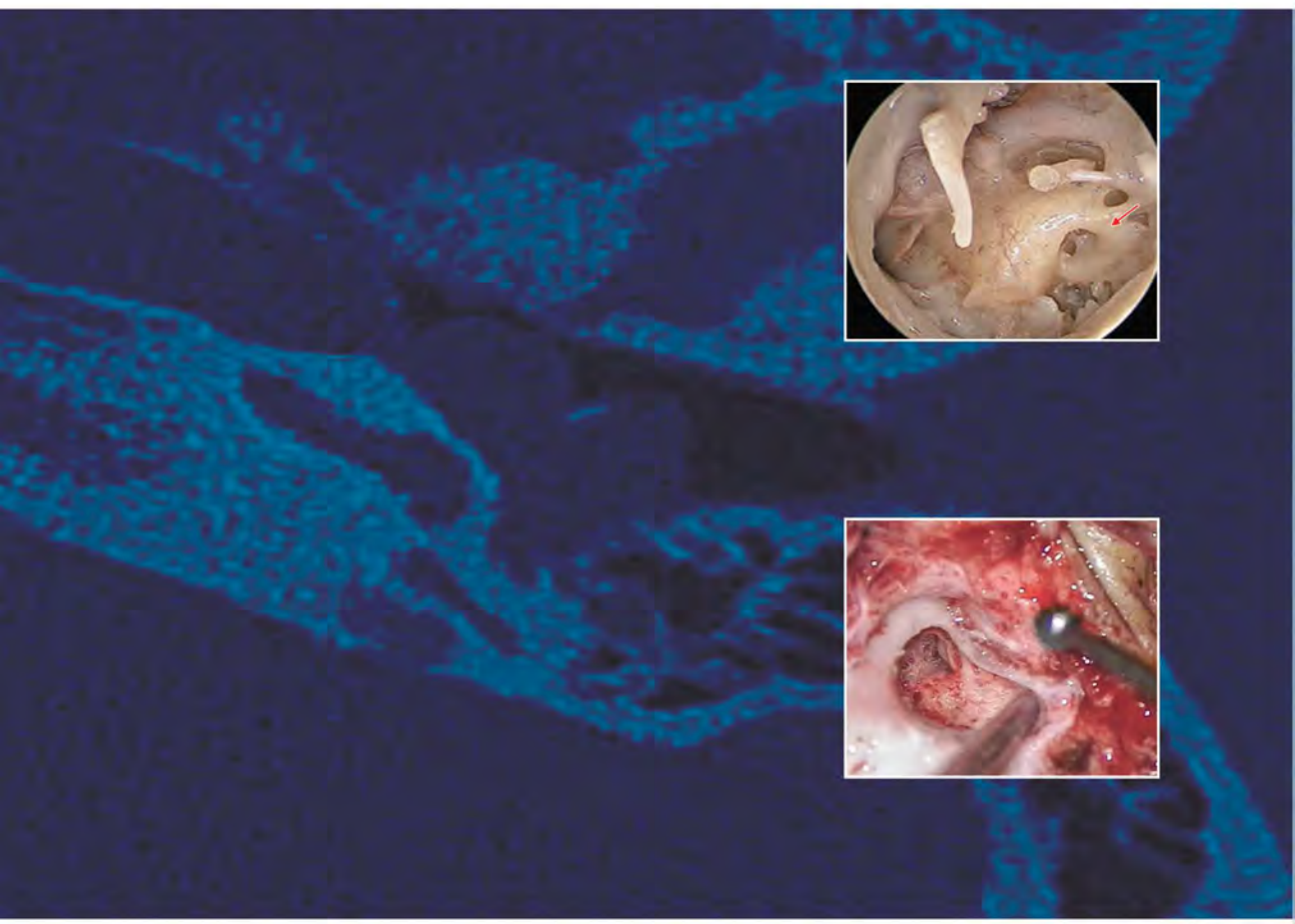
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Practical Handbook of the Temporal Bone and Middle Ear Cleft



Neena H Bhalodiya

JAYPEE

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CHAPTER 2

Middle Ear Cavity

DEVELOPMENT OF THE EAR

The temporal bone and the structures of the ear develop from the neurocranium and the brachial arches.

DEVELOPMENT OF THE EXTERNAL EAR

At 4 weeks of intrauterine life, tissue condensation of the first brachial (mandibular) and second (hyoid) arch appears at the distal portion of the first brachial groove.

This tissue condensation develops into six ridges "The hillock of His". These hillocks fuse to form two folds which again fuse superiorly and form the pinna. The entire pinna, except tragus, arises from the second brachial arch and anterior part of the external auditory canal (EAC) arises from the first pharyngeal arch. It reaches to adult configuration at fifth month, independent of progress in middle and inner ears.

DEVELOPMENT OF TYMPANOMASTOID COMPARTMENT AND THE AUDITORY TUBE

This includes the development of the tympanic ring, the tympanic membrane, middle ear cavity with contents, and Eustachian tube.

External auditory canal develops from the dorsal part of the first brachial groove, while outpouching of the first brachial pouch gives rise to tubotympanic recess **(Flowchart 1)** at third week of intrauterine life. The ectoderm of the first pharyngeal groove abuts on the endoderm of the tubotympanic recess. At sixth week, a mesodermal ingrowth breaks this.

A cord of epithelial cells, at the depth of primary EAC, grows medially into mesenchyme and develops into solid-meatal plate. The mesenchyme adjacent to the meatal plate gives rise to the lamina propria of the tympanic membrane and at 9 weeks, it is surrounded by four ossification centers of tympanic ring.

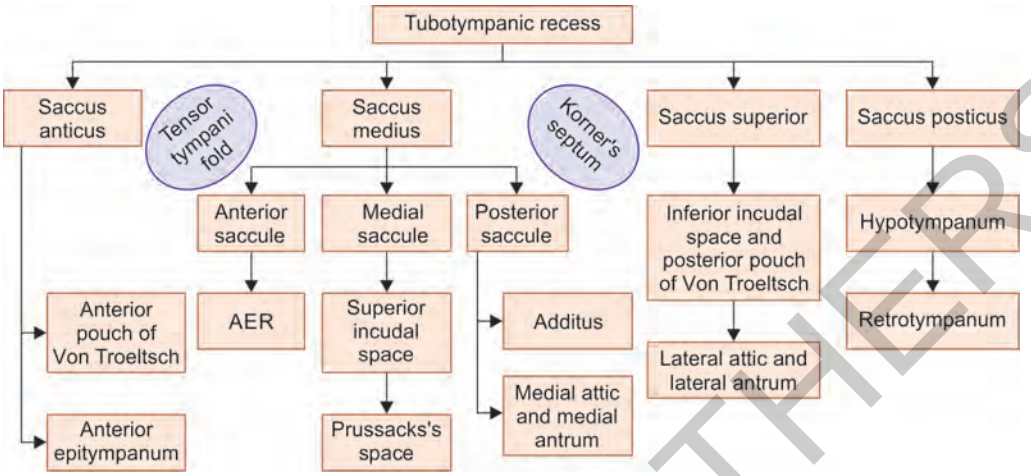
The components of the tympanic ring fuses by 10th week, except superiorly, where a defect remains as the notch of Rivinus **(Fig. 1)**. At the beginning of the 4th month, the squama projects posterior to the tympanic ring forming the lateral part of mastoid, roof of the EAC. After the 8th month, the tympanic ring starts to fuse with the otic capsule and the growth continues after birth. The styloid process appears after birth from the Reichert's cartilage.

Due to the abnormal development of the first and second branchial arches; microtia, anotia, or abnormal position of pinna occurs. External ear canal stenosis or atresia arise as noncanalization of 1st branchial groove. Deformity of middle ear or inner ear depends upon the time when development is affected.

At the 3rd week, an outpouching of the first branchial pouch known as tubotympanic

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Flowchart 1: The embryology of the middle ear spaces from tubotympanic recess.



(AER: anterior epitympanic recess)



Fig. 1: Anterior and posterior tympanic spines in the tympanic bone showing the anterior and posterior limits of Notch of Rivinus. [Anterior tympanic spine (green arrow); posterior tympanic spine (red arrow)].

recess eventually becomes the Eustachian tube and tympanic cavity. At 7th week, because of simultaneous growth of the second brachial arch, tubotympanic recess constricts at midpoint.

So primordial tympanic cavity lies laterally, while primordial Eustachian tube lies medially. The Eustachian tube develops very remarkably, it lengthens and becomes narrow with mesodermal development and fibrocartilaginous tube is established.

The terminal end of the first pharyngeal (endothelial) pouch develops into four sacci (anticus, posticus, superior, and medial) which expand and pneumatize the tympanic cavity **(Fig. 2)**.

Saccus anticus is the smallest sacci and forms anterior epitympanic recess and anterior pouch of Von Troeltsch. Mucosal fold develops ossicles by this sacci, which lines the tympanomastoid compartment. The part where these mucosal lining join transmits the blood vessels.

DEVELOPMENT OF THE OSSICULAR CHAIN

The pharyngeal arches have three layers: Ectoderm, mesoderm, and endoderm. Ectodermal cleft gives rise to the external auditory meatus and outer epithelial layer of the tympanic membrane with unique property of skin migration laterally. Endodermal pouch gives rise to tubotympanic recess. Mesoderm of this brachial arches forms the

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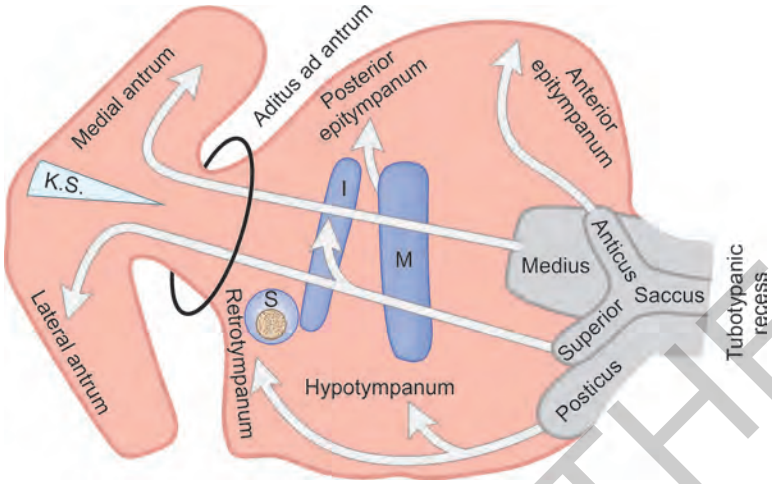


Fig. 2: The embryology of the middle ear spaces. (I: incus; M: malleus; S: stapes; K.S.: Korner's septum)

content of tympanic cavity (ossicles, muscles, and nerves and vessels).

Approximately at 4 weeks, ossicles appear as interbrachial bridge which is mesenchymal bridge between first and second brachial arch, differentiation of it forms primordial malleus and incus. The stapes blastema arises from the 2nd branchial arch (annular ligament and medial side of footplate derived from otic capsule).

After 11 weeks, cartilaginous ossicles develop, the anterior process of malleus develops as membranous ossification. The stapedial artery encircles the stapes blastema. As stapedial artery disappears, it leaves behind an empty obturator foramen.

By 15th week, the ossicles attain adult size and then ossification starts. First in the incus, followed by malleus and stapes sequentially. There is simultaneous development of the tensor tympani and stapedius from the mesenchyme of these arches. Adult size configuration of ossicles reached by 20 weeks and stapes reduce to it normal size up to 32 weeks.

DEVELOPMENT OF THE MASTOID

Outer (lateral) part of the mastoid is derived from the squamous bone and medial part of the mastoid, from the petrous bone. Pneumatization of mastoid appears at 33 weeks, then it proceeds surrounding air cells tracts. Pneumatization depends upon hereditary factors, environment, nutrition, bacterial infection, and ventilation by the auditory tube.

Antrum achieves approximately adult size at the time of birth, and it proceeds up to 1 year with mesenchymal resolution. Mastoid continues to grow very slowly up to puberty.

ANATOMY

The tympanomastoid compartment includes tympanic cavity, mastoid air cell system, connecting auditory tube as well as EAC.

Middle ear cleft is sagittally oriented air-containing space from the Eustachian tube to the mastoid antrum. External ear, middle ear, and inner ear have potential for

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the transmission of sound and balance (axis parallel to petrous ridge). Tympanic cavity lies at the crossing of both the axis.

Pinna and External Auditory Canal

The pinna focuses and localizes the sound. The shape of pinna varies. The contour of pinna is determined by yellow elastic cartilage. Attachment of skin to the cartilage is different (tightly attach to the perichondrium laterally, while loose attachment medially). The pinna skin has hairs and sebaceous glands. It is continuous with cartilage of canal as well as tympanic bone. The postauricular nerve, branch of facial nerve, supplies the muscle.

External Auditory Meatus

Lateral cartilaginous (1/3rd) and medial bony meatus (2/3rd). There is deficient area of cartilage known as incisura terminalis. This gap is utilized in the endaural incision. The narrowest part of the canal lies just medial to junction of bony and cartilaginous part known as isthmus. Skin of the bony external canal is very thin (absence of hairs), only 0.2 mm in thickness, it requires meticulous shaped dissection between anterosuperior (tympanosquamous suture) and postero-inferior (tympanomastoid suture). The pinna and EAC get innervation by facial nerve, auriculotemporal nerve (trigeminal nerve), greater auricular and lesser occipital nerve (c2, c3 connection), and auricular branch of vagus nerve.

- For local anesthesia, infiltration is done in a four quadrant (at 2, 4, 8, 10 o'clock)
- *Vascular strips:* Tympanosquamous and tympanomastoid suture defines the sites for incisions.
- Inflammatory condition of the external ear is painful due to its adherence to the cartilage.
- Perichondrium of the pinna starts to necrose as blood supply is affected and it gets deformity after 3 days.

Tympanic Cavity

It is air-filled cavity connecting to the nasopharynx by the auditory tube and to the mastoid antrum through aditus ad antrum (sagittally oriented). It is air containing (around 2cc) and it transmits the sound from the tympanic membrane to the oval window. Tympanic cavity containing an ossicular chain and ligaments which connect wall of tympanic cavity.

Tympanic cavity considered as box with roof (tegmen tympani), a floor (bone separating jugular bulb), and four walls (anterior, posterior, medial, and lateral). Medial wall and lateral wall have convexity, so it is constricted in the middle (varying depth of the cavity) **(Fig. 3)**.

Tympanic cavity is developed from the tubotympanic recess. Otic capsule extends the cartilaginous rim laterally toward the tubotympanic recess superiorly, inferiorly, anteriorly, and posteriorly. This way petrous bone forms medial wall of the middle ear cleft. Lateral and anterior wall is formed by the tympanic bone. Posterior wall is formed by the Reichert' cartilage.

Roof of the Tympanic Cavity (Tegmen Tympani) (Figs. 4A and B)

The tegmen plate is a bony plate which separates the middle ear cleft and middle cranial fossa. Tegmen plate above the middle ear cavity is known as tegmen tympani, while above the mastoid antrum and Eustachian tube is the tegmen antri and tegmen tubari, respectively.

Tegmen is formed by the petrous bone and the squamous bone. It is not horizontal.

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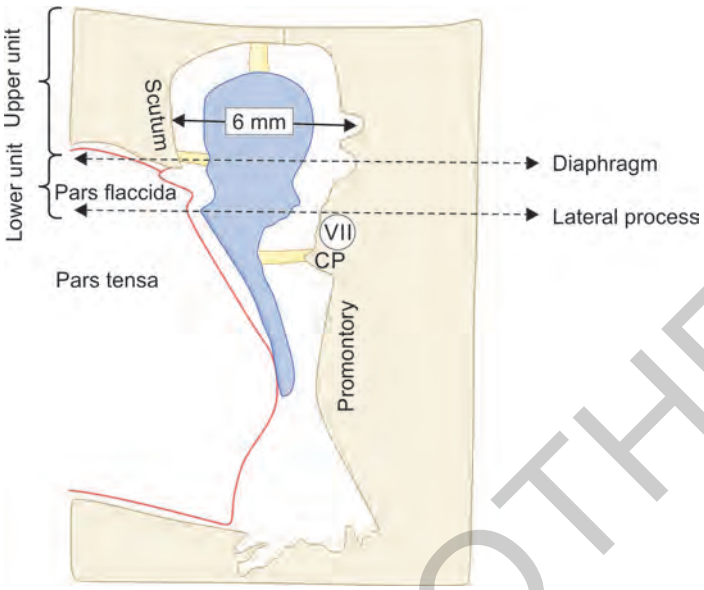


Fig. 3: Middle ear cavity with its dimensions. (Upper unit and lower unit of the attic; VII: facial nerve; CP: cochleariform process)

Plate of bone in tympani, tegmental process of the petrous bone covers the roof of anterior attic, while posterior part of the attic and the antrum are covered by the horizontal process of squamous bone and the tegmental process of petrous bone. The entire tegmen is formed with strength of junction of two bones.

This plate is not horizontal, there are two slopes: (1) From lateral to medial side. It slopes inferiorly from medial to lateral (high at the level of superior semicircular canal). (2) From posterior to anterior: As from mastoid antrum to the zygomatic area, it slopes down gradually placing the tegmen higher anteriorly.

Subarachnoid space surrounding the facial nerve extends up to the geniculate ganglion and very rarely, it can create cerebrospinal fluid (CSF) fistula in the middle ear through the tegmen tympani.

Cog is coronally oriented bony plate of the tegmen tympani toward the cochleariformis process and anterior to the head of malleus.

The cog is located superiorly to the facial nerve with its tip pointing to it. The cog is one of the landmarks for the tympani segment of facial nerve.

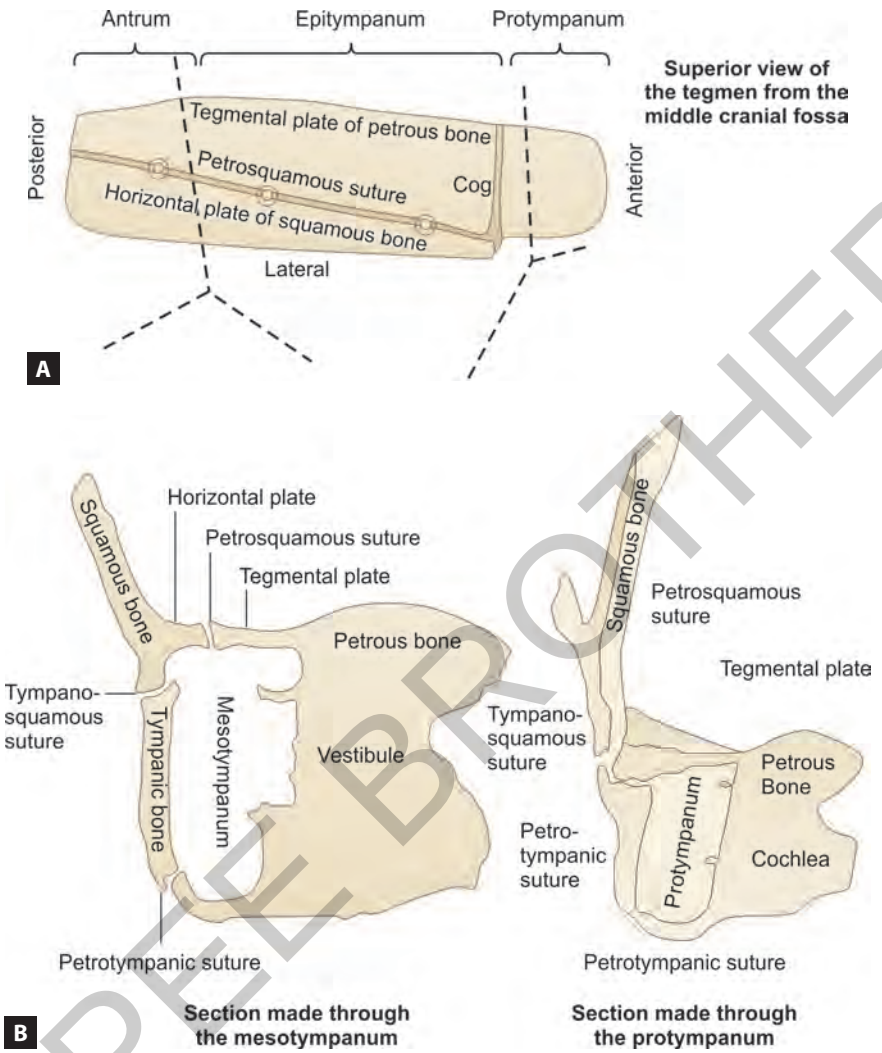
In tympanomastoid surgeries, preservation of the tegmen tympani is very important. It is not horizontal plate.

Floor of the Tympanic Cavity

It is irregularly contoured floor which separates the mesotympanum and the hypotympanum and features the jugular bulb and root of styloid process posteriorly and internal carotid artery (ICA) anteriorly **(Fig. 5)**.

The hypotympanum develops between 22 and 32 weeks as fusion of three bones: (1) Tympanic bone (membranous bone), (2) Canalicular otic capsule (endochondral bone), and (3) a petrosal bone (periosteal bone). These structures are thought to predispose this area for the abnormal development such as dehiscent jugular bulb. Incomplete fusion leads to formation

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Figs. 4A and B: Superior wall of the middle ear cavity.

of the hypotympanic fissure which leads to inferior canaliculi through which branch of the inferior tympanic artery and Jacobson nerve enter tympanic cavity. The jugular bulb lies in the floor of the tympanic cavity which connects the lateral sinus to internal jugular vein. The jugular bulb is situated medial to the vertical segment of facial nerve and inferior to the posterior semicircular canal. The lower cranial nerve (9th, 10th, and 11th) exits the skull through jugular foramen. Bony or fibrous compartmentalization of foramen leads to anteromedial compartment with glossopharyngeal nerve, whereas cranial nerve X and XI and the jugular bulb located posterolaterally.

The inferior petrosal sinus through its multiple opening in the anterior aspect of jugular bulb, closely related to the glossopharyngeal nerve.

- The jugular foramen is of particular importance in skull base surgery.

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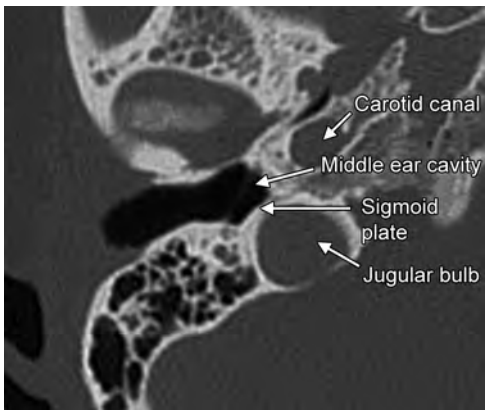


Fig. 5: Computed tomography (CT) scan axial cut showing floor of tympanic cavity with jugular bulb and internal carotid artery.

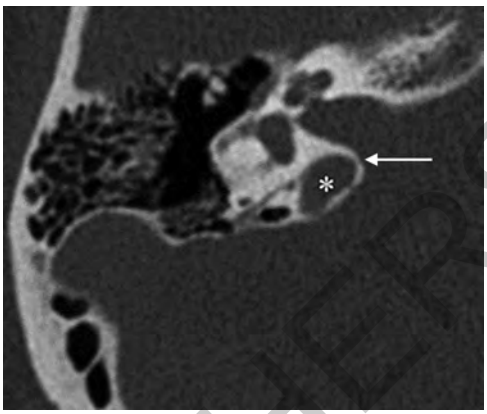


Fig. 6: Computed tomography (CT) scan axial cut showing high riding jugular bulb. [High riding jugular bulb (asterix)].

- *Retrofacial approach:* Hypotympanic space can be approached medial to the mastoid segment of the facial nerve and inferior to the posterior semicircular canal. High and lateral jugular bulb make this approach difficult.
- *High jugular bulb:* Jugular bulb can rise up to the petrous ridge **(Fig. 6)**.
- *Dehiscent jugular bulb:* If covering bony plate is absent make the exposed jugular bulb in the middle ear cavity **(Fig. 7)**.
- In translabyrinthine approach for cerebellopontine (CP) angle surgery:
  - The cochlear duct (perilymphatic duct) runs from the medial aspect of scala tympani to the subarachnoid space and terminates anteromedial to the jugular bulb and inferior to the internal auditory canal. Decompression of CSF into mastoid is an important procedure and is done by drilling medial to jugular bulb and opening of the cochlear duct in translabyrinthine approach for CP angle tumor.
- Cranial nerves 9, 10, and 11 and the inferior petrosal sinus found immediately inferior to the opening of cochlear aqueduct can be used as lower limit of translabyrinthine surgery.

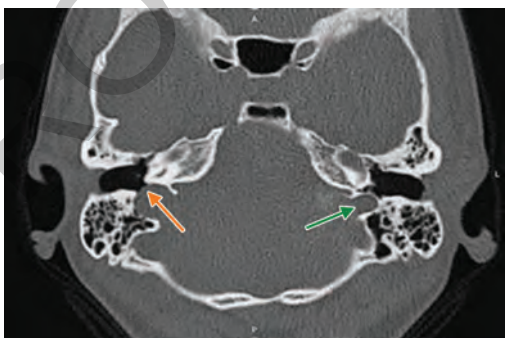


Fig. 7: Computed tomography (CT) axial cut showing dehiscent jugular bulb in the right ear. [Dehiscent jugular bulb (orange arrow); normal jugular bulb (green arrow)].

Lateral Wall of the Tympanic Cavity

It is formed by the tympanic bone, the tympanic membrane, and outer attic wall (scutum). It separates the external ear and the middle ear.

Lateral wall is membranous as well as bony structure. Tympanic bone at the medial end harbors the sulcus in which tympanic membrane with annulus lodges.

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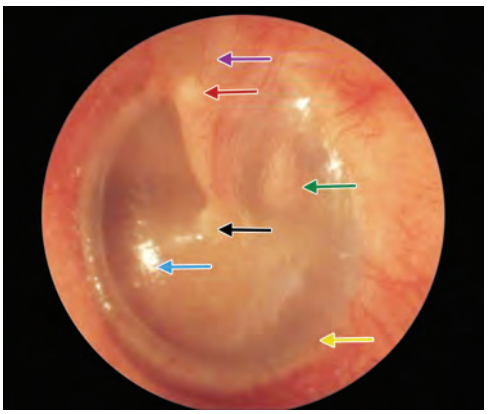


Fig. 8: Parts of a normal tympanic membrane. [Pars flaccida (purple arrow); annulus (yellow arrow); cone of light (blue arrow); lateral process of malleus (red arrow); IS joint (green arrow); umbo (black arrow)].

The conically shaped tympanic membrane **(Fig. 8)** is tilted anteroinferiorly, therefore anteroinferior bony wall is longer than posteroinferior one and anterior tympanomeatal angle is more acute than the posterior one. Adult's tympanic membrane is about 9 mm in diameter. The fibrous annulus (peripheral fibrocartilaginous part of the tympanic membrane) anchors in the tympanic sulcus (tympanic ring is C shaped and deficient part is notch of Rivinus), so annulus extends the fibrous stria from the anterior and posterior tympanic spine to the neck of malleus and forming anterior and posterior tympanic malleolar ligament which divides tympanic membrane into superior pars flaccida (Shrapnell's membrane) and inferior (pars tensa) (tympanic spine is anterosuperior and posterior superior prominent edge of the tympanic sulcus). Pars flaccida attaches to the outer wall of attic (scutum). The tympanic membrane is composed of three layers: (1) Epithelial layer, (2) fibrous layer (lamina propria), and (3) mucosal layer.

Tympanic membrane is conical in shape with its apex at umbo (at the tip of manubrium). The tympanic membrane attaches to the malleus at the lateral process and the umbo. In between these two points there is a weak mucosal fold, the plica mallearis, which connects the tympanic membrane to the malleus.

Microscopically tympanic membrane has three layers, but it arranges differently, reflects different tensile strength of pars tensa and pars flaccida. The three canaliculi lie at the medial surface of the tympanic ring, medial to the tympanic spine and the tympanic annulus.

1. *The iter chordae anterior:* Through this opening chorda tympani exits the tympanic cavity. This opening is located at the medial end of the petrotympanic fissure.
2. *The iter chordae posterior:* Through this opening chorda tympani enters the tympanic cavity, medial to the tympanic annulus, traverses cavity with lateral to long process of incus and medial to the handle of malleus to reach up to the petrotympanic fissure.
3. *The petrotympanic fissure:* Anterior malleolar ligament, anterior tympanic artery, and the chorda tympani pass through this fissure.

Scutum or outer attic wall forms the superior part of the lateral wall. It is part of the squamous bone. The part of the attic which lies below the roof of the EAC is known as the scutum. It is a sharp bony spur where the pars flaccida is attached.

- Retraction of the pars flaccida and posterosuperior part of the pars tensa occur due to their attachment strength in organized fibers in the lamina propria.
- *Prussak's space:* The superior recess of the tympanic membrane. It is the space between the pars flaccida and the neck of malleus.
  - *Roof:* Lateral malleal fold
  - *Floor:* The neck of malleus

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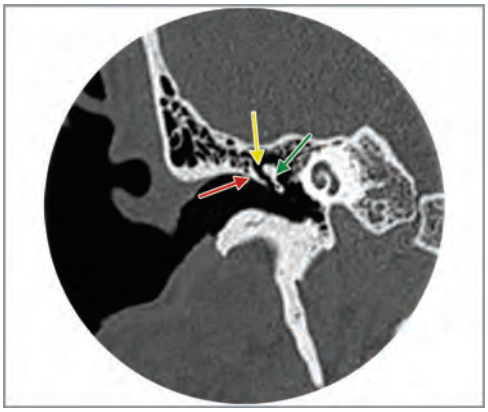


Fig. 9: Computed tomography (CT) image of the outer attic wall and Prussak's space. [Outer attic wall (red arrow); Ossicles (green arrow); Prussak's space (yellow arrow)].

- *Anterior wall:* Anterior malleal fold
- *Lateral wall:* Pars flaccida and the lower edge of the outer attic wall
- *Posterior wall:* Open to the posterior pouch of Von Troeltsch.

The Prussak's space **(Fig. 9)**, where epitympanic cholesteatoma starts to invaginate medially from the pars flaccida.

- Lateral wall of the tympanic membrane is the site through which clinical examination is possible for the diseases of the ear.
- As cartilaginous "cap" of the lateral process of malleus is adherent to the lamina propria of the tympanic membrane. It requires sharp, meticulous dissection to dissect the tympanic membrane in the tympanoplasty.

The Medial Wall of the Tympanic Cavity (Cochlear Wall or Surgical Floor of the Middle Ear)

The medial wall is derived from the otic capsule. It features prominent promontory with oval window and round window, cochleariformis process, tympanic segment of the facial nerve, and anterior aspect of lateral semicircular canal **(Fig. 10)**.

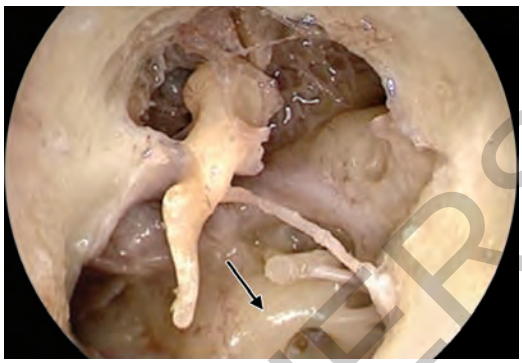


Fig. 10: Endoscopic view, promontory (arrow) on the medial wall of the middle ear.

The promontory: It is located anteriorly to the oval window, inferiorly to the cochleariformis process. Cochlea turns around the spongy bone modiolus around 2¾ turns. Basal turn gives prominence of the promontory, middle and apical turn lies medial to the cochleariformis process and tensor tympani muscle (axis of cochlea is directed anteriorly and laterally).

The oval window and round window: The oval window is situated posterosuperior to the promontory, posterior to cochleariformis process, and the pyramidal eminence lies posteriorly, inferior to the facial nerve and covered with annular ligament and the footplate of the stapes **(Fig. 11)**.

The round window is located in the round window niche, inferiorly to the oval window and posteroinferior to the promontory. Oval window and round window are openings of the labyrinth to the tympanic cavity. True round window membrane is in horizontal plane and to see it, removal of superior overhang of niche is required.

- The superior border of the round window is very near to the basilar membrane and osseous spiral lamina.
- Intracochlear inferior border of the round window is called the "crista fenestra."

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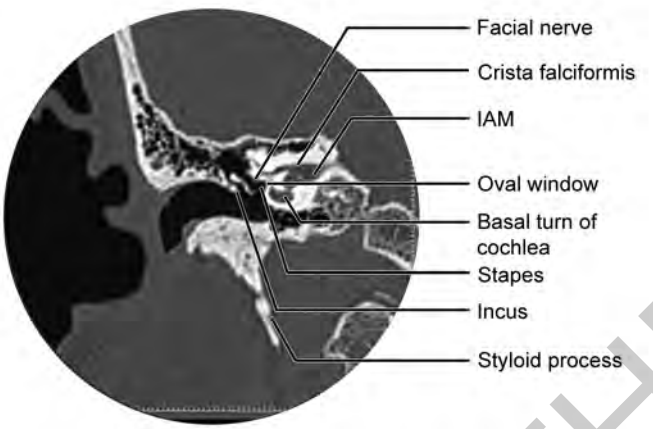


Fig. 11: Computed tomography (CT) scan axial cut showing area of stapes and oval window.

It is not closely related to the basilar membrane.

The cochleariformis process: It corresponds to the posterior end of the semicanal of tensor tympani. It is conical eminence anterosuperior to the oval window, inferior and lateral to the horizontal facial nerve. It is located just medial to the neck of malleus. The tendon of tensor tympani curves round and with right angle attaches to the neck of malleus. It is a constant landmark for the identification of the facial nerve.

The facial nerve: The tympanic segment of facial nerve courses obliquely in the medial wall of tympanic cavity from area above the supratubal recess to the area just superior to the oval window. Above the oval window, facial nerve forms prominence along with prominence of promontory, oval window lies under the level of these prominences. At the posterior edge of the oval window, facial nerve turns inferiorly and laterally from medial wall of tympanic cavity to the posterior wall of the tympanic cavity. At this turning point, facial nerve is anteroinferior to lateral semicircular canal and medial to the short process of the incus **(Fig. 12)**.

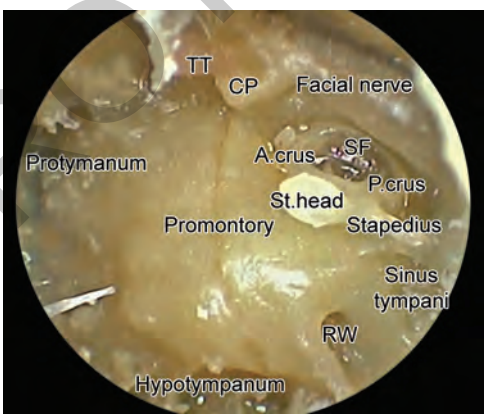


Fig. 12: Endoscopic view of the middle ear with relations of facial nerve.

Lateral Semicircular Canal (Fig. 13)

Anterior aspect of the lateral semicircular canal lies in the posterior part of the attic. The ampullae of the superior and the lateral semicircular canal are situated in the medial wall of the posterior attic.

- Anomaly of the facial nerve is associated with the anomalies of the labyrinth.
- Congenital anomalies of the oval window and the round window appear along with malformation of the labyrinth. Atresia or fixation of oval window may appear.

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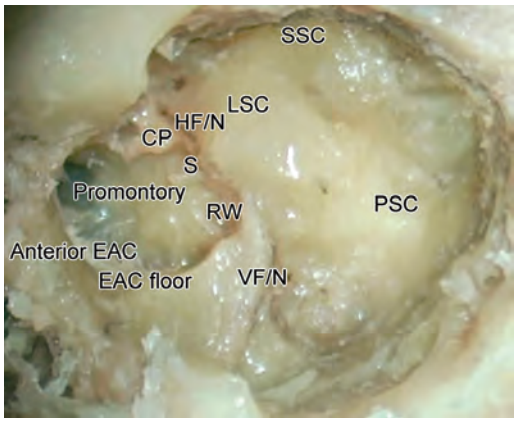


Fig. 13: Cadaveric dissection photo of mastoid with all the three superior semicircular canal (SCC).

- Cochleariformis process is constant landmark for the identification of the facial nerve.
- Facial recess approach (posterior tympanotomy) allows exposure of lower half of the basal turn of cochlea for the cochlear implant surgery.
- For exposure of middle turn and apical turn of the cochlea, cochleariformis process and the semicanal of tensor tympani must be removed.
- Oval window shows different degree of otosclerosis ranging from focal thickening to complete obliteration.
- Ampulla of posterior semicircular canal is close to the round window niche. Singular nerve supplies this ampulla. This singular canal lies immediately inferior to the posterior attachment of the round window membrane.
- *Perifenestral otosclerosis:* Round window gets obliterated in the otosclerosis and the meningitis.
- Round window membrane allows passage of the bacterial exotoxins as well as drugs such as dexamethasone and steroids into the inner ear.

The Anterior Wall of Tympanic Cavity

The anterior wall of tympanic cavity develops from otic capsule. This wall covers ICA and it contains the semicanal of Eustachian tube and semicanal of the tensor tympani muscle. A bony septum lies between the auditory tube and tensor tympani, it extends into the cochleariformis process and tensor tympani tendon rests on it. Anterior wall corresponds to the vertical segment of the ICA, medial to the semicanal of the Eustachian tube. There are two canaliculi in the bony carotid canal which transmit the superior caroticotympanic nerve and inferior caroticotympanic nerve both of which arises from superior cervical ganglion to the tympanic plexus of the middle ear.

Rarely, there is a dehiscent wall between the cochlea and carotid artery. Preoperative imaging helps to prevent inadvertent penetration into carotid during cochlear implant surgery.

The Posterior Wall of the Tympanic Cavity (Fig. 14)

This wall develops from the cartilage of the 2nd pharyngeal arch (Reichert's cartilage). The cartilaginous bar extends between the facial nerve medially to the tympanic annulus laterally. It is the highest wall of the middle ear cavity. In upper one-third, aditus ad antrum lies which connects the epitympanum to antrum. The remaining lower two-thirds of wall connects the annulus to the structure of the otic capsule containing the mastoid segment of the facial nerve. There are three eminences in the posterior wall:

1. *Pyramidal eminence:* It is triangular shape, base lies anteromedial wall of the facial nerve (mastoid). Apex gives attachment to the stapedius muscle and it transmits the nerve to stapedius, branch of facial nerve.

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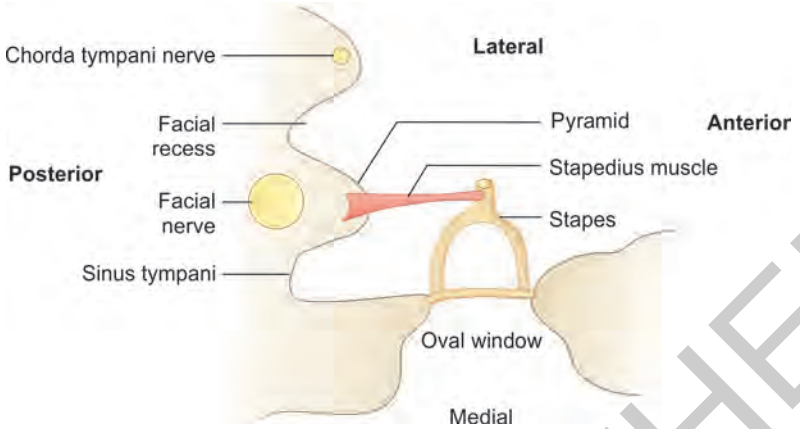


Fig. 14: Schematic diagram of posterior mesotympanum. Contents of the middle ear cavity.

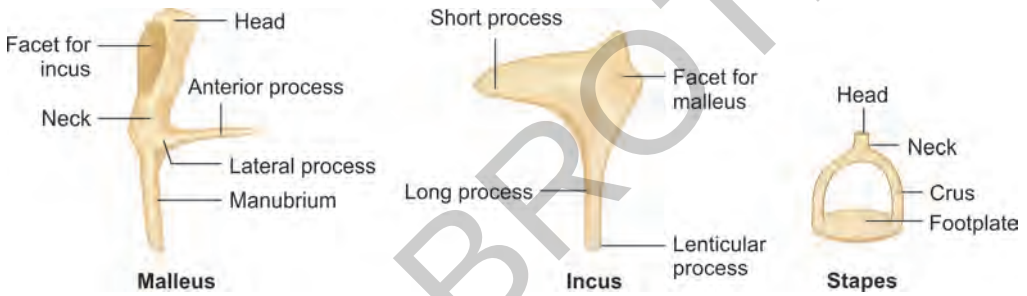


Fig. 15: Middle ear ossicles.

2. *Chordal eminence:* It lies medial to annulus and lateral to the pyramidal eminences.
3. *Styloid eminences:* It is in the inferior part of the posterior wall, represents the base of styloid process and the landmark for the facial nerve (facial nerve lies posterior to the eminence).

The middle ear cavity contains the ossicular chain with ligament and muscles. It is mucosal lining air containing cavity essential for the transmission of the sound from the tympanic membrane to the oval window.

The Ossicular Chain (Fig. 15)

The malleus, incus, and stapes resemble to their shape derived from the 1st and 2nd pharyngeal arches, respectively.

The malleus **(Fig. 16)** is the most lateral of the ossicles. It has head, neck, handle (manubrium) and processes, anterior and lateral process. The handle of malleus firmly attaches to the tympanic membrane at the lateral process and the umbo. The lateral process lies at the superolateral end of the manubrium, close to anterior canal wall, meticulous care should be taken not to touch this process with burr while performing canaloplasty. Anterior malleolar ligament and posterior incudal ligament creates the axis of ossicular rotation. The tendon of tensor tympani muscle attaches the medial side of the neck of malleus and contraction of this muscles moves the ossicles medially, tenses the tympanic membrane. There are three suspensory ligaments (anterior, lateral,

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