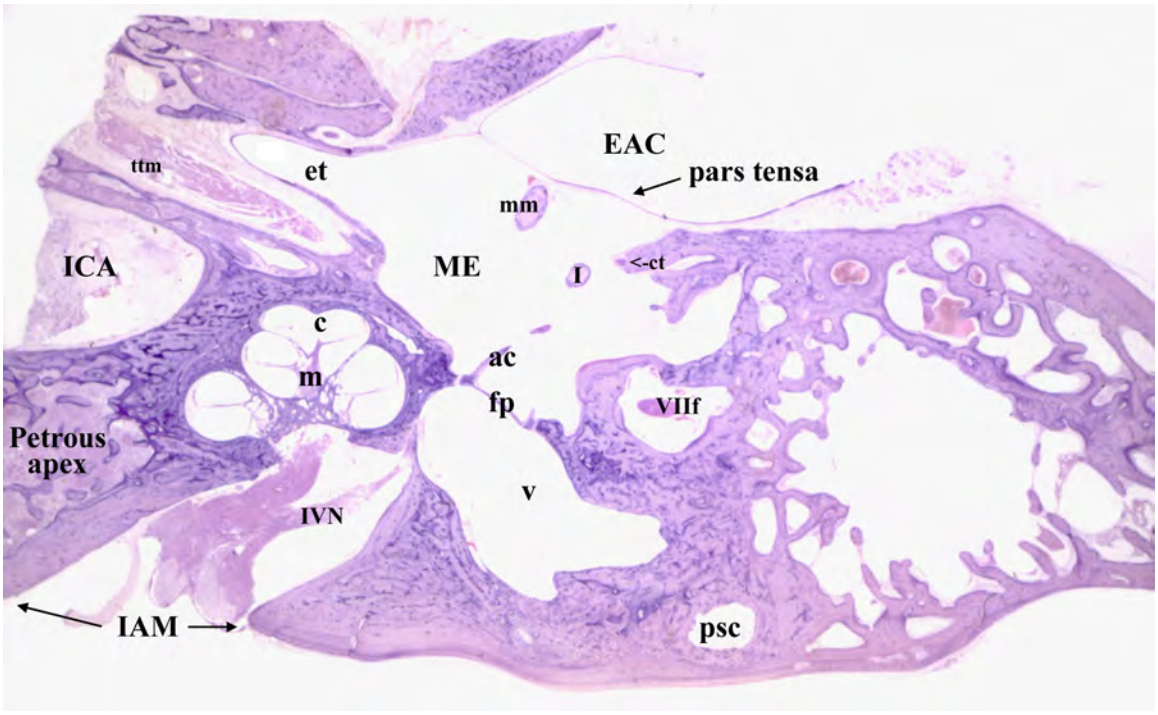
**Surgical perspective** - At this level as well as that shown in sections 101 and 141, the facial nerve canal is part of the lateral wall of the vestibule. The medial wall of the vestibule is the lateral wall of the internal auditory canal.

## FOOTPLATE of STAPES in OVAL WINDOW



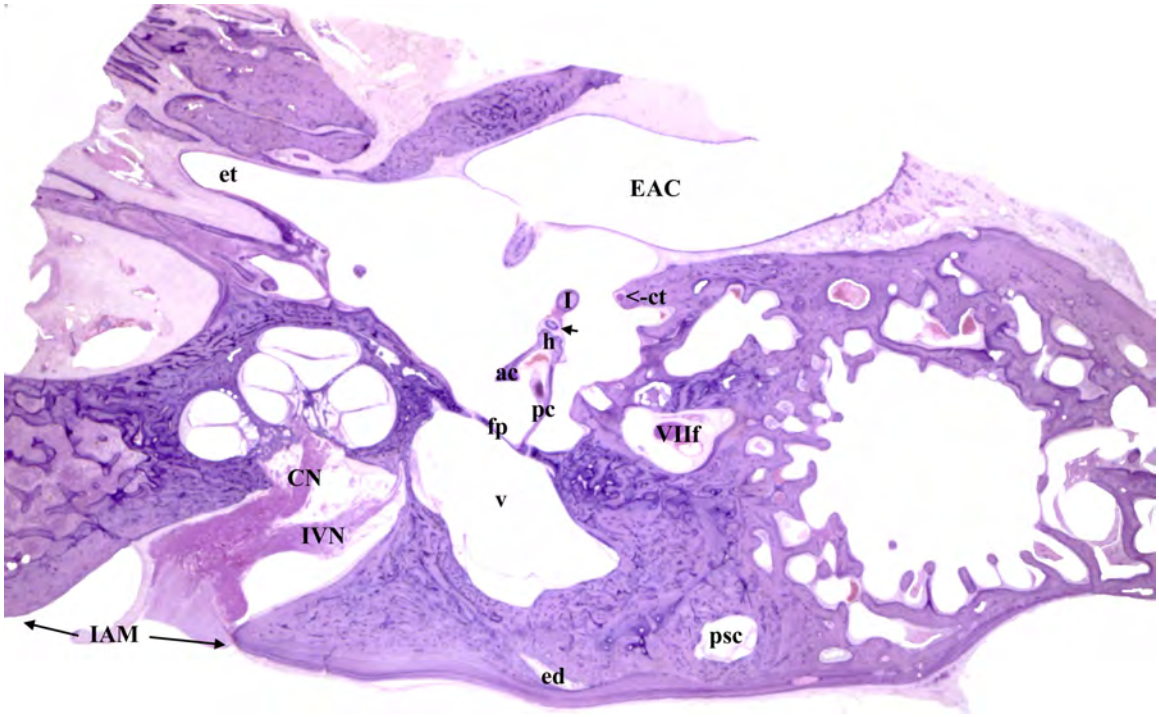

**Section 181**: The tympanic segment (**VIId**) of the facial nerve is about to reach the posterior wall of the middle ear space to form the pyramidal bend. Note that there is a dehiscence (**arrow**) in the bony facial canal so that there is only a thin connective tissue covering between the nerve and the middle ear space. The footplate of the stapes (**fp**) is held in the oval window by the annular ligament. The origin of the endolymphatic duct (**ed**) is visible at the origin of the vestibular aqueduct. **c** - Cochlea; **CN -** cochlear division of VIII$^{th}$ CN; **ct** - chorda tympani; **et** - Eustachian tube; **I** - long process of incus; **TM** - tympanic membrane.

**MID-MODIOLAR SECTION of the COCHLEA**



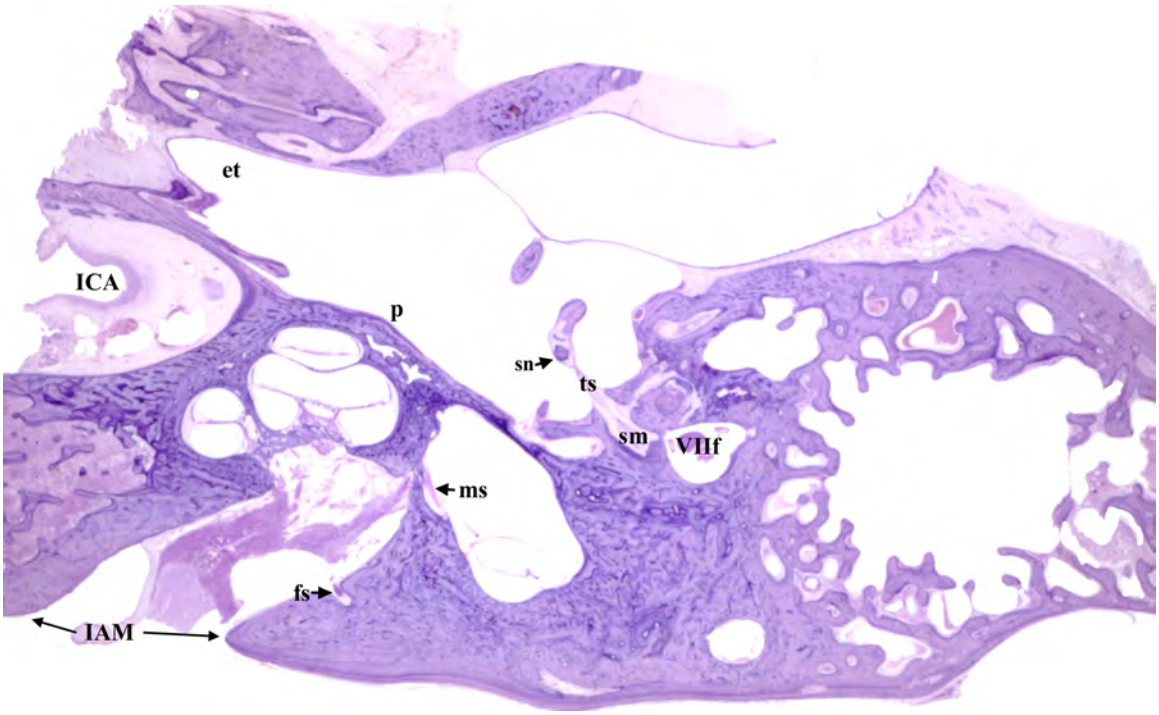

**Section 200**: The tympanic membrane (eardrum) forms the boundary between the external auditory canal (**EAC**) and middle ear (**ME**). The manubrium (**mm**) of the malleus is attached to the medial surface of the eardrum. The long process of the incus (**I**) is located medial to the manubrium and lateral to the stapes (**ac** - anterior crus). Anteriorly, the middle ear narrows down to form the bony portion of the Eustachian (auditory) tube (**et**) which connects the middle ear to the nasopharynx. Running parallel to the auditory tube is the tensor tympani muscle (**ttm**) in its bony semicanal. The chorda tympani (**ct**) is nearing the posterior wall of the middle ear space. The footplate (**fp**) of the stapes which is held in the oval window by the annular ligament forms the boundary between the middle and inner ears. In this section both the cochlear and inferior vestibular portion (**IVN**) of VIII$^{th}$ CN are visible. Note that the cochlea is anterior to the vestibular portion of the membranous labyrinth. In the cochlea, 5 cuts through the coiled cochlear duct are seen as it spirals around the modiolus (**m**). The vestibule (**v**) and the posterior semicircular canal (**psc**) are visible. **IAM** - internal auditory meatus; **ICA** - Internal carotid artery; **VIIf** - Mastoid segment of facial nerve.

## STAPES, INCUS and INCUDOSTAPEDIAL JOINT




**Section 221**: Nearly the complete stapes is present: **ac** - anterior crus; **fp** - footplate; **h** - head; **pc** - posterior crus. The incudostapedial joint between stapes head and lenticular process of the incus is visible. The lenticular process (arrow) is connected to the long process (**I**) of the incus by a connecting stem (Grayboyes et al., 2011). The chorda tympani (**ct**) has reached the posterior wall of the middle ear space at the posterior iter. Both the cochlea and vestibule (**v**) are still present. Only the non-sensory portion of the posterior semicircular canal (**psc**) is visible. The endolymphatic duct (**ed**) can be seen within the osseous vestibular aqueduct. The inferior division of the VIII nerve with branches to the cochlea **(CN**) and saccule (**IVN**) is visible in the internal auditory canal. **EAC** - external auditory canal; **IAM** - internal auditory meatus; **VIIf** - Mastoid segment of facial nerve.

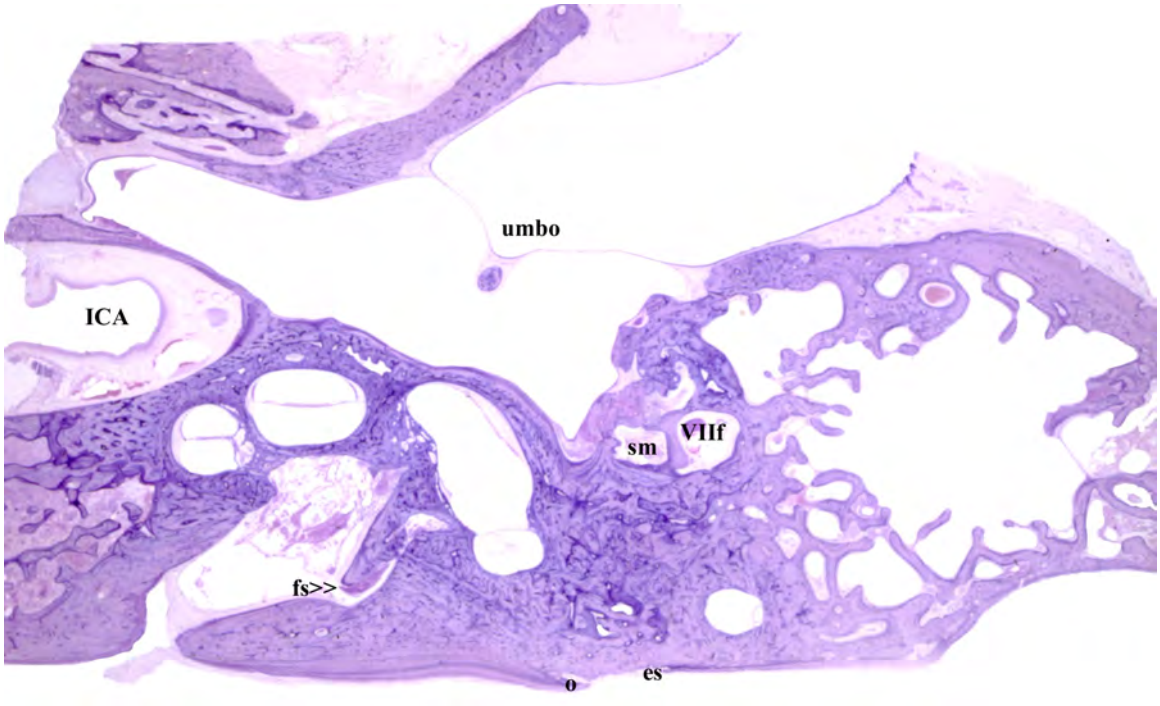
## STAPEDIUS MUSCLE




**Section 241**: The stapedius muscle (**sm**) is visible in the posterior wall of the middle ear space. Its tendon (**ts**) enters the middle ear space through the pyramidal eminence to insert into the stapes neck (**sn**). The inferior portion of the VIII$^{th}$ nerve extends into the internal auditory canal toward the macula of the saccule (**ms**). The origin of the foramen singulare (solitary) (**fs**) from the internal auditory canal is visible. This foramen transmits the nerve to the crista of the posterior semicircular canal. Scarpa's ganglion forms a bulge on the vestibular division of the VIII$^{th}$ nerve within the internal auditory canal. The cochlea makes a bulge, termed the promotory (**p**), on the labyrinthine wall of the middle ear space. **et** - Eustachian tube; **ICA** - Internal carotid artery; **VIIf** - Mastoid segment of facial nerve.

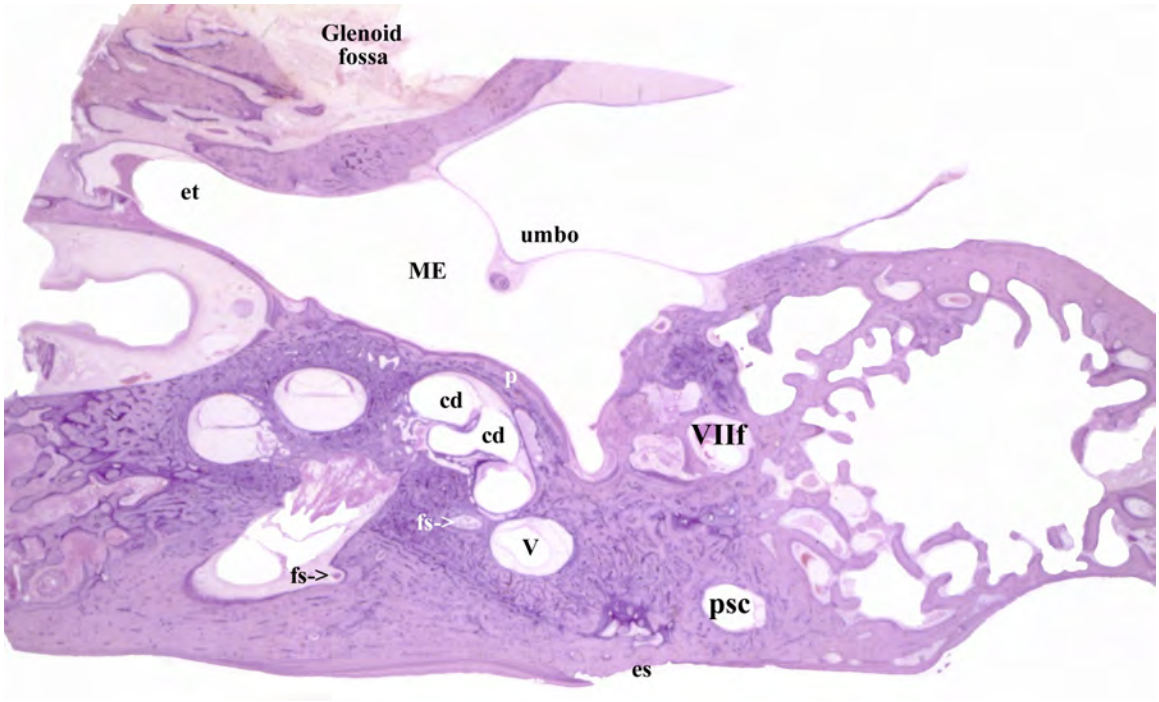
**Surgical perspective** - Innervation by the inferior division of the VIII nerve goes directly from medial to the cochlea and the macula of the saccule (**ms**).

## ENDOLYMPHATIC DUCT REACHES POSTERIOR CRANIAL FOSSA



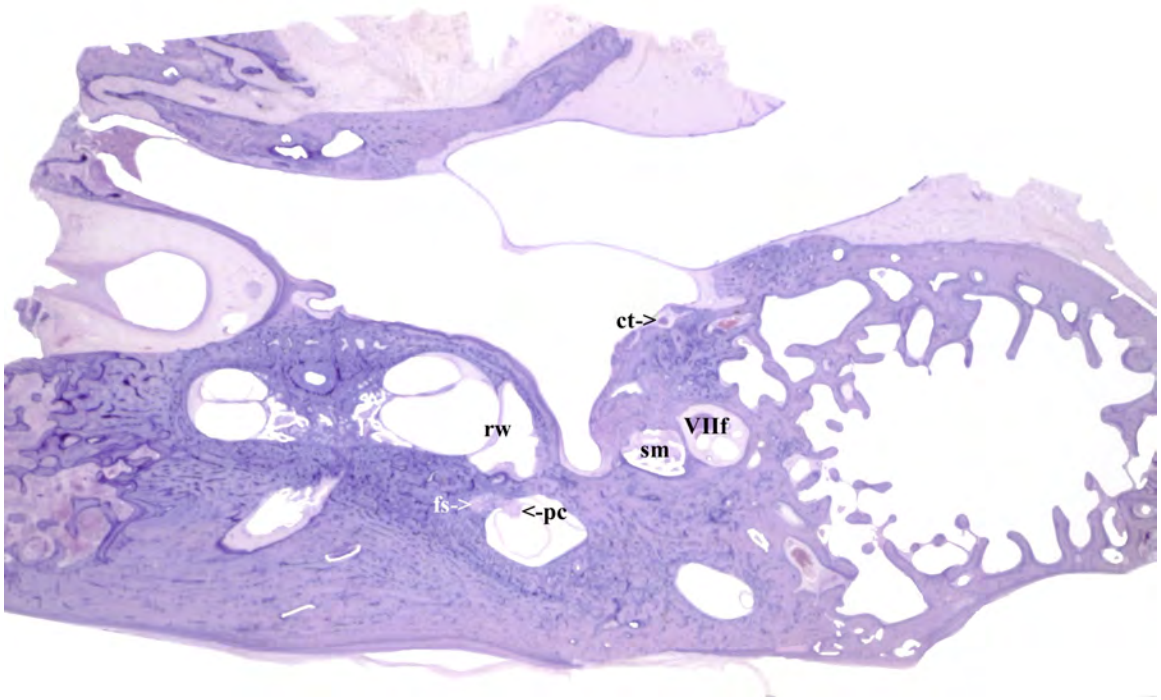

**Section 281**: The umbo of the tympanic membrane, which marks the inferior end of the manubrium of the malleus, is visible. The stapedius muscle (**sm**) can be seen in the posterior wall of the middle ear space. The endolymphatic sac (**es**) is present in the posterior cranial fossa. The osseous opening of the canal, which transmits the endolymphatic duct, is called the external aperture of the vestibular aqueduct. The medial lip of that aperture is known as the "operculum" (**o**) (i.e., like the gill flap in fish). Nearly the entire course of the foramen singulare (**fs**) is visible. The internal carotid artery (**ICA**) is seen in the carotid canal. **VIIf** - Mastoid segment of facial nerve.

## ENDOLYMPHATIC SAC and DUCT




**Section 300**: The hook portion of the cochlea duct (**cd**) is visible on the medial wall of the middle ear space. The promontory (**p**) which bulges into the middle ear space (**ME**) marks the position of the hook. Only a small part of the vestibule (**v**) remains. The end of the foramen singulare (**fs**) is visible. The non-sensory portion of the posterior semicircular canal (**psc**) is still present. The endolymphatic sac (**es**) is located in the posterior cranial fossa. **et -** Eustachian tube; **VIIf** - Mastoid segment of facial nerve.

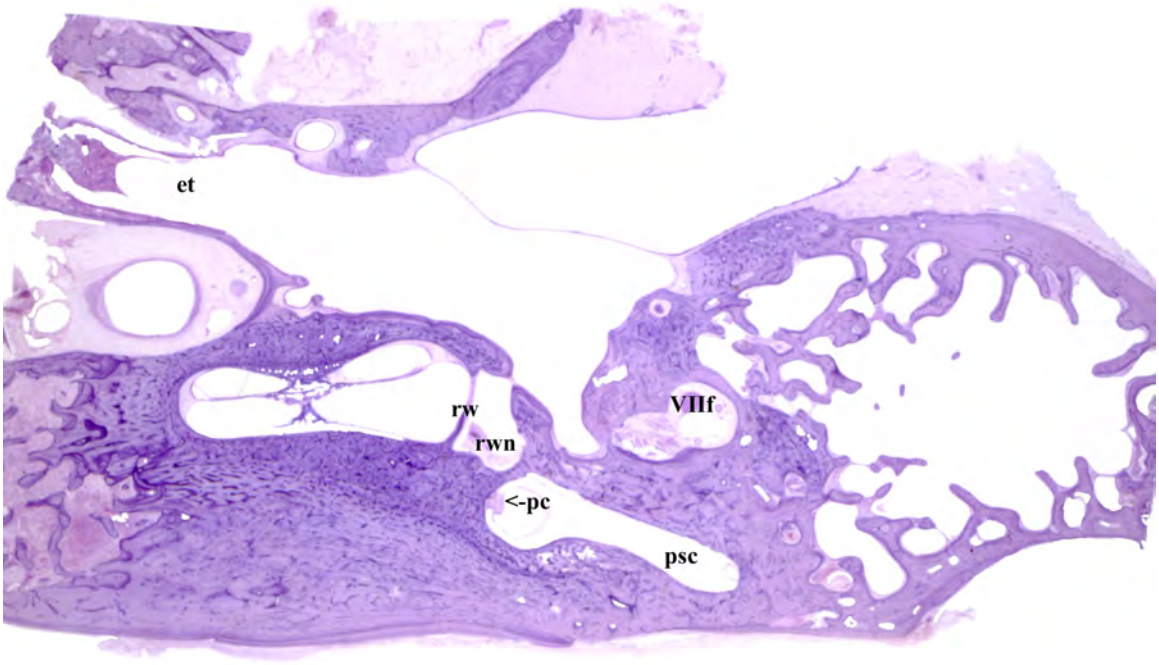
## ROUND WINDOW MEMBRANE




**Section 321**: The round-window membrane (**rw**) closes scala tympani at the posterior extreme of the hook. This membrane separates the inner ear from the middle ear space. The crista of the posterior semicircular canal (**pc**) is now visible along with the nerve to the posterior canal in the foramen singulare (**fs**). **ct** - chorda tympani; **sm** - stapedius muscle; **VIIf** - Mastoid segment of facial nerve.

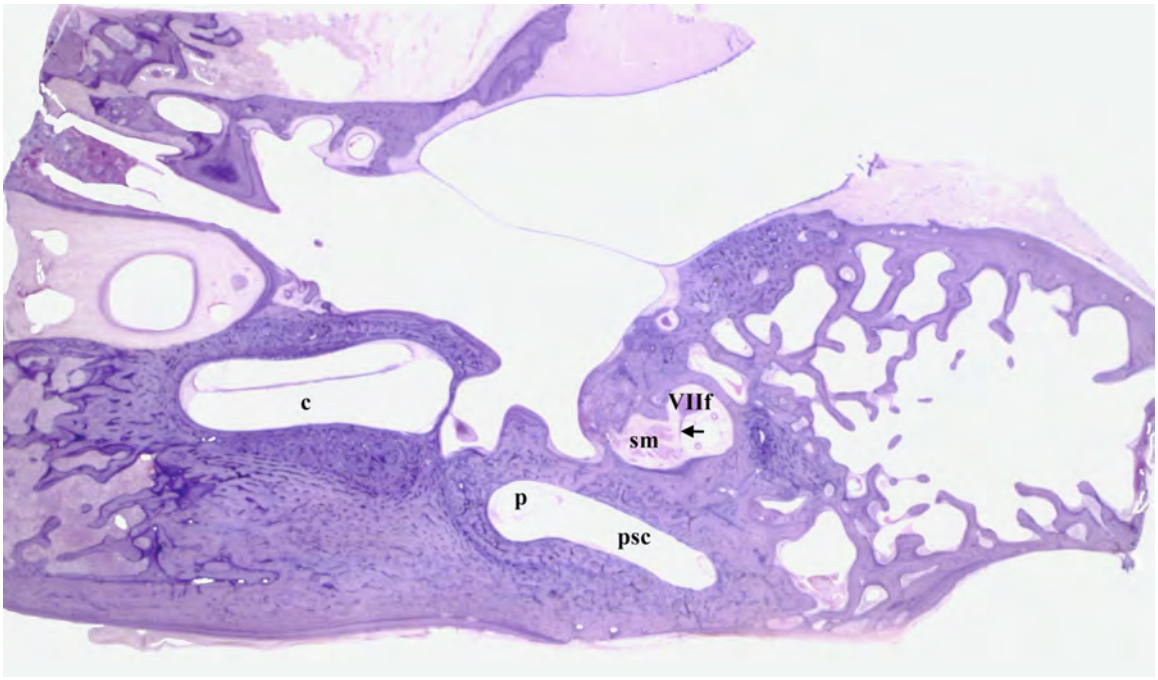
**Surgical perspective** - The nerve to the posterior crista innervates the end organ from an anterolateral position (same as superior division did in section 101). There is a narrow surgical course from the middle ear, past the proximate round window, to the nerve.

## NICHE of ROUND WINDOW



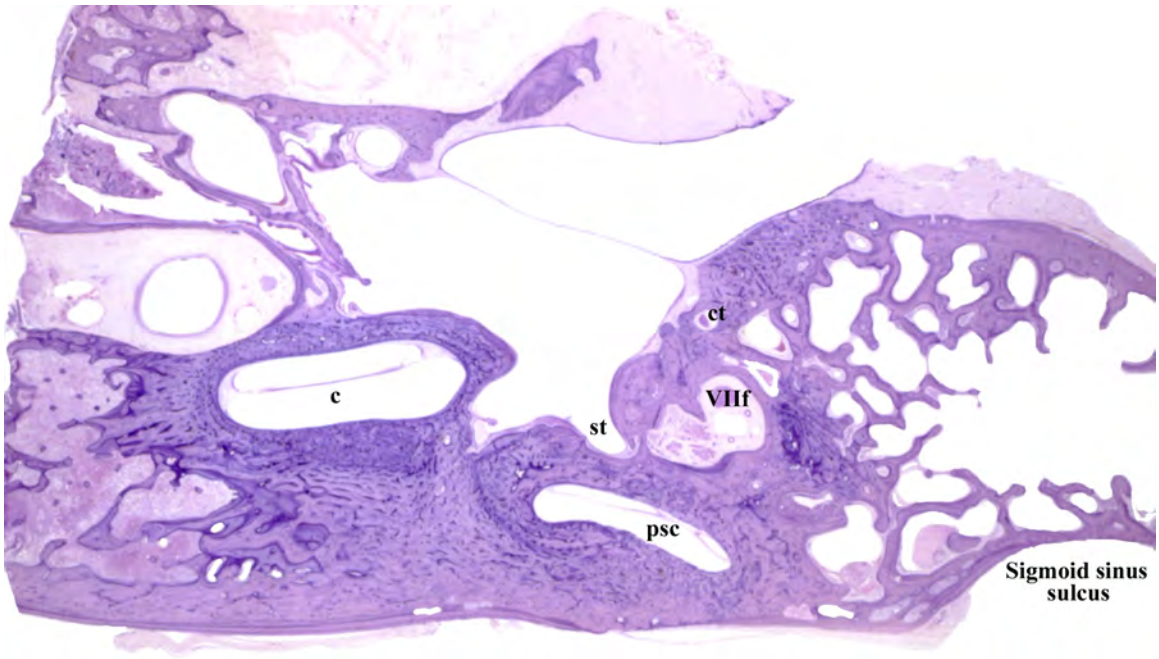

**Section 341**: The round window niche (**rwn**) is just posterior to the round window membrane (**rw**). The crista (**pc**) of the posterior semicircular canal (**psc**) is still visible. **et** - Eustachian tube; **VIIf** - Mastoid segment of facial nerve.

## INNERVATION of the STAPEDIUS MUSCLE



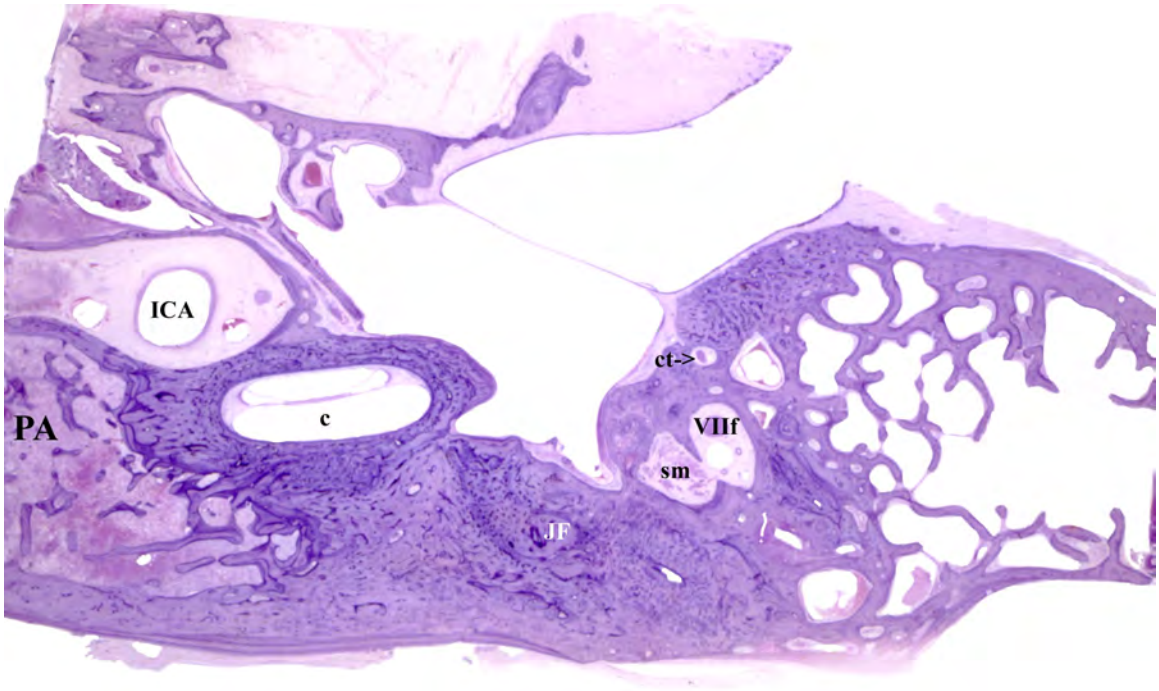

**Section 361**: The most inferior portion of the basal turn of the cochlea (**c**) is visible along with the ampullated end (**p**) of the posterior semicircular canal (**psc**). A branch (**arrow**) from the mastoid segment of the facial nerve (**VIIf**) innervates the stapedius muscle (**sm**).

**END of POSTERIOR SEMICIRCULAR CANAL**




**Section 381**: The most inferior portion of the basal turn of the cochlea (**c**) is still visible. The non-sensory region of the posterior semicircular canal (**psc**) is disappearing. The sinus tympani (**st**) which is a depression in the tympanic cavity posterior to the promotory is visible. **ct** - chorda tympani**; VIIf** - Mastoid segment of facial nerve. .

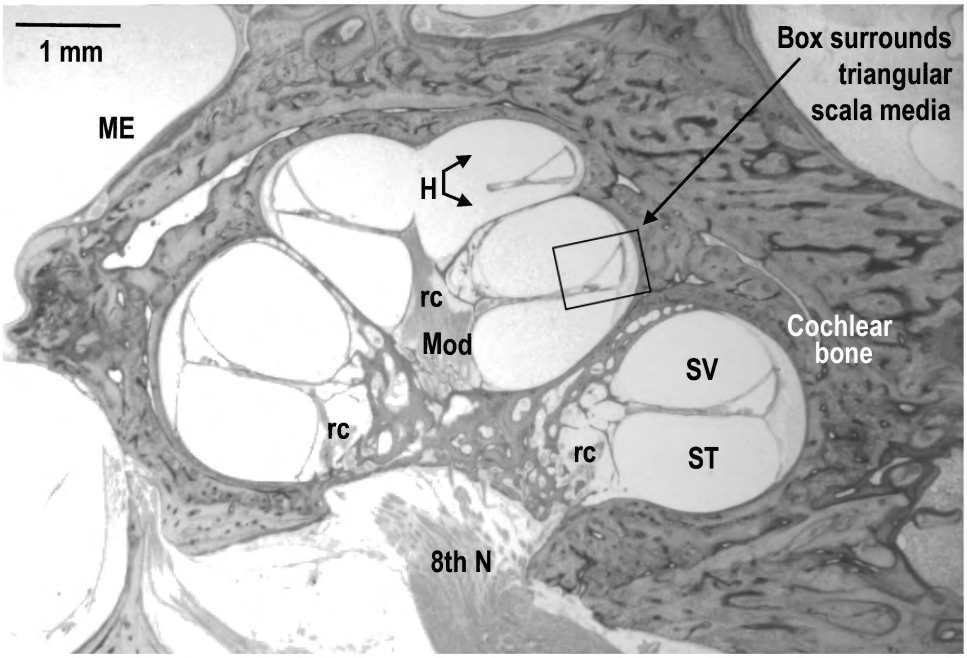
**END of COCHLEA**




**Section 401**: The basal turn of the cochlea (**c**) is disappearing. The stapedius muscle (**sm**) is still present. The chorda tympani (**ct**), running in a separate canal, is close to the mastoid segment of the facial nerve (**VIIf**). The chorda tympani separates from the lateral surface of the facial nerve about 0.5 cm superior to the stylomastoid foramen. This area is generally not included in human temporal bone specimens.

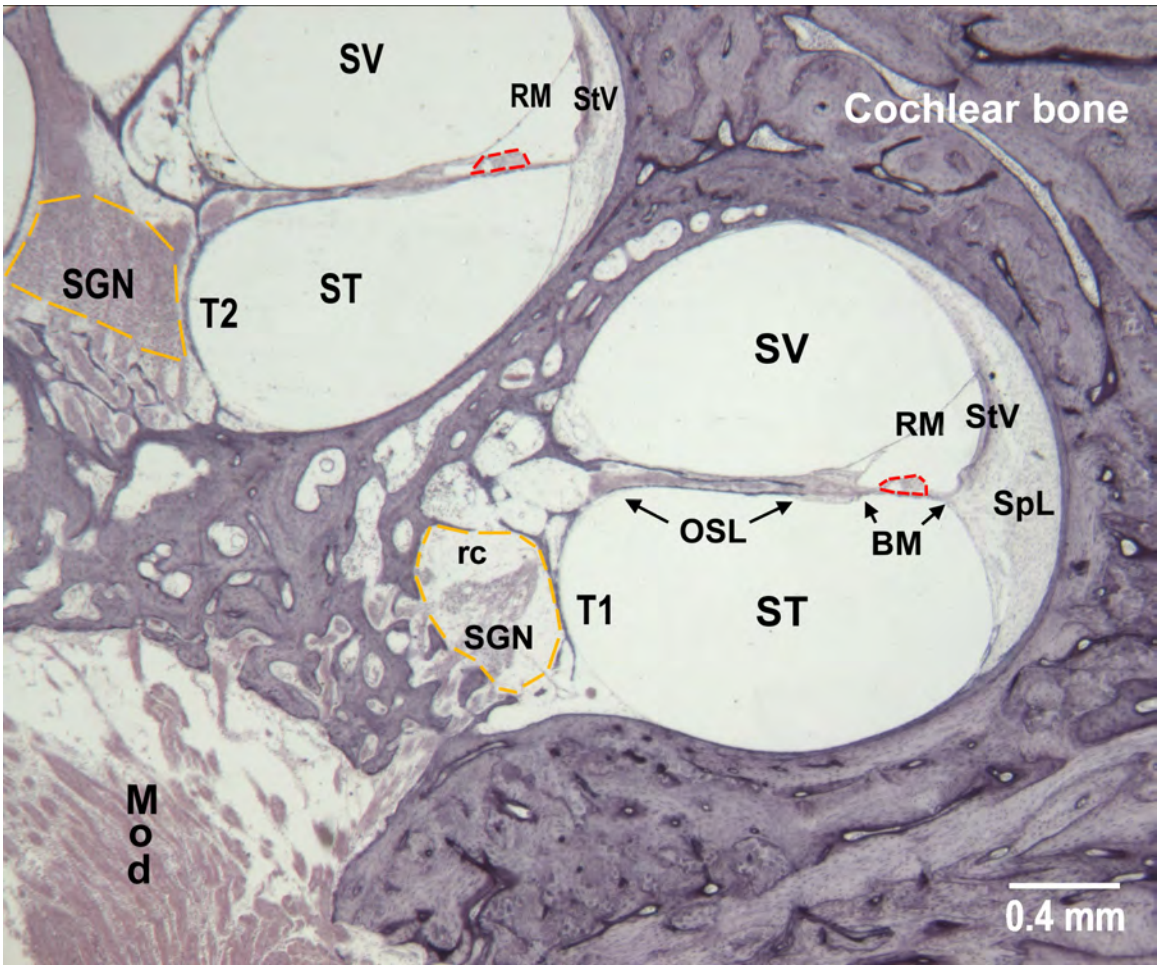
**Surgical perspective** - A surgical route to the petrous apex (**PA**) is anterior to the facial nerve, inferior to the cochlea, posterior to the internal carotid artery (**ICA**) and anterior to the jugular foramen (**JF**). In this section the jugular foramen appears as condensing bone which is just superior to the foramen. Most of the inferior portion of the tympanic bone must be removed to expose the petrous apex via this route.

## MID-MODIOLAR SECTION of the COCHLEA



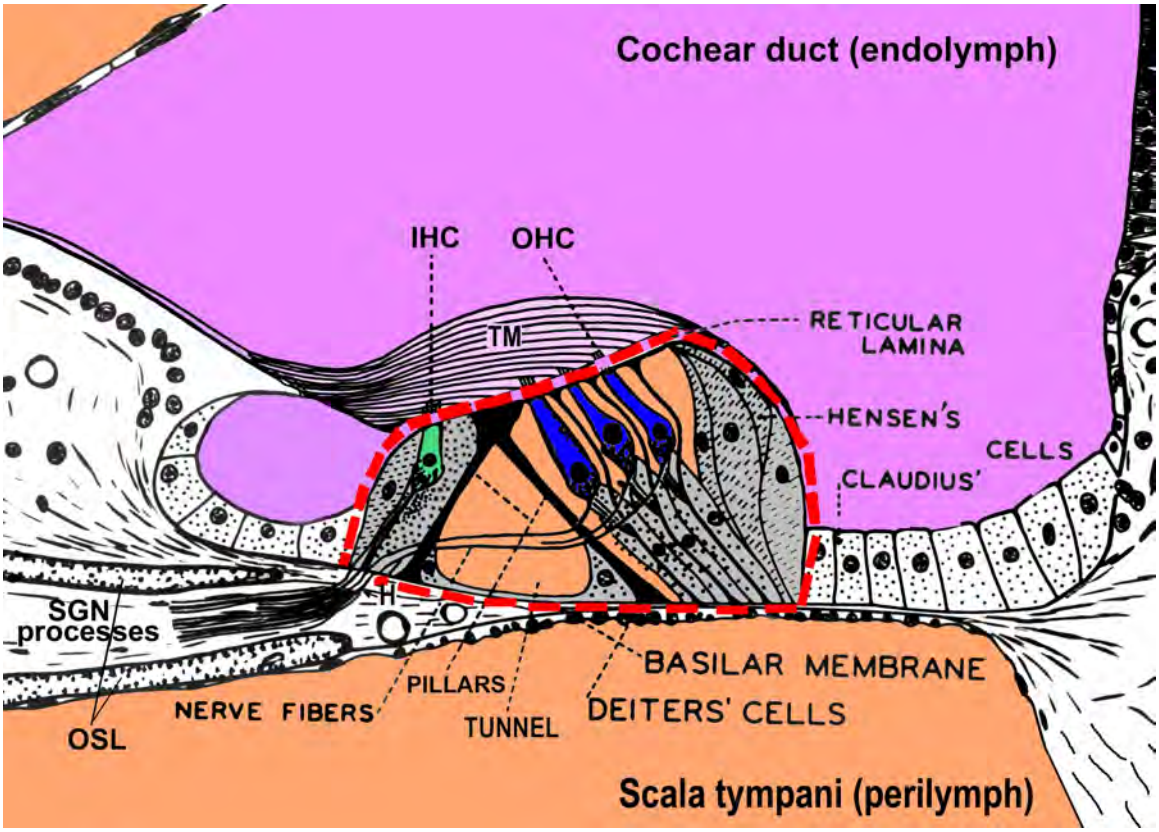

This section passed through the middle of the cochlea. The triangular-shaped cochlear duct (scala media) has been cut five times as it spirals around the modiolus (**Mod**). The cochlear duct is filled with the fluid endolymph that contains a high concentration of potassium ions and a low concentration of sodium ions. The cochlear division of the 8$^{th}$ nerve (**8$^{th}$ N**) exits the modiolus at the base of the cochlea. The cell bodies for these nerve fibers are called spiral ganglion neurons and are located in Rosenthal's canal (**rc**), a spiral canal positioned at the periphery of the modiolus. Scala vestibuli (**SV**) and scala tympani (**ST**) are filled with the fluid perilymph that has a high concentration of sodium ions and a low concentration of potassium ions. The two perilymphatic spaces are connected with each other by the helicotrema (**H**) at the apex of the cochlea. **ME** - middle ear. (Photomicrograph adapted from Chapter 8 by Bohne and Harding in Clark and Ohlemiller, 2008).

**COCHLEAR TURNS and ADJACENT ROSENTHAL'S CANAL**



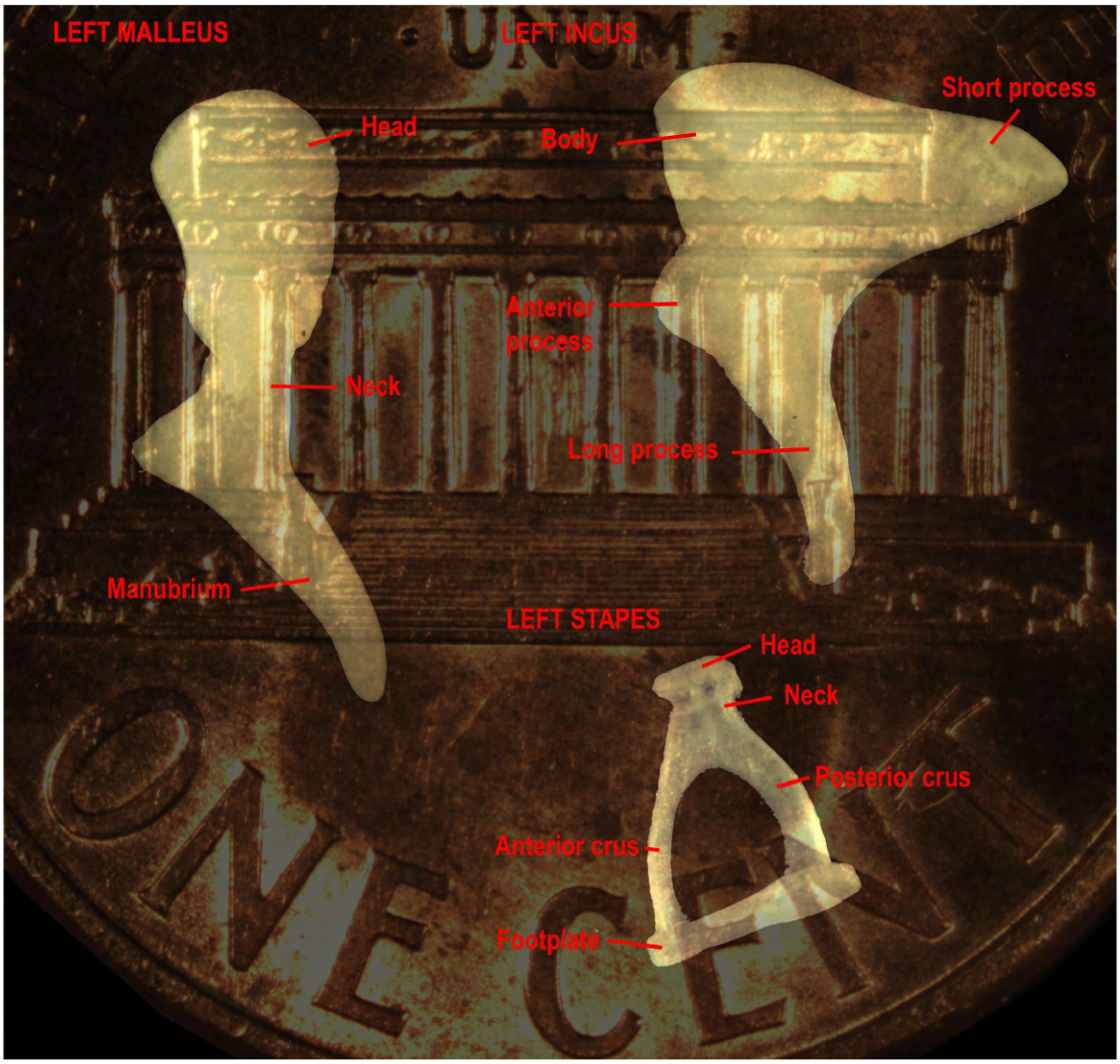

A higher magnification of the cochlea shows the triangular-shaped cochlear duct, the boundaries being the basilar membrane (**BM**) and attached organ of Corti (outlined in red), the spiral ligament (**SpL**) and stria vascularis (**StV**), and Reissner's membrane (**RM**). The cochlear duct is filled with the fluid endolymph. Superior and inferior to the cochlear duct are scala vestibuli (**SV**) and scala tympani (**ST**), respectively. These scalae are filled with the fluid perilymph. The primary auditory neurons or spiral ganglion neurons (**SGN**) are seen in Rosenthal's canal (rc; outlined in yellow) at the periphery of the modiolus (**Mod**). The distal processes of the SGNs traverse the osseous spiral lamina (OSL). The fibers then enter the organ of Corti and synapse on the hair cells. **T1** - 1st turn of cochlea; **T2** - 2nd turn of cochlea. (Photomicrograph by V. Militchin).

**ORGAN of CORTI**



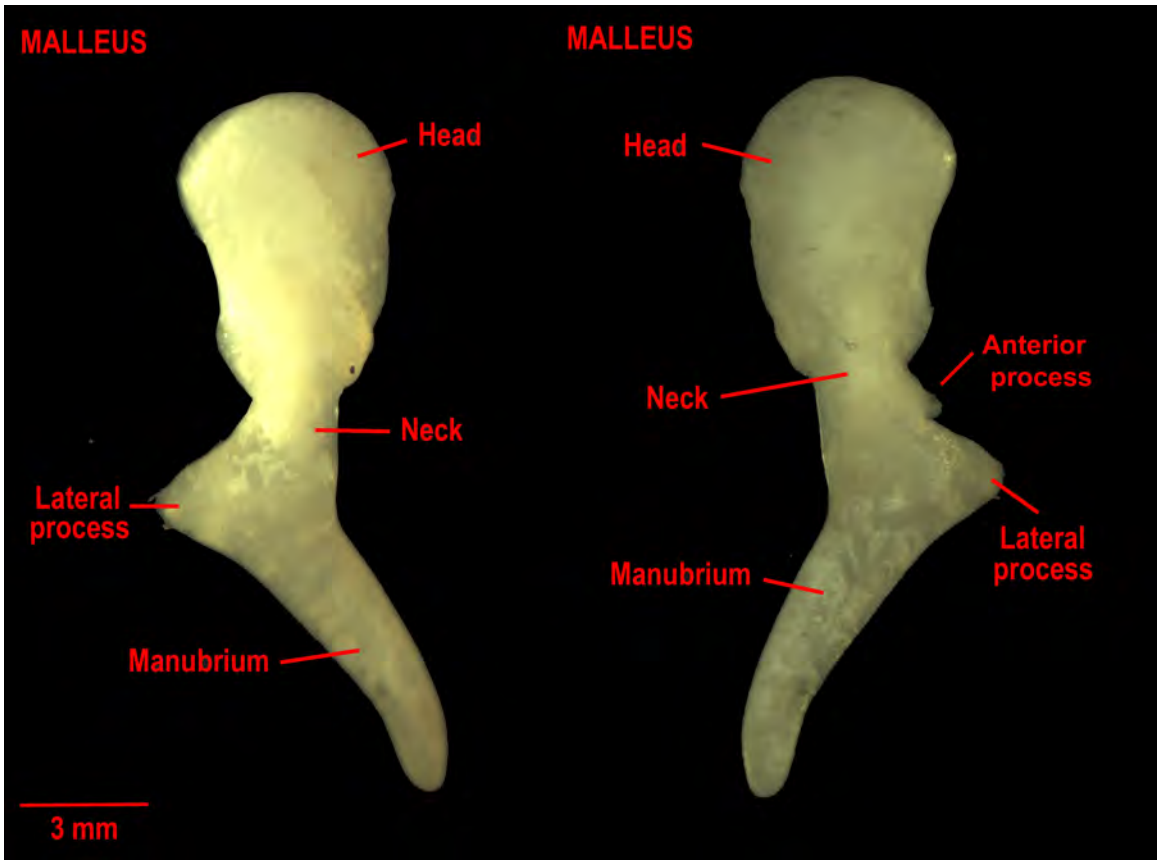

This schematic drawing of the organ of Corti (outlined in red) shows that it is attached to the scala media side of the basilar membrane. Note that the organ of Corti, including its surface (reticular lamina), forms part of the boundary of the cochlear duct or endolymphatic space that is filled with the fluid endolymph (lilac). The organ of Corti consists of hair cells and supporting cells (gray), fluid spaces (orange) and nerve fibers. There are two types of hair cells - the inner hair cells (**IHC** - green) forming a single row towards the modiolar side of the cochlear duct and the outer hair cells (**OHC** - blue) forming three rows on the spiral ligament side. Supporting cells in the organ of Corti include: inner phalangeal cells (stippled gray cells around the IHC); inner and outer pillar cells; Deiters' cells and Hensen cells. Fluid spaces within the organ of Corti consist of the tunnel (between the pillars) and the Nuel spaces (around the OHCs). These spaces are filled with a perilymph-like fluid (orange). The peripheral processes of the spiral ganglion neurons traverse the osseous spiral lamina, enter the organ of Corti through a series of holes (**H**; habenulae perforata) in the spiral lamina beneath the IHCs and synapse on the bases and sides of the IHCs or cross the tunnel to synapse on the OHCs. Scala tympani, located beneath the basilar membrane, is filled with the fluid perilymph (orange). (Drawing adapted from Davis et al., 1953).

**AUDITORY OSSICLES with PENNY OVERLAID**



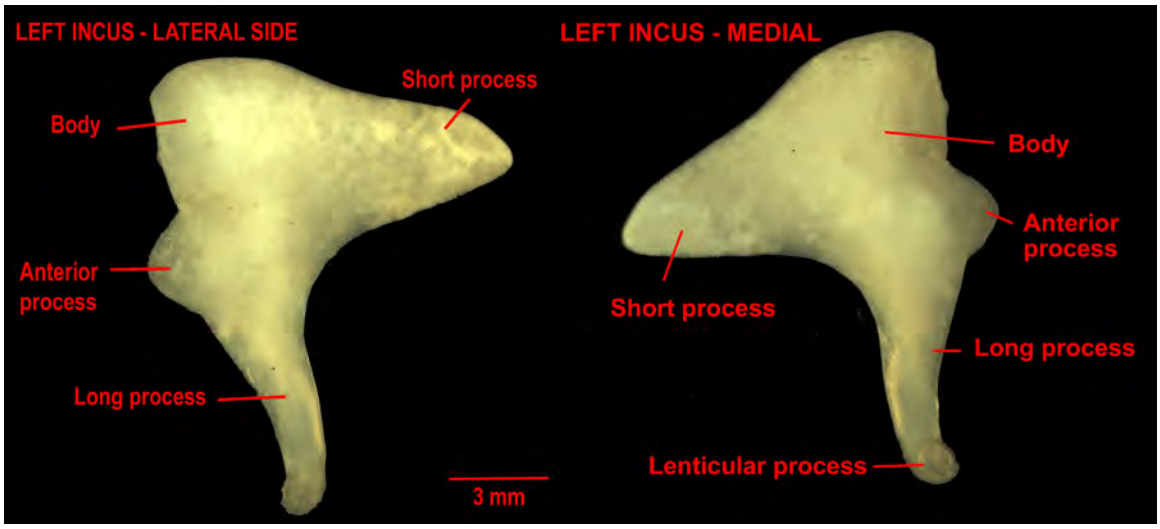

The three separated left auditory ossicles (i.e., malleus, incus, stapes) are compared to a penny in this dissection microscope view. (Photomicrographs by V. Militchin).

**MALLEUS**



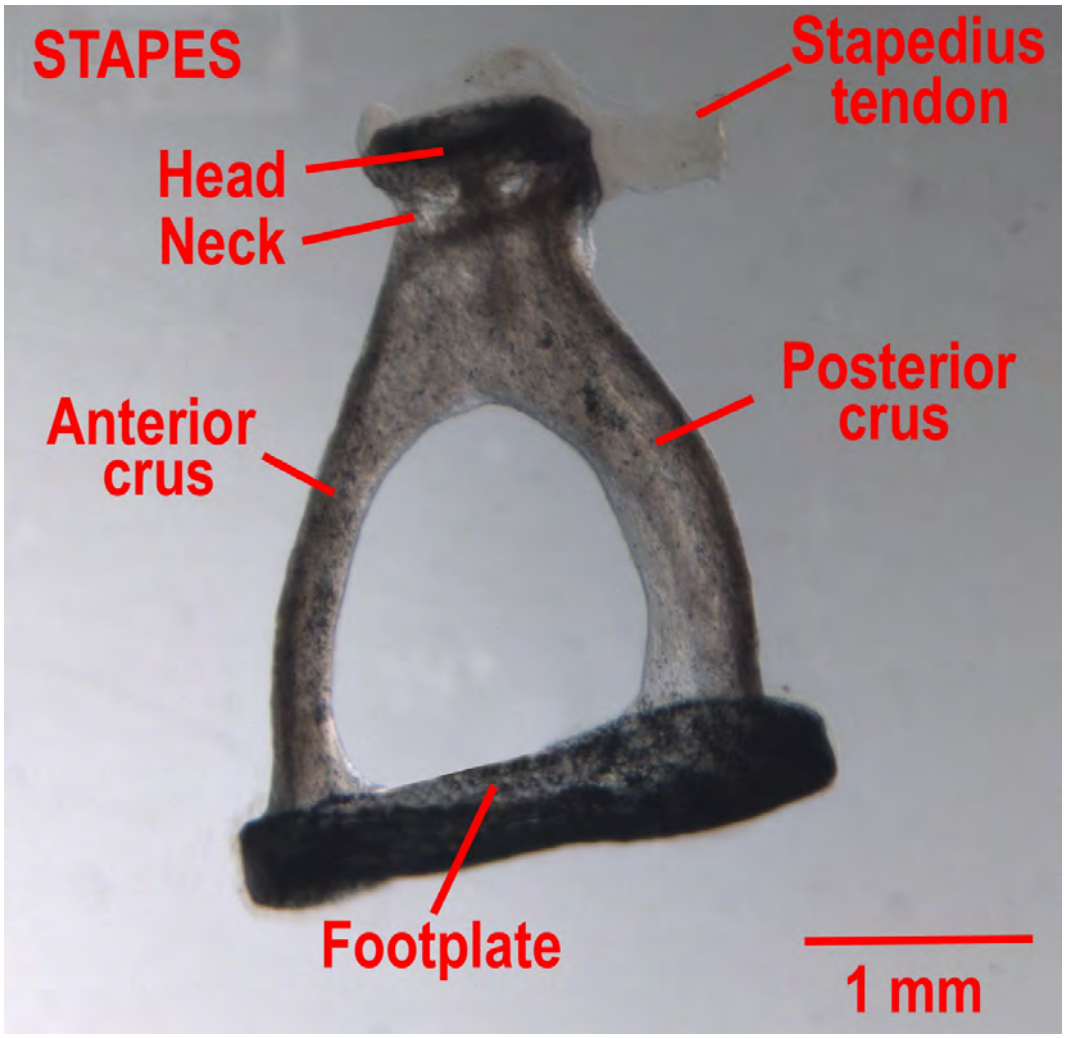

The posterior and anterior surfaces, respectively, of the left malleus, the 1st auditory ossicle, are shown. The manubrium is tightly attached to the tympanic membrane while the articular facet on the head of the malleus makes a synovial joint with the body of the incus. In-vivo, the head of the malleus is located in the epitympanic recess of the middle ear, above the level of the tympanic membrane. The tensor tympani muscle has its origin on the cartilaginous portion of the Eustachian tube. It runs posterolaterally and becomes tendinous at the cochleariform process. At this point the tendon extends laterally to insert into the medial side of the manubrium (p 16). Contraction of the tensor tympani muscle pulls the manubrium and tympanic membrane medially, thereby attenuating sound transmission through the middle ear. The tensor tympani muscle is innervated by a branch of the Vth cranial nerve. (Photomicrographs by V. Militchin).

**INCUS**



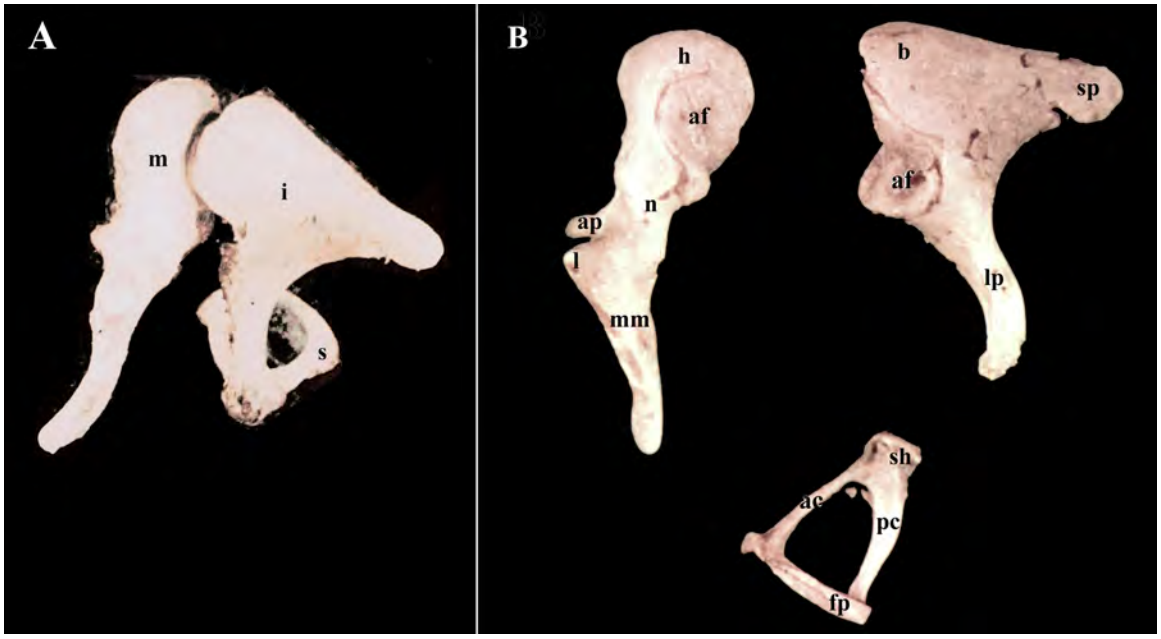

The lateral and medial surfaces of the incus, the 2nd auditory ossicle, are shown. The body of the incus makes a synovial joint with the head of the malleus. The lenticular process, which is attached to the long process of the incus by a connecting stem (Graboyes et al., 2011; p 20), articulates with the head of the stapes by a synovial joint. Ligaments attach the body of the incus to the roof (i.e., tegmen tympani) of the middle ear and the short process of the incus to the floor of the aditus ad antrum on the posterior wall of the middle ear. (Photomicrographs by V. Militchin).

**STAPES**



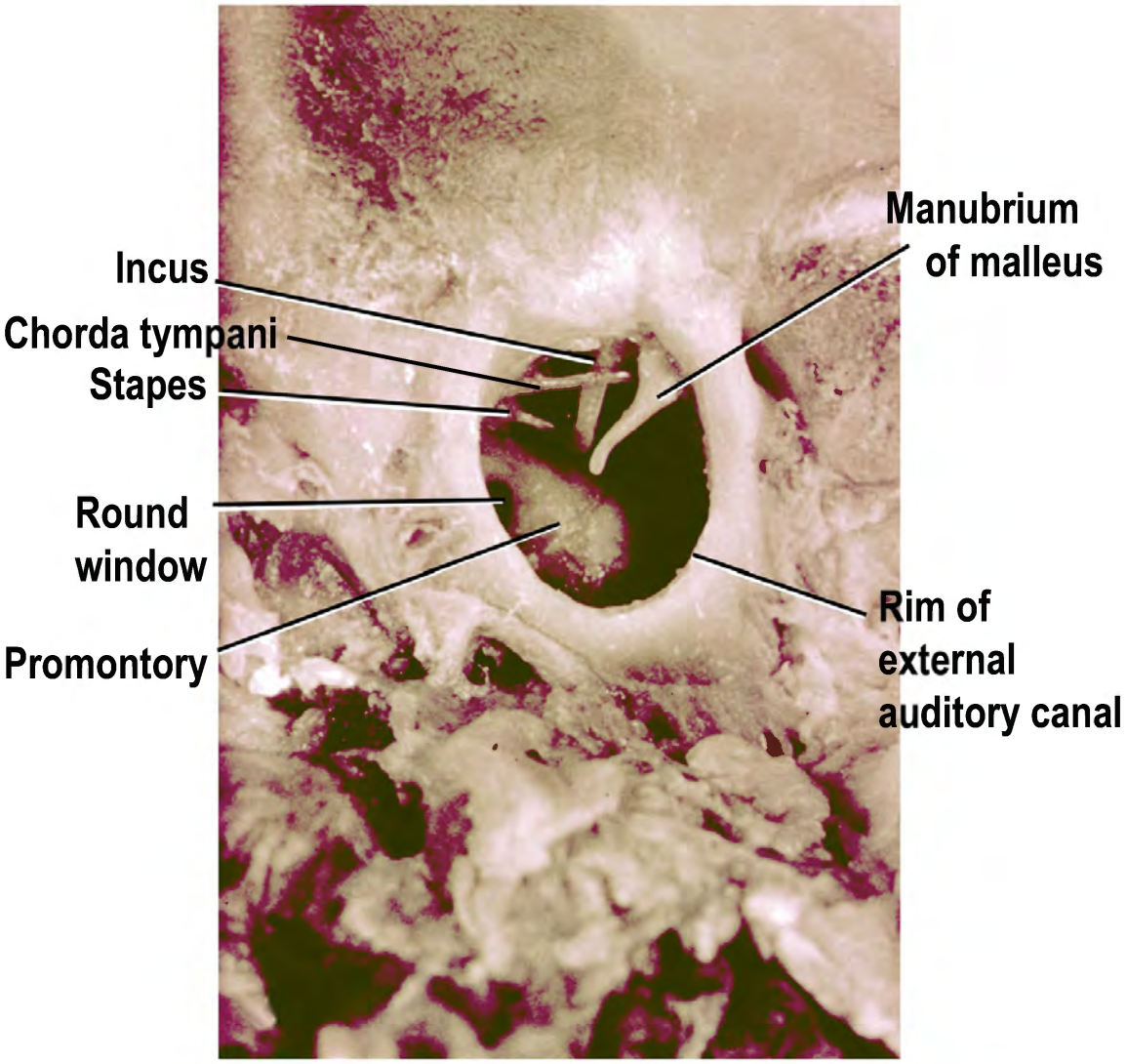

The ventral side of the stapes, the 3rd auditory ossicle, is shown. The head of the stapes makes a synovial joint with the lenticular process of the incus while the footplate is sealed in the oval window by the annular ligament. The stapedius muscle, located on the posterior wall of the middle-ear space, sends its tendon through the pyramidal eminence. This muscle is innervated by a branch from the VIIth cranial nerve. Its tendon inserts into the stapes neck (p 21). Contraction of the stapedius muscle pulls the stapes posteriorly and stiffens motion of the ossicular chain. (Photomicrograph by V. Militchin).

**OSSICLES - ARTICULATED and DISARTICULATED**



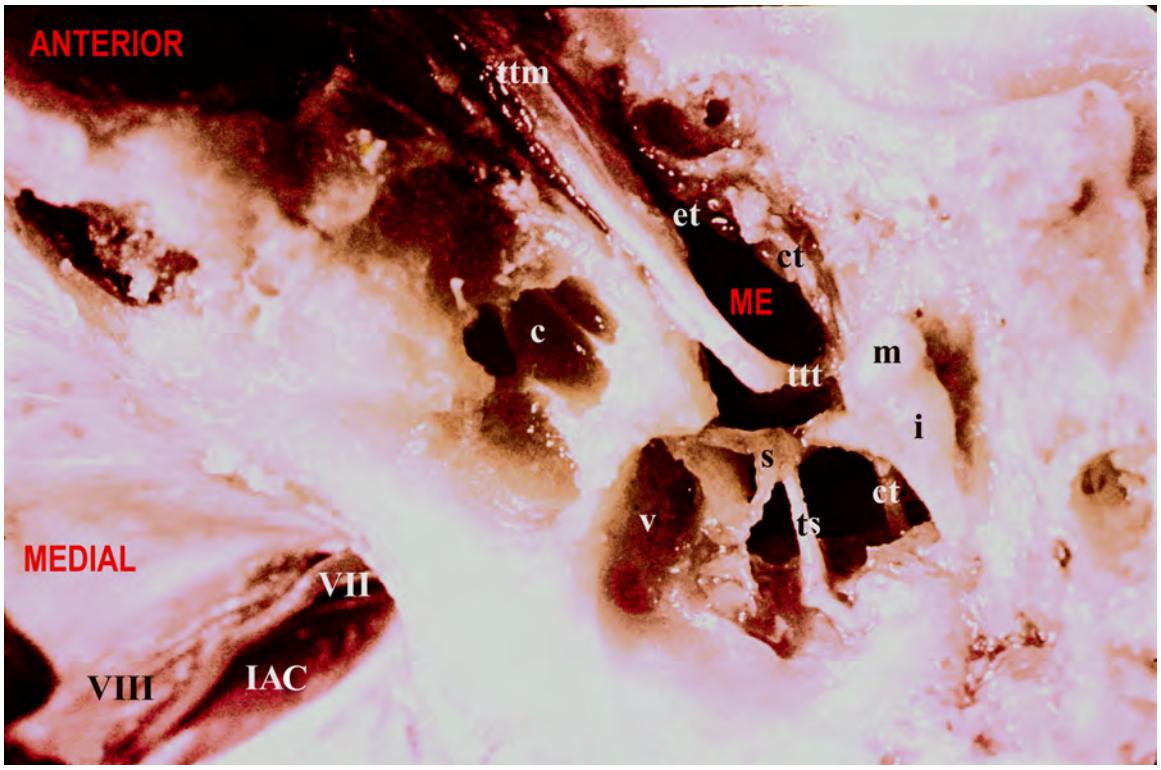

These photomicrographs show dried ossicles (left ear) as they articulate with one another (A) and after they were disarticulated (B). Note that the manubrium (**mm**) of the malleus (**m**) and the long process (**lp**) of the incus (**i**) are nearly parallel to one another and that the stapes (**s**) sits at right angles to the incus (A). **ac** - anterior crus of stapes; **af** - articular facets of malleus and incus; ap - anterior process of malleus; b - body of incus; fp - footplate of stapes; **h** - head of malleus; **l** - lateral process of malleus; **n** - neck of malleus; **pc** - posterior crus of stapes; **sh** - stapes head; **sp** - short process of incus. (Photographs adapted from Vidic and O'Rahilly, 1971).

**OSSICLES IN-SITU**



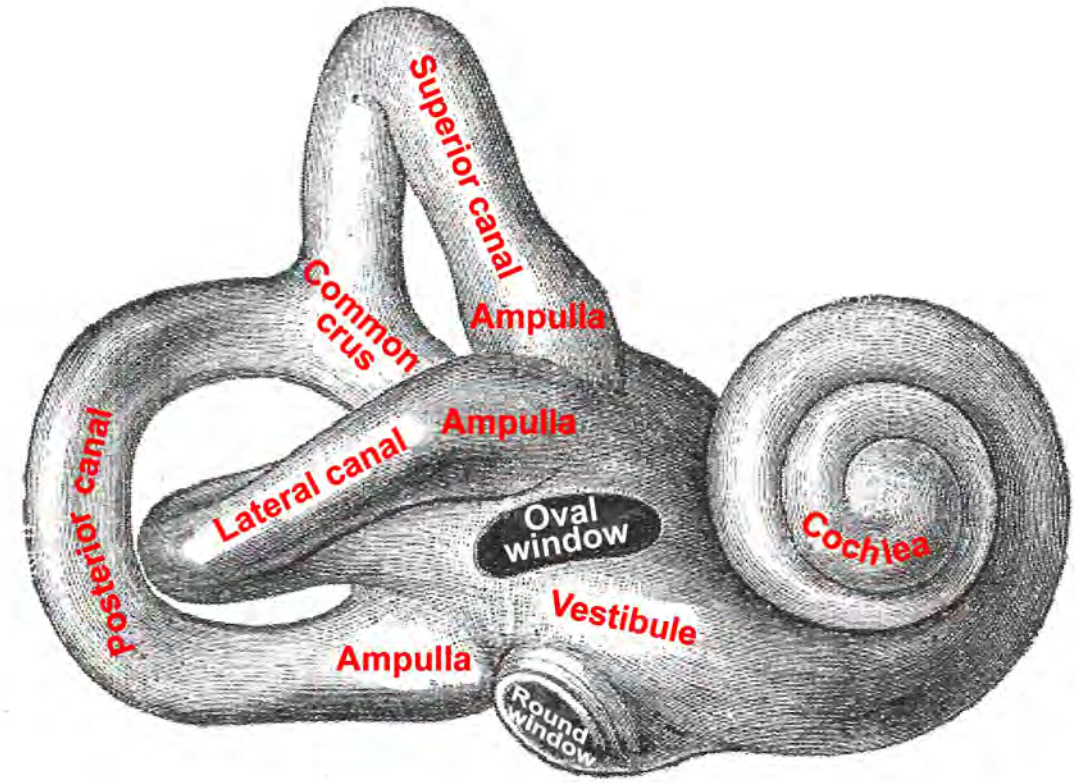

This photograph shows the right side of a cadaver head where the cartilaginous portion of the external auditory meatus was removed along with the tympanic membrane. The ossicles can be seen in-situ along with the basal turn of the cochlea (promontory) and a portion of the round window. Note that the chorda tympani (branch of the facial nerve) that carries taste sensation from the anterior 2/3 of the tongue passes anteriorly through the temporal bone between the manubrium and the long process of the incus. (Photograph adapted from Vidic and O'Rahilly, 1971).

**HORIZONTAL VIEW of MIDDLE and INNER EARS from SUPERIOR SURFACE**



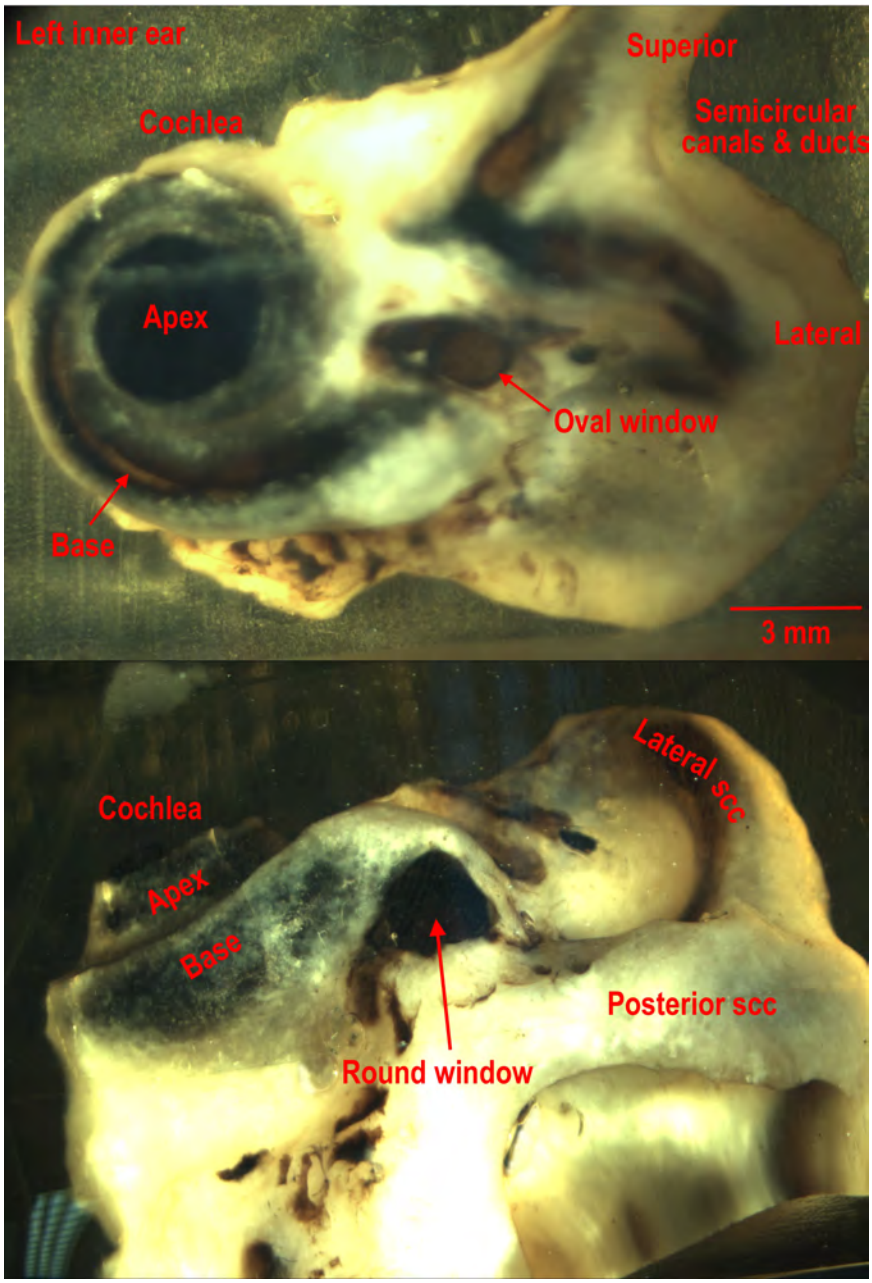

This is the right temporal bone viewed from its superior surface. The roof (i.e., tegmen tympani) of the middle ear (**ME**) was removed to reveal: the chorda tympani (**ct**), middle-ear ossicles (i.e., **i** - incus, **m** - malleus, **s** - stapes), a portion of the Eustachian tube (**et**), tendon of the stapedius muscle (**ts**), tensor tympani muscle (**ttm**), and tendon of the tensor tympani (**ttt**). On the medial wall of the middle ear, the cochlea (**c**) and vestibule (**v**) have been opened. The VII$^{th}$ (facial) and VIII$^{th}$ (vestibulocochlear) cranial nerves can be seen entering the internal auditory canal (**IAC**). (Photograph adapted from Vidic and O'Rahilly, 1971).

**BONY LABYRINTH**



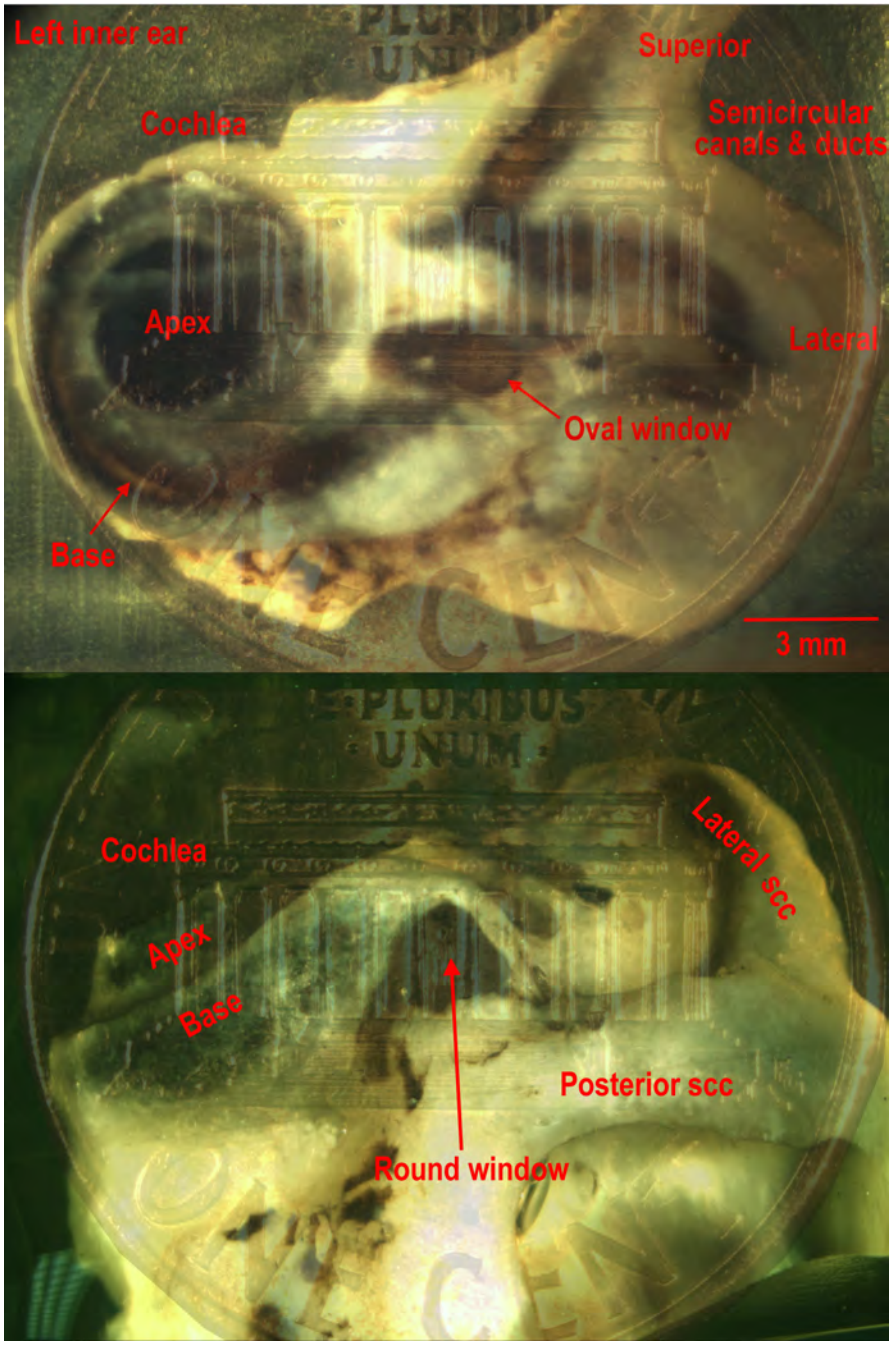

This is the bony labyrinth after it was drilled out of the temporal bone. Visible structures include: the cochlea, the lateral, posterior and superior semicircular canals, their ampullated ends, each containing a crista, the common crus (joined non-ampullated ends of posterior and superior canals), and the vestibule that houses the utricle and saccule. Also visible are the openings from the middle ear into the inner ear - the oval window (into which is fitted the footplate of the stapes) and the round window. (Adapted from a drawing by H Gray, 1918).

**TEMPORAL BONE THINNED to REVEAL MEMBRANOUS LABYRINTH**



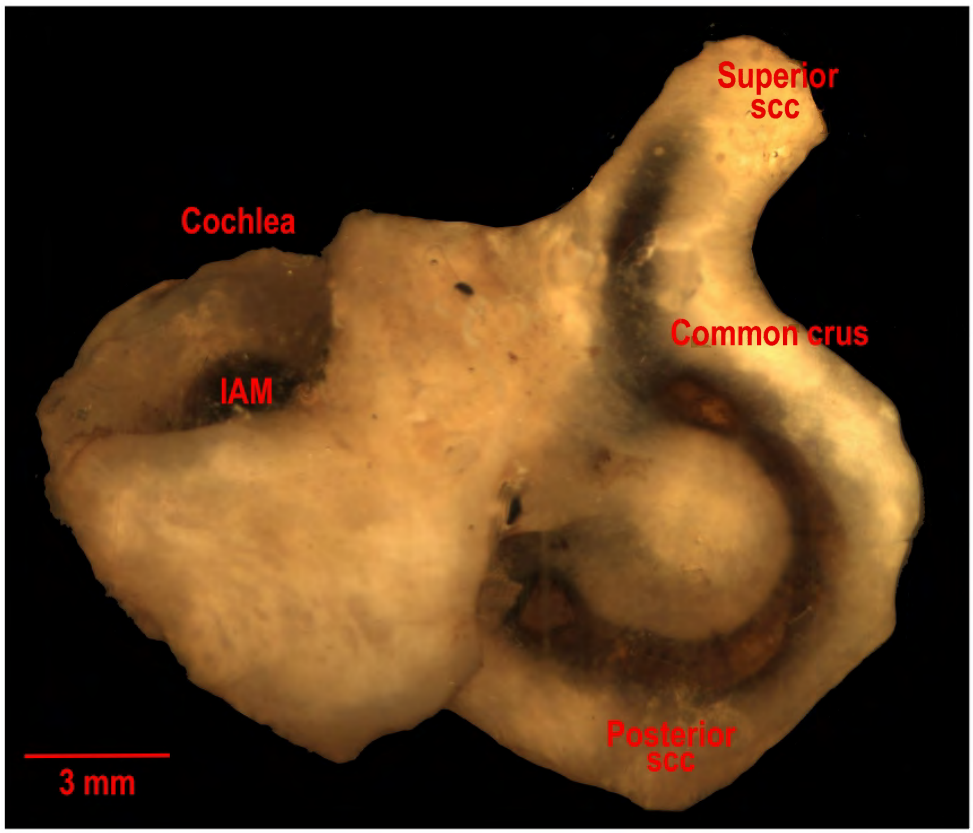

This left inner ear was fixed by perfusing osmium tetroxide through its perilymphatic spaces. While immersed in 70% alcohol, the bony labyrinth was thinned with an electric drill and diamond burs to reveal the cochlear spiral (apex and base) and the semicircular canals and ducts (i.e., superior, lateral and posterior). The in-vivo sizes of the oval window and round window were not altered by drilling. (Photomicrographs by V. Militchin).

**MEMBRANOUS LABYRINTH with PENNY OVERLAID**



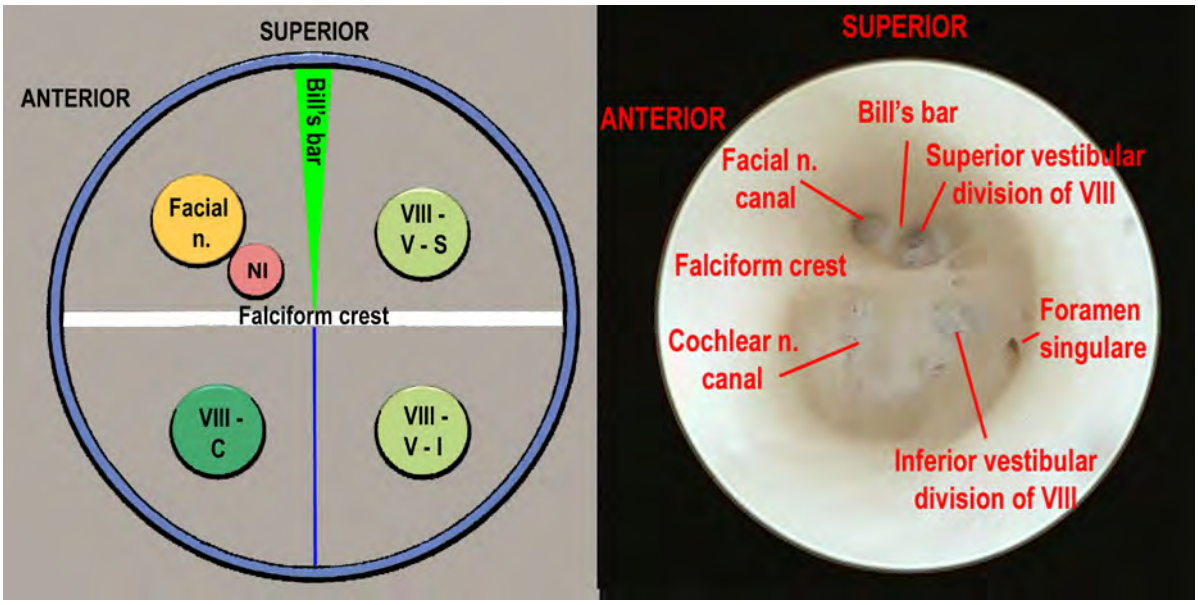

This is the same specimen as shown on the previous page. A penny has been overlaid on the membranous labyrinth to show its relative size. (See previous page for label descriptions).

**TEMPORAL BONE THINNED to SHOW SEMICIRCULAR CANALS**



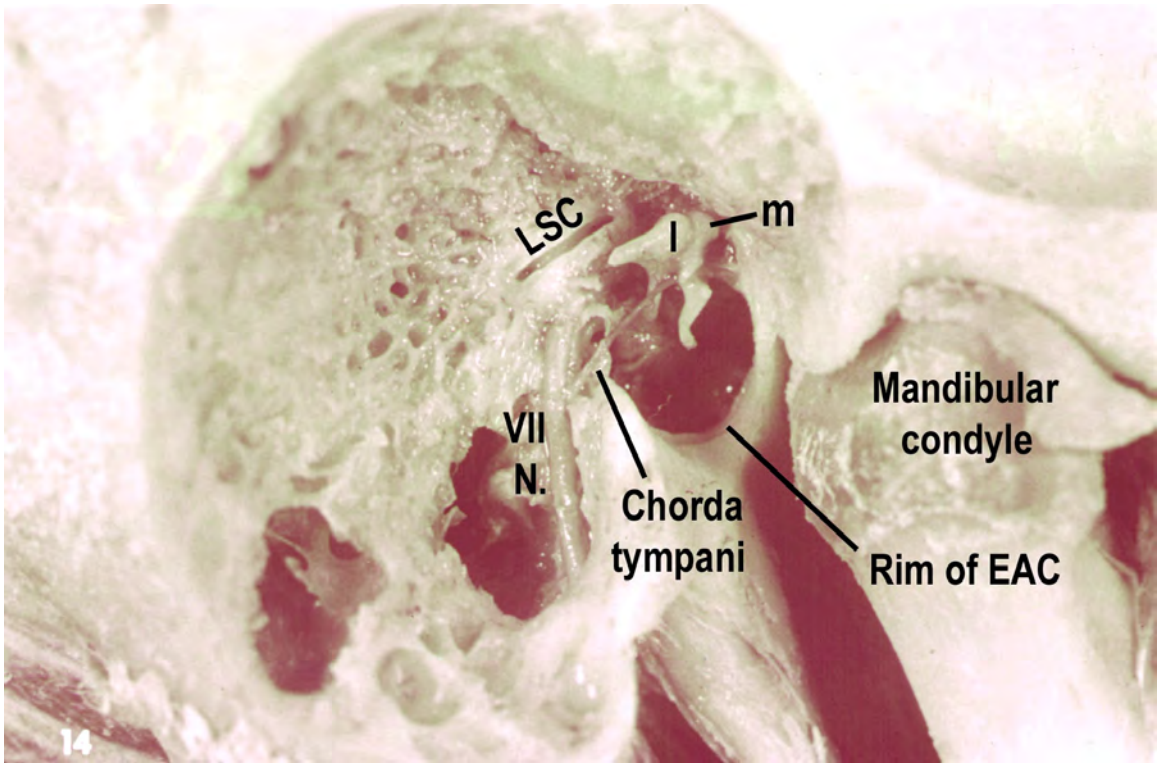

This right temporal bone, viewed from its medial surface, was drilled down to show the location of the superior and posterior semicircular canals. The non-ampullated (i.e., non-sensory) ends of these canals join together to form the common crus which makes a single entrance into the utricle (not visible here). The internal auditory meatus (IAM) is the site where the VII$^{th}$ and VIII$^{th}$ cranial nerves enter and exit the temporal bone. The size of the IAM was not altered by drilling. (Photomicrograph by V. Militchin).

**FUNDUS of INTERNAL AUDITORY CANAL**



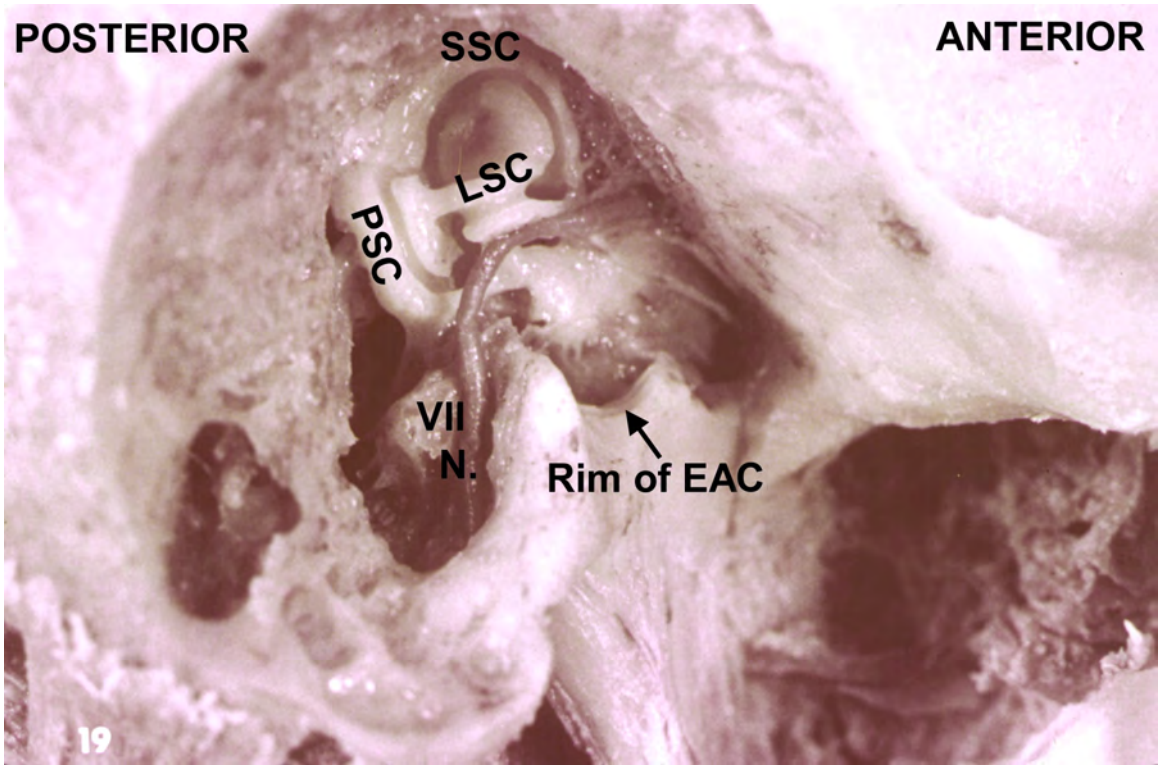

These are views of the fundus of the right internal auditory canal (IAC). Nerve position within the IAC is shown schematically on the left [i.e., Facial nerve (VII$^{th}$ CN); NI - nervus intermedius (i.e., carries taste fibers from anterior 2/3 of tongue); VIII - C - cochlear portion of vestibulocochlear nerve (VIII$^{th}$ CN); VIII - V - S and I - superior division (i.e., innervates cristae of the superior and lateral semicircular canals and macula of utricle) and inferior division (i.e., innervates macula of the saccule and crista of posterior semicircular canal), respectively, of vestibular portion of vestibulocochlear nerve]. The arrangement of nerve foramina in the IAC is shown in the photomicrograph on the right [i.e., facial nerve canal; cochlear nerve canal; canal for the superior vestibular division of VIII$^{th}$ nerve; canal for the inferior vestibular division of VIII$^{th}$ nerve; and foramen singulare (i.e., canal transmits nerve to crista of the posterior semicircular canal)]. Bill's bar, named for Dr. William House, is a vertical crest of bone that divides superior portion of IAC into anterior and posterior compartments; The falciform crest is a horizontal ridge of bone that divides the IAC into superior and inferior compartments. [Modified from a drawing by R Agrawal (left) and an original photograph by JG Neely (right)].

**COURSE of CHORDA TYMPANI through TEMPORAL BONE**



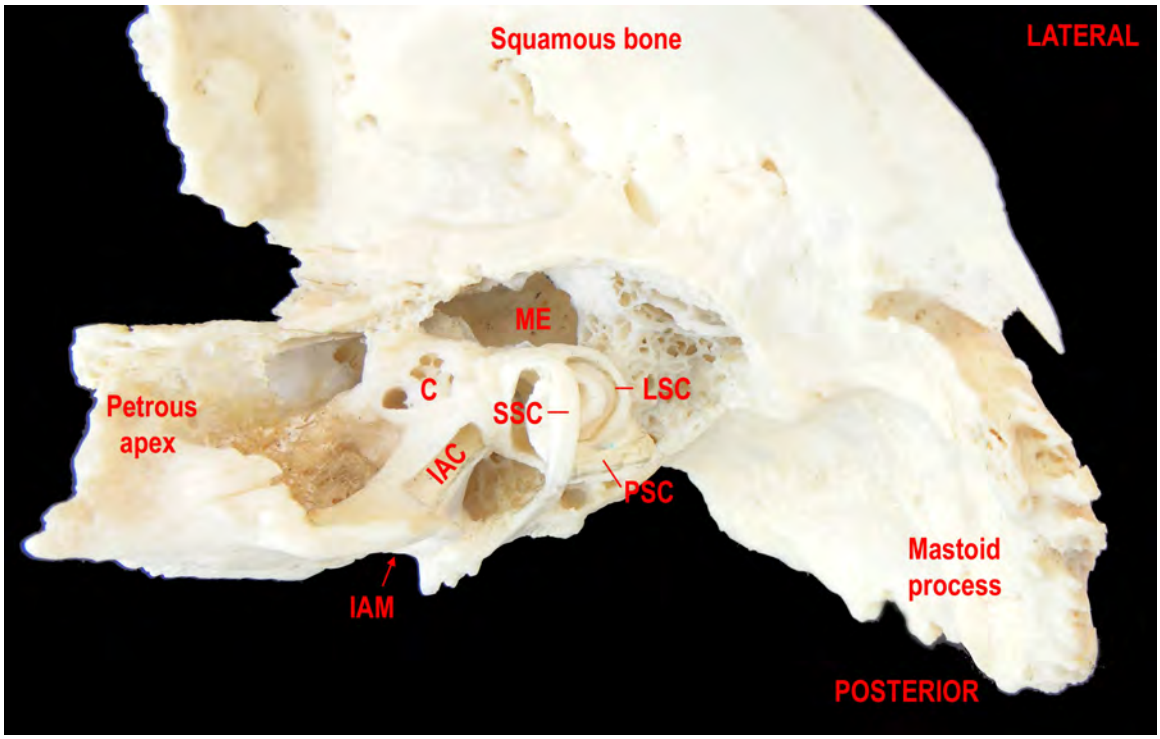

This is the drilled down right ear of a cadaver. The mastoid, posterior and part of the lateral walls of the middle ear were opened to reveal the vertical portion of the facial (VII$^{th}$) nerve and the chorda tympani. Note that the chorda tympani separates from the VII$^{th}$ nerve during its vertical descent within the posterior wall of the middle ear space. The chorda tympani crosses the middle ear by passing between the long process of the incus and the manubrium of the malleus and exits the middle ear anteriorly through a canaliculus. **EAC** - external auditory canal; **LSC** - lateral semicircular canal; **I** - incus; **m** - malleus (Photograph adapted from Vidic and O'Rahilly, 1971).

**COURSE of FACIAL NERVE through TEMPORAL BONE**



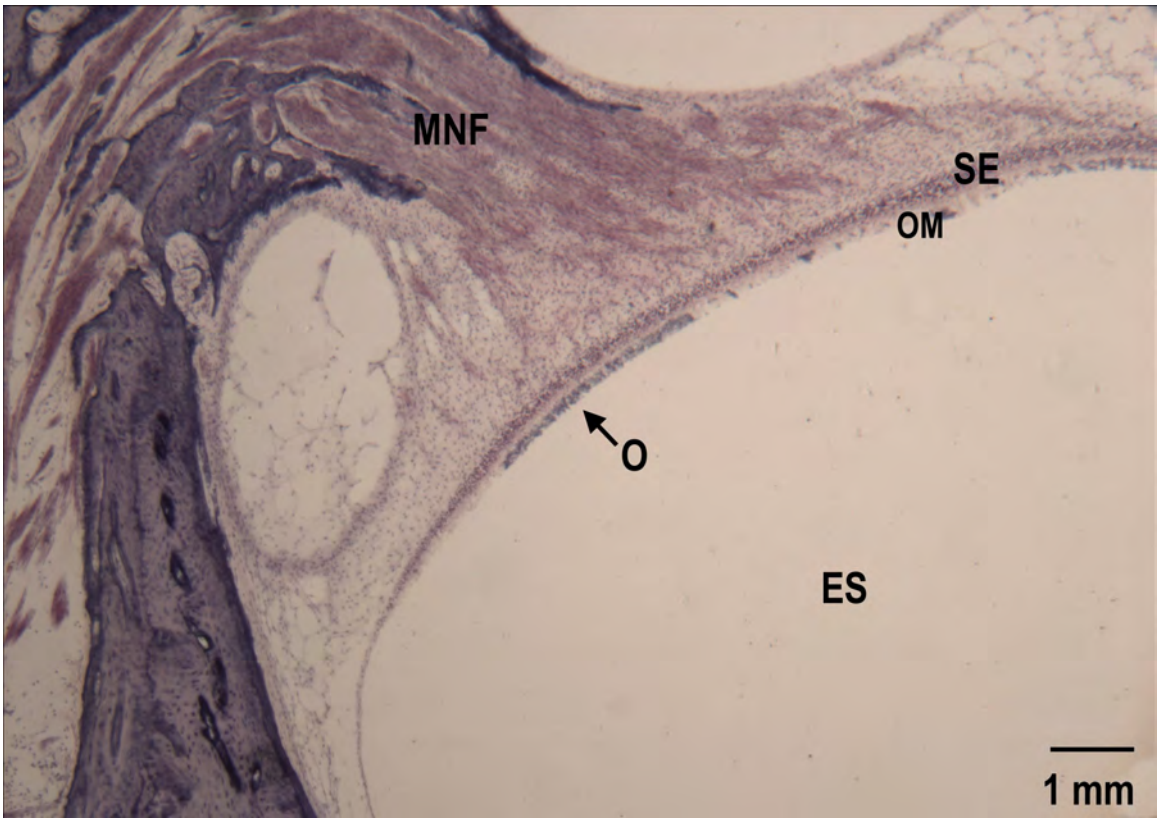

This is the drilled down right ear of a cadaver. The mastoid, posterior, medial and lateral walls of the middle ear were widely opened to reveal the mastoid and tympanic portions of the facial (**VII$^{th}$**) nerve and the three semicircular canals (**LSC** - lateral; **PSC** - posterior; **SSC** - superior). Note that the posterior and superior canals are perpendicular to the floor while the lateral canal is parallel to the floor when the head is tipped 30° forward. The horizontal portion of the facial nerve runs posteriorly, inferior and parallel to the lateral semicircular canal. The facial nerve exits the stylomastoid foramen (p 6) on the inferior side of the temporal bone. **EAC** - external auditory canal. (Photograph adapted from Vidic and O'Rahilly, 1971).

**ORIENTATION of COCHLEA and SEMICIRCULAR CANALS in TEMPORAL BONE**




Dried right temporal bone viewed from its superior surface. The semicircular canals (**LSC** - lateral; **PSC** - posterior; **SSC** - superior) and cochlea (**C**) have been drilled open. **IAC** - internal auditory canal; **IAM** - internal auditory meatus; **ME** - middle ear space. (Photograph by V. Militchin).

## UTRICULAR MACULA

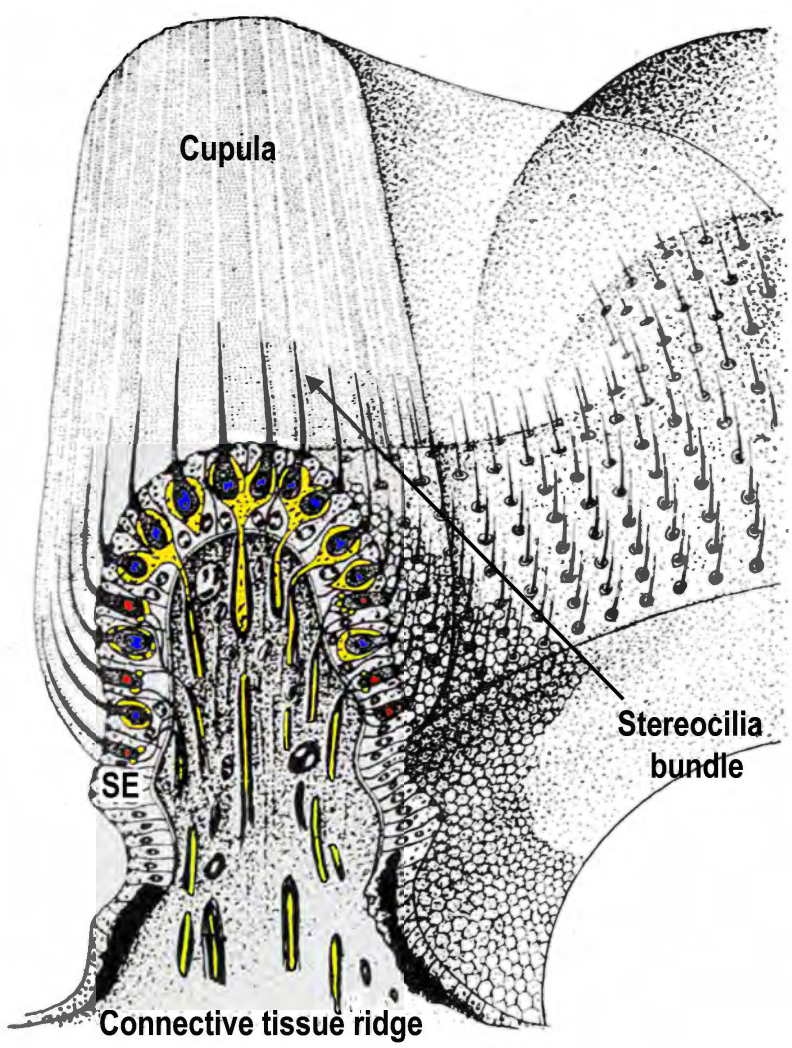



This is a stained, 20-µm-thick section through the utricular macula. The sensory epithelium (SE) forms a flat plate containing both hair cells (type I and II) and supporting cells. The endolymphatic surface of the sensory epithelium is covered by the otolithic membrane (OM) in which are embedded a number of small stones called otoconia (O; purple line). Myelinated nerve fibers (MNF) enter from below the epithelium and lose their myelin sheaths before crossing the basal lamina and innervating the hair cells. ES - endolymphatic space. (Photomicrograph by V. Militchin).

**CRISTA of the POSTERIOR SEMICIRCULAR CANAL**

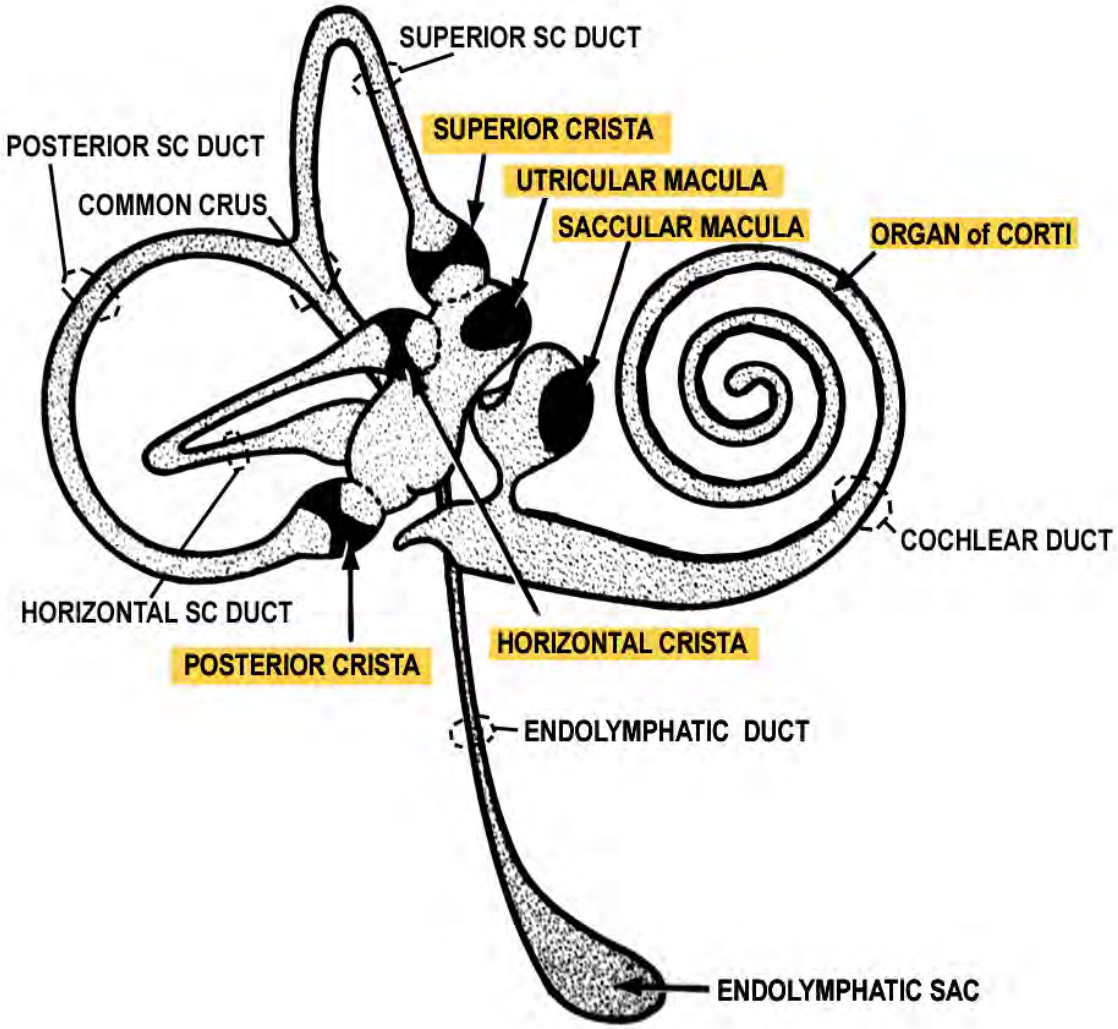

This is a stained, 20-µm-thick section through the crista in the ampullated (A) end of the posterior semicircular canal. The sensory epithelium (SE) forms a single layer on the endolymphatic surface of a ridge of connective tissue. The sensory epithelium contains both hair cells (type I and II) and supporting cells. Apical projections from each hair cell extend into an overlying gelatinous structure termed the cupula (not visible here). In-vivo, the cupula extends from the surface of the sensory epithelium to the opposite side of the ampullary wall. Myelinated nerve fibers enter the epithelium through the ridge of connective tissue to innervate the hair cells. The ampulla is filled with endolymph while perilymph (P) surrounds the canal. (Photomicrograph by V. Militchin).

## SEMICIRCULAR CANAL CRISTA




This drawing shows the sensory epithelium (SE) in the crista of a semicircular canal. The sensory epithelium forms a thin layer on the surface of the ridge of connective tissue. It consists of type I hair cells (blue nuclei), type II hair cells (red nuclei) and supporting cells. Myelinated nerve fibers (yellow with heavy black rim) approach the epithelium from the epithelial ridge, losing their myelin sheaths as they penetrate the epithelium. They then form nerve endings on the hair cells; nerve chalice on the type I hair cells (yellow cup) or boutons on the type II hair cells (small, yellow spots). Both types of hair cells have a bundle of stereocilia and a single kinocilium projecting into the cupula, an extracellular gelatinous structure. Movement of the endolymph within the canal moves the cupula and depolarizes the hair cells by deflecting their stereocilia and kinocilium. The depolarized hair cells release neurotransmitter which then stimulates applied nerve endings. (Drawing scanned and adapted from Wersäll and Bagger-Sjöbäck, 1974).

**SENSORY AREAS in the COCHLEA and VESTIBULE**




This schematic drawing shows the membranous labyrinth that consists of the cochlear duct, the semicircular canal (SC) ducts, saccule, utricle and endolymphatic duct and sac. Sensory areas in the membranous labyrinth consist of the organ of Corti in the cochlea, the maculae in the saccule and utricle in the vestibule and the cristae in the horizontal, posterior and superior semicircular ducts. These six sensory end organs are composed of sensory (i.e., hair) cells and supporting cells. Nerve fibers from the cochlear or vestibular division of the vestibulocochlear nerve (i.e., VIII$^{th}$ cranial) synapse on the bases and sides of the hair cells. The apices of hair cells in the organ of Corti, maculae and cristae are in contact with endolymph (i.e., stippled spaces). The endolymphatic duct and sac are part of the endolymphatic space. The sac may be involved with immune responses in the inner ear and as well as fluid volume regulation in the endolymphatic system. (Drawing scanned and adapted from Goodhill, 1979).

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