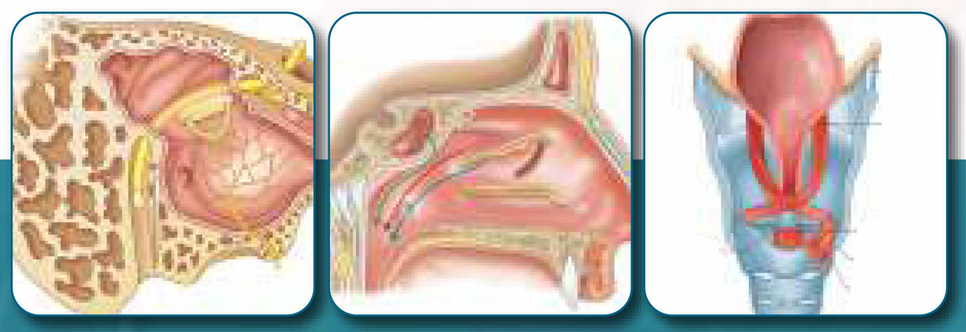
Fifth Edition

Textbook of Ear, Nose, Throat and Head–Neck Surgery

Clinical and Practical



According to the latest CBME Guidelines | Competency based Undergraduate Curriculum for the Indian Medical Graduate

with
Indexes of Competencies

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Contents

CHAPTER

1

Embryology of the Ear

Competency achievement: The student should be able to:
EN1.1 Anatomy and physiology of ear, nose, throat, head and neck.

Ear has a very complex source of development. The sound conductive apparatus develops from the branchial apparatus, whereas the sound perceptive apparatus develops from the ectodermal otocyst (pars otica). Because of this dual source of origin, the developmental anomaly produced, commonly affects either the sound conductive system which includes anomaly of the external and/or the middle ear or the sound perceptive apparatus which includes the labyrinth. Both these anomalies rarely coexist because of different source of origin.

Development of the External Ear

This develops around the first branchial cleft.

The Pinna

Around 6th week of intrauterine life, six hillocks or 'tubercles of His' appear around the first branchial cleft (Fig. 1.1). The first tubercle is derived from the first branchial arch and the rest from the 2nd branchial arch. Some authors believe that the first 3 tubercles develop from the first arch and the rest from the 2nd arch.

Structures Derived from Various Hillocks

1. Tragus
2. Crus of the helix
3. Helix
4. Antihelix
5. Scapha and the antitragus
6. Ear lobule

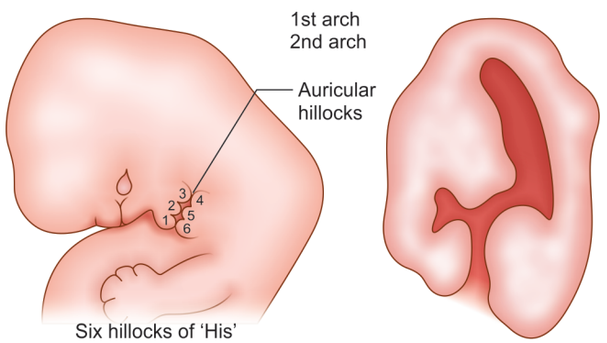


Fig. 1.1: Development of external ear from six hillocks

The ear takes definitive form by the end of third month of intrauterine life. Defective fusion of the tubercles gives rise to preauricular sinus and failure of the development of the hillocks causes anotia. Defective development of 4th tubercle can cause absence of antihelix leading to 'bat ear' deformity.

External Auditory Canal

This develops from the first branchial cleft as an invagination into a funnel-shaped pit to form a primary external auditory canal. Subsequent medial growth with a solid core of ectoderm leads to formation of a meatal plate called the secondary external auditory canal. Between 8th and 10th weeks of IUL, the solid core of epithelium undergoes canalization forming the definitive external auditory canal.

Anomalies of the External Auditory Canal

1. Complete atresia (fibrous and/or bony)
2. Shallow depression
3. Changes in the curvature of the canal
4. Stenosis

Development of Tympanomastoid Cavity and Eustachian Tube (Fig. 1.2)

Around 3rd week of IUL, the first pharyngeal pouch develops which is phylogenetically the aquatic gill apparatus. This outpouching of the first pharyngeal pouch gives rise to two components, namely:

1. The proximal narrow part which forms the eustachian tube.
2. The distal dilated part which gives rise to the developing middle ear cleft and is known as the tubotympanic recess. This forms the definitive tympanic cavity by progressively and systematically invaginating into the adjacent mesenchyme.

Towards the later part of the fetal life a diverticulum appears from the tubotympanic recess which

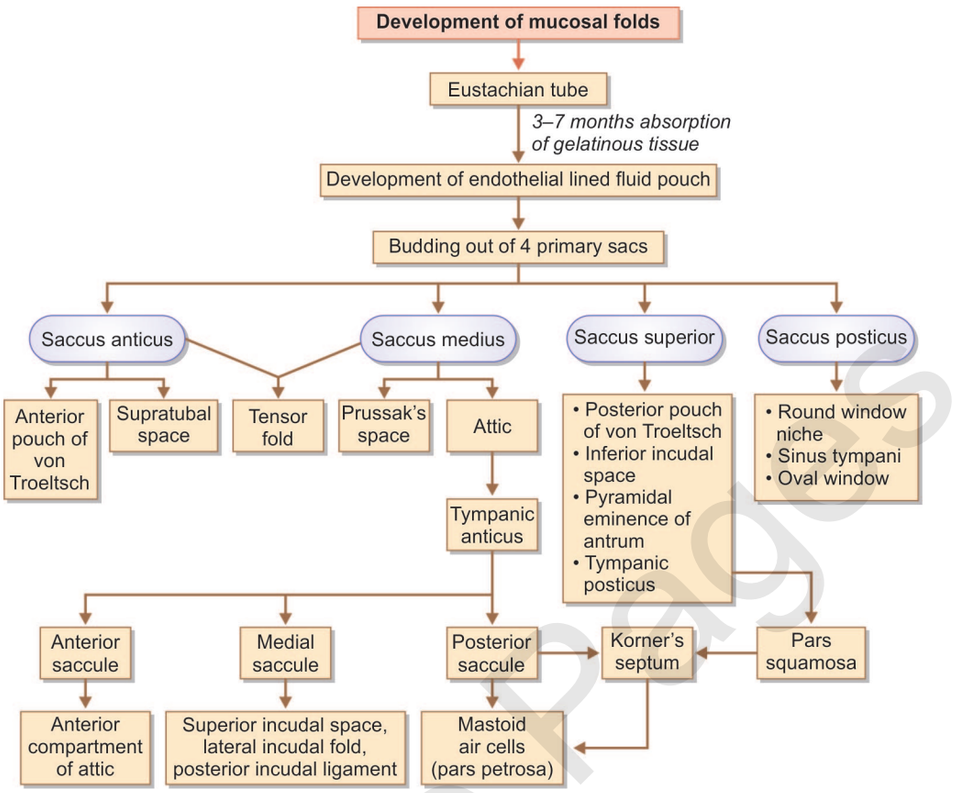


Fig. 1.2: Development of mucosal folds

subsequently forms the mastoid antrum. This antrum is about 3 mm thickness at birth and it increases 1 mm every year till it reaches the adult size of 15 mm thickness.

Development of Ossicles

Anson in 1959 described the details of the development of the ossicles. The first arch cartilage (Meckel's cartilage) forms the head of the malleus and the body of the incus. The second arch forms the manubrium (handle) of the malleus and the long process of the incus and the crurae of the stapes. These sources of development confirm the various developmental anomalies involving the ossicles as encountered during surgery. The footplate of the stapes develops from three sources, namely:

1. The outer periosteal layer of the otic capsule.
2. Middle enchondral layer from the otic capsule.
3. Inner endosteal layer is same as the endosteum of the bony labyrinth and develops from the periotic mesoderm.

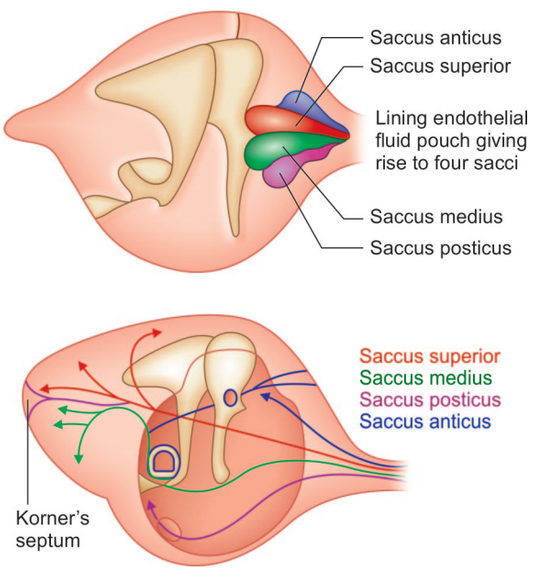
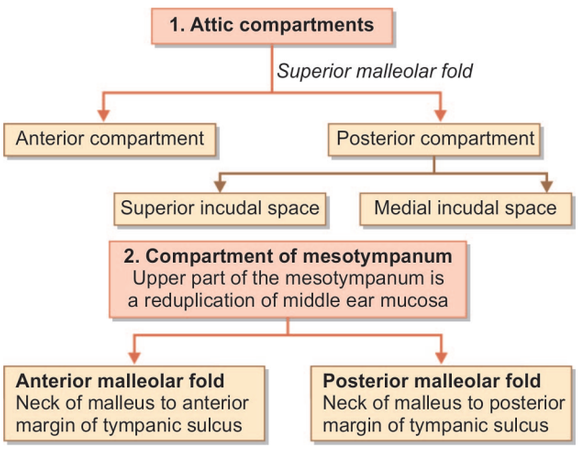


Fig. 1.3: Development of four primary sacs

Development of Middle Ear Spaces and Folds

The envelopment of the ossicles by the mucous membrane lining of the tubotympanic recess occurs between 3 and 7 months of IUL. This mucous lining while encircling the ossicles form numerous folds and spaces as follows (Figs 1.2 to 1.5A to D).



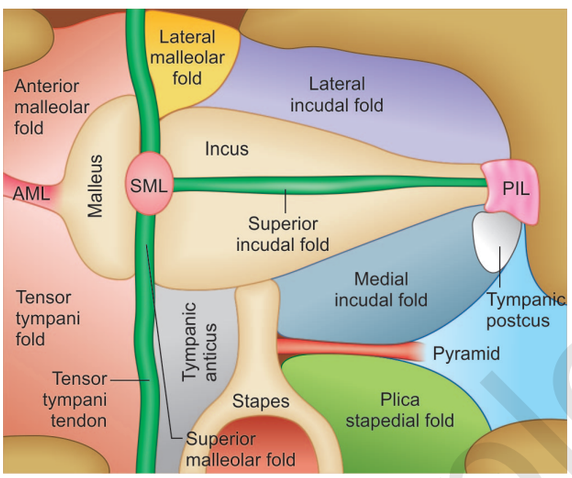


Fig. 1.4: Various middle ear folds and boundaries of tympanic anticus (TA)

COMPARTMENT AND FOLDS OF THE TYMPANIC CAVITY (Figs 1.5A to D)

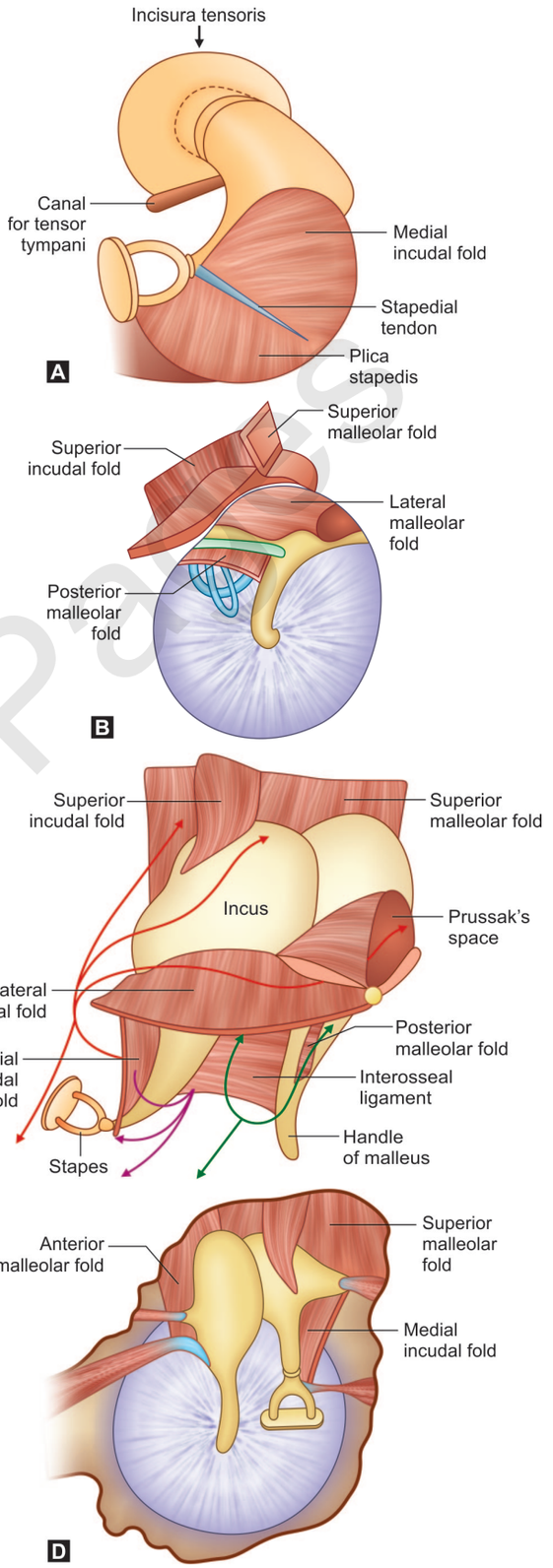
Prussak's Space (Figs 1.5C and 1.6)

It is a potential space which may be the first to involve during the extension of cholesteatoma, it is bounded by (Fig. 1.6):

- Laterally by Shrapnell's membrane (pars flaccida)
- Medially by the neck of malleus
- Superiorly by fibers of lateral malleolar fold
- Inferiorly lateral process of malleus.

Development of the Inner Ear

The inner ear develops from the otic capsule (pars otica). Initially a thickening appears in the ectoderm of the hindbrain known as otic placode. It later invaginates forming otic cyst which is also known as otic capsule. Subsequent differentiation of this otic cyst (vesicles) leads to formation of membranous labyrinth. After the formation of ectodermal otocyst at 4 weeks of fetal life (WFL), the growth of the semicircular canals occurs at 5 WFL, and the elongation and coiling of the



Figs 1.5A to D: Various mucosal folds that are developed during the process of development and the middle ear spaces that are formed from these folds

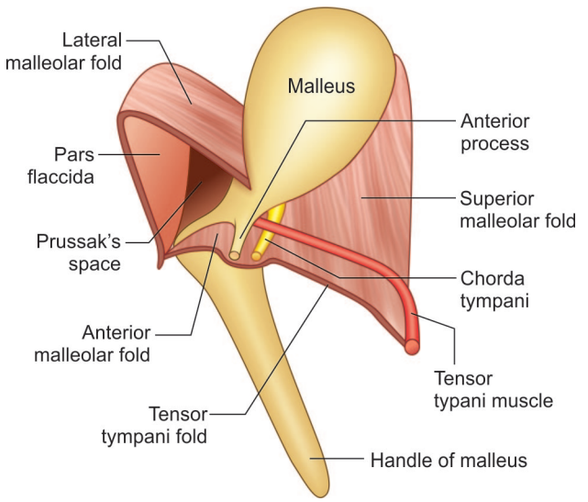


Fig. 1.6: Boundaries of Prussak's space

cochlea at 10 WFL. The mesoderm surrounding the otic capsule forms the bony labyrinth along with endochondral layer of the otic capsule. As the membranous labyrinth takes shape, there is a concomitant development of the sensory neuroepithelia and their associated structures within. The prenatal labyrinth attains an adult equivalent size between 17 and 19 weeks of fetal life (Fig. 1.7). Incomplete development of otic capsule can be associated with various inner ear abnormalities leading to deafness.

Pneumatization of mastoid: It is the process by which the aircell system extends as an outgrowth from the epithelial sac of the middle ear and antrum in conjuction with the enlargement of temporal bone which starts immediately after birth. Both genetic and acquired factors have been implicated to influence pneumatization process. The mastoid process develops at the end of 1st year due to the contraction of the sternocleidomastoid muscles as the child tries to lift the head. In 80% of cases, mastoid is fully pneumatized and in rest of the cases it may be partially pneumatized or sclerotic. Based on this the mastoid can be of three types:

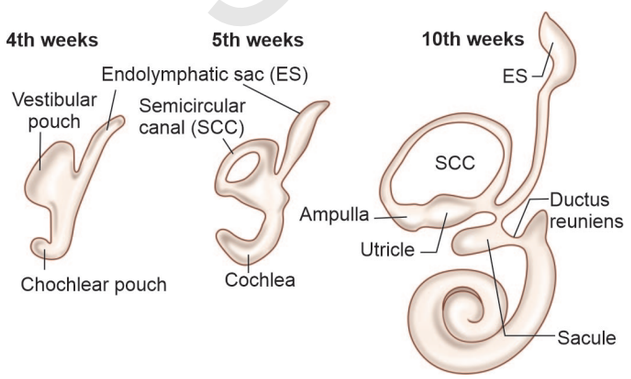


Fig. 1.7: Developing inner ear

1. Cellular (well pneumatized)
2. Diploeic (poorly pneumatized) few small-sized cells
3. Sclerotic (non-pneumatized) absence of cells that are replaced with dense, compact bone. Sclerotic mastoid can be divided further into:
   - Primary sclerotic mastoid (not developed)
   - Secondary sclerotic mastoid (acquired).

Theories of Faulty Pneumatization

1. *Tumarkin theory:* Poor ventilation of the middle ear cleft due to eustachian tube dysfunction leading to arrest of pneumatization.
2. *Wittmaack theory:* He proposed that otitis media in infancy and early childhood leads to poor ventilation of middle ear cleft causing arrest of pneumatization.
3. Diament was of the view that pneumatization of the mastoid bone is determined by hereditary factors.
4. Genetic factors were also implicated by Stern
5. *Graham and Brackmen:* The size of mastoid depends upon the final size of the skull in an individual as in acromegaly (large expansive mastoid) and in microcephaly (underdeveloped mastoid).

Classification of Mastoid Air Cell System

Allam (1969) classified the pneumatized spaces of the temporal bone into five different regions: Middle ear region, mastoid region, perilabyrinthine region, petrous apex region and accessory region (*see* Fig. 2.19).

1. *Middle ear region*: Hypotympanic cells, etc.
2. *Mastoid region:*
   - Central: Antrum and periantral cells.
   - Peripheral: Tegmen cells, sinodural cells, perisinus cells, retrofacial cells and tip cells
3. *Perilabyrinthine region*: Supra- and infralabyrinthine cells
4. *Petrous apex region*: Apical cells.
5. *Accessory region*: Zygomatic, squamous, occipital, styloid and peritubal cells

Points to Remember

1. The sound conducting apparatus develops from the branchial apparatus, whereas the sound perceptive apparatus from the ectodermal otocyst.
2. The pinna develops from the six hillocks around the 1st branchial cleft.
3. Defective fusion of tubercles gives rise to preauricular sinus.
4. The outpouching of the 1st pharyngeal pouch gives rise to a proximal narrow part that forms the eustachian tube and distal dilated part that forms the middle ear cavity.
5. Prussak's space is a potential space lateral to the Shrapnell's membrane and medially by the neck of malleus that can be involved during the extension of cholesteatoma.

CHAPTER

2

Anatomy of the Ear

Competency achievement: The student should be able to:
EN1.1 Anatomy and physiology of ear, nose, throat, head and neck.

"Otology is almost unique even ill the later part of the 20th century in not being able to explain at least a few of its diseases in biochemical terms."

—Ruben, 1975

Ear is divided into three parts (Fig. 2.1):
1. External ear
2. Middle ear
3. Inner ear

EXTERNAL EAR

It consists of pinna and external auditory canal. Pinna develops from **six tubercles** around the **1st branchial cleft,** whereas external auditory canal develops from the **1st branchial cleft**.

External auditory canal is the only cul-de-sac in the body lined by skin.

Pinna (or auricle) is the prominent part of the external ear composed of **a single sheet of yellow elastic cartilage** covered by fat, subcutaneous tissue and skin. It has two surfaces**—medial (cranial) and lateral**. The lateral surface is concave with folds and hollows. The medial surface is convex. The most prominent outer fold is called **the helix** and the fold in front is the anti-helix. In front of the **anti-helix** is a hollow called concha which is divided by root of helix into Symba and cavum conchae.

Cavum conchae leads inwards to the external auditory canal. Anterior to the cavum conchae there is a small cartilaginous projection known as **tragus**. In the upper part of the cavum conchae, in front of the

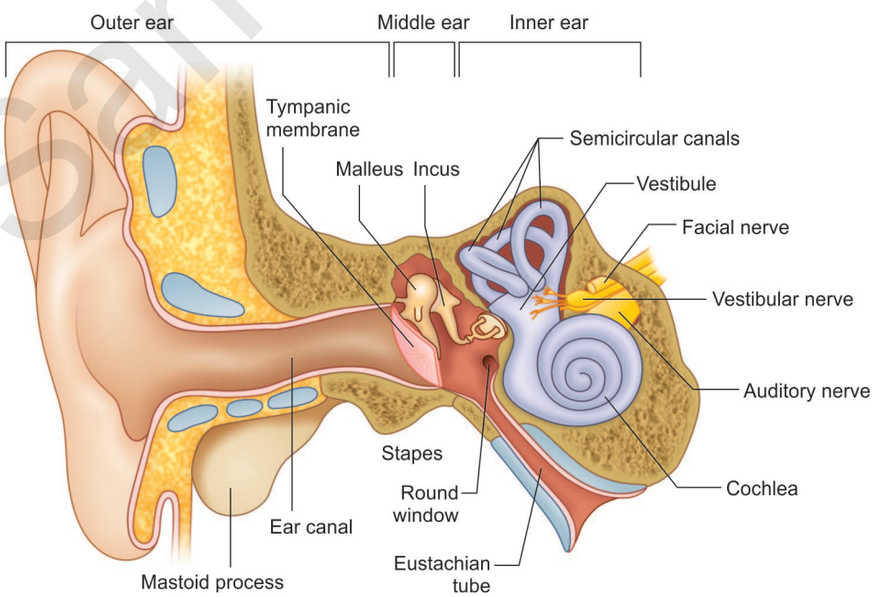


Fig. 2.1: Cross-section of ear: External ear, middle ear and inner ear

anti-helix, there is a triangular space known as **fossa triangularis**. There is also a boat-shaped space in-between the upper part of helix and anti-helix known as **scaphoid fossa** (Fig. 2.2).

The whole of the pinna is composed of a single sheet of cartilage except in the lobule and in the space between the crus of the helix and tragus. This space is called **incisura terminalis** (Fig. 2.3). Since this area is devoid of cartilage, otologists can safely give an incision here for procedures in the ear to avoid postoperative perichondritis. The skin lining on the lateral or outer surface of the pinna and external auditory canal is firmly adherent to the perichondrium of the cartilage with minimal or no subcutaneous tissue. Hence, the outer surface of the pinna is more prone to **frost bite** and inflammatory lesions are painful. In the cranial surface there is more subcutaneous tissue and the skin is loosely adherent to the underlying cartilage. Cysts like **sebaceous cyst** are commonly seen on this surface. The cartilage of the pinna **extends medially** to form the cartilaginous part of the external auditory canal.

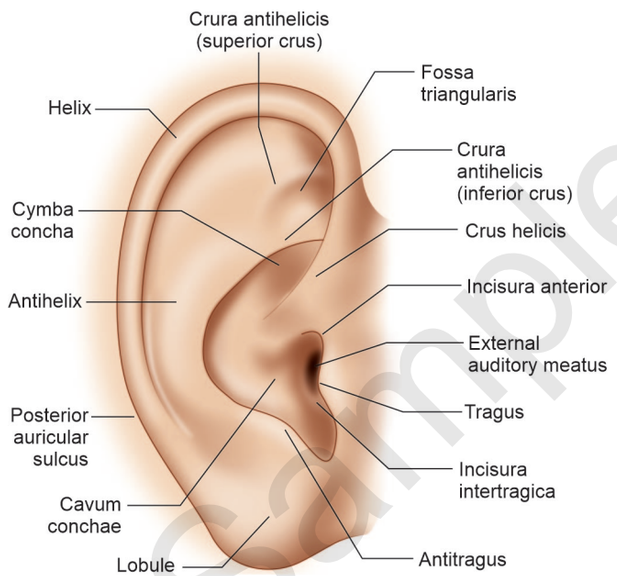


Fig. 2.2: Parts of pinna

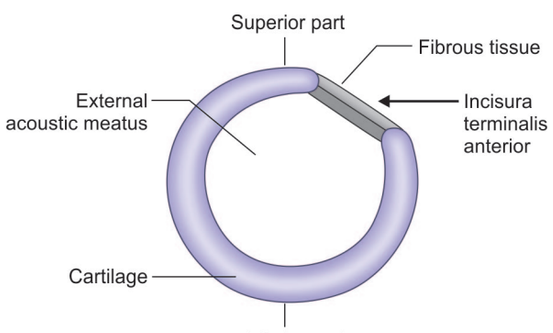


Fig. 2.3: Cross-section of external auditory canal (cartilaginous part)

External auditory meatus is **S-shaped** and approximately 2.5 cm in length. It has **two** parts—the outer one-third is **cartilaginous** and inner two-thirds is **bony**. The cartilaginous part is a continuation of the auricular cartilage. It is firmly attached to the bony part by fibrous tissue. In infants, the cartilaginous meatus may remain collapsed because of the non-development of the bony part. Hence, to examine the deeper part of the meatus in an infant, one has to pull the pinna outward, downward and backward.

It has two horizontal fissures—the **"fissures of Santorini"** in the cartilaginous canal through which the parotid or superficial mastoid infections can appear in the meatus, or vice versa.

The external auditory canal is directed first inward, backward and upward and then goes forward, downward and medially. Isthmus is the narrowest part of the canal lying medial to the junction of bony and cartilaginous parts, nearly 5 mm lateral to the tympanic membrane. To examine the deeper part of the EAC in adult, one has to pull the pinna upward, backward and laterally. The roof and posterior wall of the external auditory canal are **shorter** than the floor and anterior wall. Thus, the tympanic membrane fits obliquely in the deeper end of the canal.

The anterior wall goes sharply forward to the tympanic membrane to form a blind pouch known as the **anterior recess**. Examination of this area is likely to be missed on routine otoscopic examination unless one takes care. This may be a common site for **foreign body impaction lodgement**.

Skin of cartilaginous canal contains hair follicles, ceruminous and sebaceous glands and these are absent in the skin of bony canal. Thus, furunculosis occurs only in the outer cartilaginous canal and diffuse inflammation may occur in the bony canal.

The skin lining the tympanic membrane and bony canal has a self-cleansing property due to migration of the keratin layer of epithelium from drum towards the cartilaginous portion. Migration is rapid near the attachment of handle of malleus and slows as it reaches the canal. Loss of this property is seen in keratosis obturans.

Relation

It is closely related to the temporomandibular joint and parotid gland **anteriorly**. Mastoid antrum and mastoid air cells are the **posterior** relations.

Nerve Supply (Figs 2.4A and B)

Nerve Supply of Pinna

Greater auricular nerve is common to lower one-third of both the surfaces. Upper two-thirds of the medial surface is supplied by the lesser occipital nerve and the upper two-thirds of the lateral surface is supplied by

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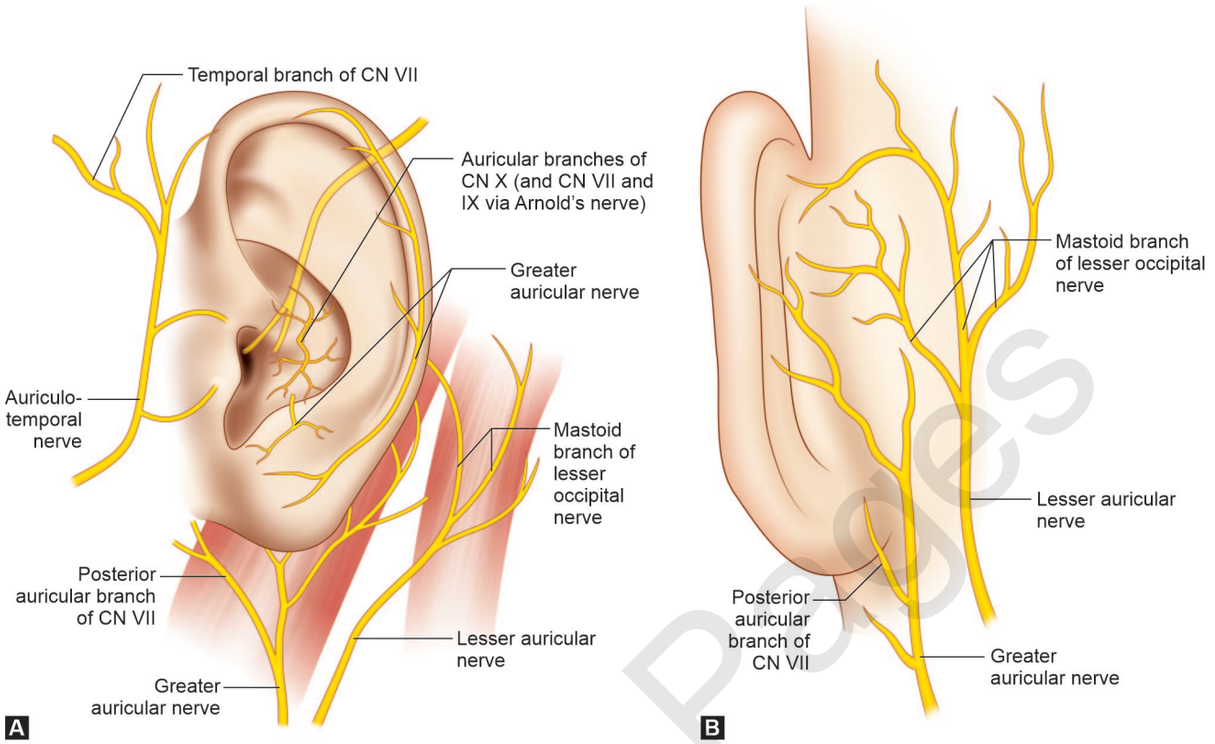


Figs 2.4A and B: Nerve supply of pinna

the auriculotemporal nerve. In addition, the concha and posterior superior deep meatus is supplied by facial nerve.

Nerve Supply of External Auditory Canal

The anterior wall, floor and contiguous portion of the tympanic membrane are supplied by the auriculotemporal nerve. Rest of the canal and posterior part of the tympanic membrane are supplied by the auricular branch of vagus, also known as **Arnold's nerve**. While cleaning the posterior meatal wall with a cotton swab, **cough is produced** which **reminds us of the presence of this vagal branch**. It is also thought that a twig from the facial nerve is incorporated with the auricular branch of vagus and distributed along with it as evident in **herpes zoster infection**.

Blood supply: Pinna and lateral part of external auditory canal are supplied by the post auricular, superficial temporal arteries.

Medial part is supplied by deep auricular artery. Veins from the external canal drain into the superficial temporal and posterior auricular veins.

Lymphatic Drainage (Fig. 2.5)

From the anterior wall it drains to the preauricular lymph nodes lying on the surface of the parotid gland in front of the tragus. The posterior wall drains to the

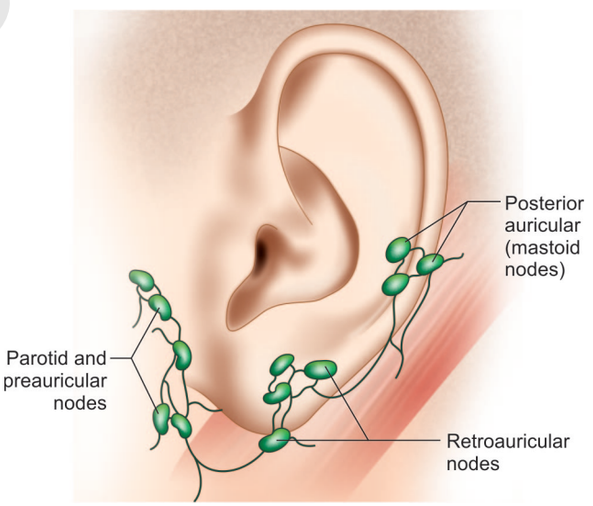


Fig. 2.5: Lymphatic drainage of pinna and external auditory canal

postauricular gland. The floor and lobule drains into retroauricular gland.

Tympanic Membrane
(Eardrum; Drum Head) (Fig. 2.6)

It is a thin semitranslucent membrane pearly white in color, lying obliquely in the medial end of the external auditory canal, with the angle of 55°, forming the major

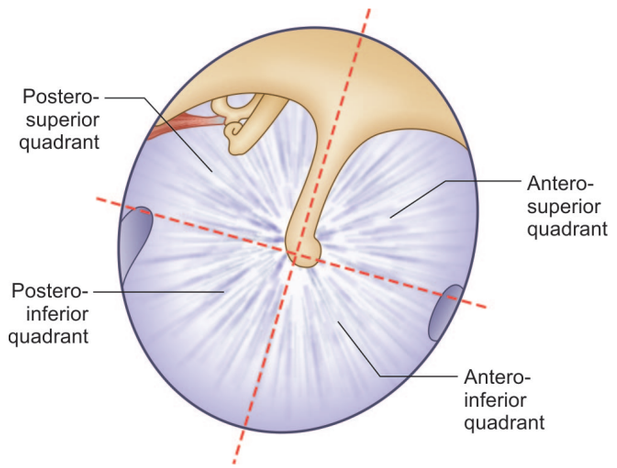


Fig. 2.6: Quadrants of right tympanic membrane

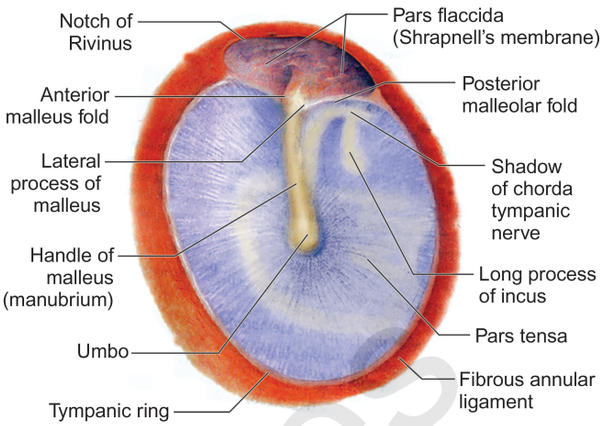


Fig. 2.7: Parts of left tympanic membrane

part of the lateral wall of the middle ear. Peripheral part of the tympanic membrane is thicker and rounded (except in the upper part) known as the annulus tympanicus. The annulus tympanicus is attached at its circumference to the tympanic sulcus. This tympanic sulcus ends in a notch known as the **notch of Rivinus** in the upper part. There are two folds seen arising from the **notch of Rivinus** to the lateral surface of malleus known as **anterior and posterior malleolar folds**.

Tympanic Membrane Consists of Three Layers Except in the Upper Part

1. Outer cuticular or epithelial layer which is continuous with the skin of the external ear.
2. Middle fibrous layer has both circular and radial fibers. Radial fibers normally merge with the annulus tympanicus. This middle layer is missing in the upper part (pars flaccida).
3. Inner mucosal layer which is continuous with the middle ear mucosa.

Tympanic Membrane Consists of Two Parts

1. **Pars tensa** is the larger part below the malleolar folds. It has all the three layers and is tense. The inner surface at the center is attached to the handle of malleus. When light is reflected over the tympanic membrane, the anteroinferior part is the most illuminated part in the pars tensa.
2. **Pars flaccida (Shrapnell's membrane; attic)** is a triangular area above the malleolar folds which are thin and devoid of fibrous tissue and annulus. It fits into the notch of Rivinus (Fig. 2.7).

The eardrum measures approximately 10 mm in vertical diameter and 9.0 mm in horizontal diameter. It is oval in shape and placed obliquely at an angle of 55 degrees with the floor of the meatus. The inner

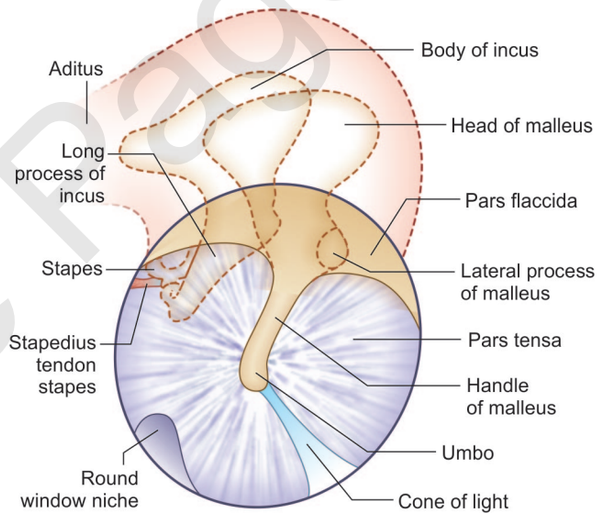


Fig. 2.8: Lateral wall of right tympanic cavity with its relation to the middle ear ossicles

surface is convex. The point of its greatest curvature is called umbo which corresponds to the tip of the handle of malleus on the inner surface (Fig. 2.8).

Blood Supply (Figs 2.9A and B)

The outer surface of the tympanic membrane is supplied by manubrial artery whose origin is not known and also by the deep auricular branch of the maxillary artery.

The inner surface of the tympanic membrane is supplied by the following arteries:

- Anterior tympanic branch of the maxillary artery.
- Posterior tympanic branch of stylomastoid artery.
- Inferior tympanic artery, a branch from the ascending pharyngeal artery.
- Middle meningeal artery.

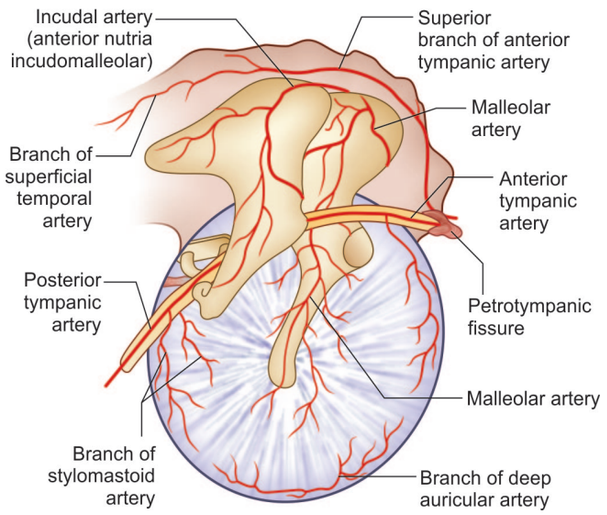


Fig. 2.9A: Blood supply of inner surface of tympanic membrane

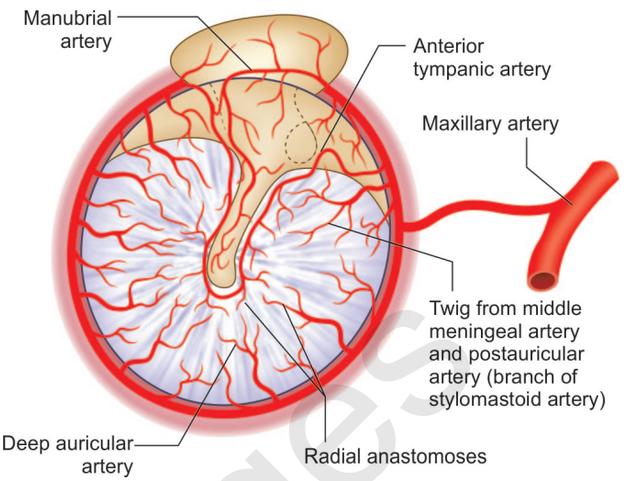


Fig. 2.9B: Blood supply of outer surface tympanic membrane

Venous Drainage

The external jugular vein provides drainage for the outer surface. The inner surface is drained by the transverse sinus and the venous plexus located around the eustachian tube.

Nerve Supply

The outer surface is supplied by the auriculotemporal nerve in the anterior half and tympanic branch of vagus in the posterior half. Tympanic plexus supplies the inner surface.

MIDDLE EAR CLEFT

STRUCTURES OF TYMPANIC CAVITY

(Figs 2.10 and 2.11)

The entire middle ear cleft is lined by columnar ciliated (eustachian tube, mesotympanum and hypotympanum) and pavement epithelium (epitympanum and mastoid antrum). It is an extension of the respiratory mucous membrane from nasopharynx. The middle ear cleft consists of:

1. Eustachian tube
2. Tympanic cavity

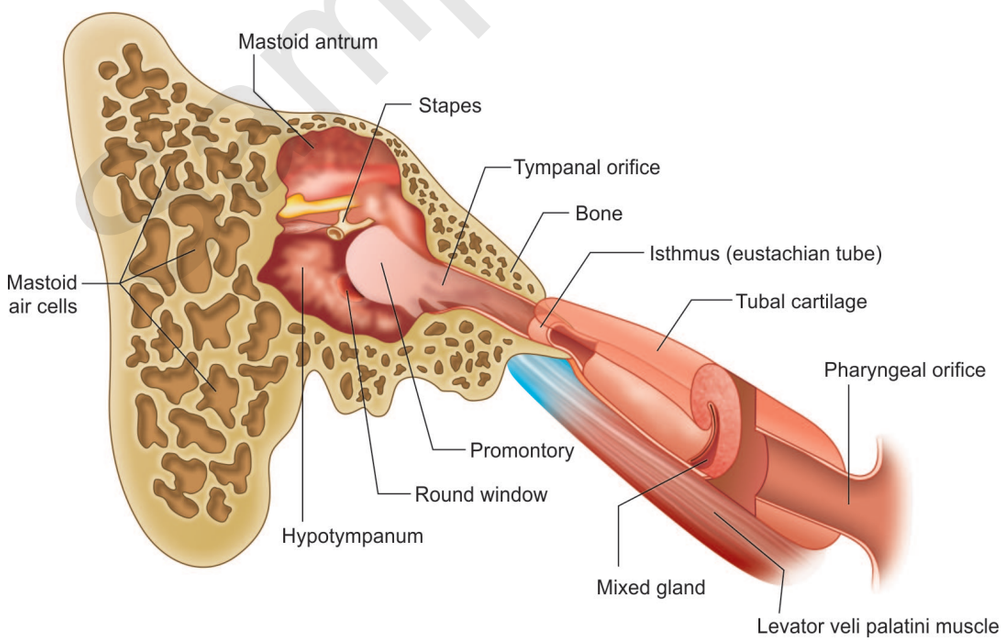
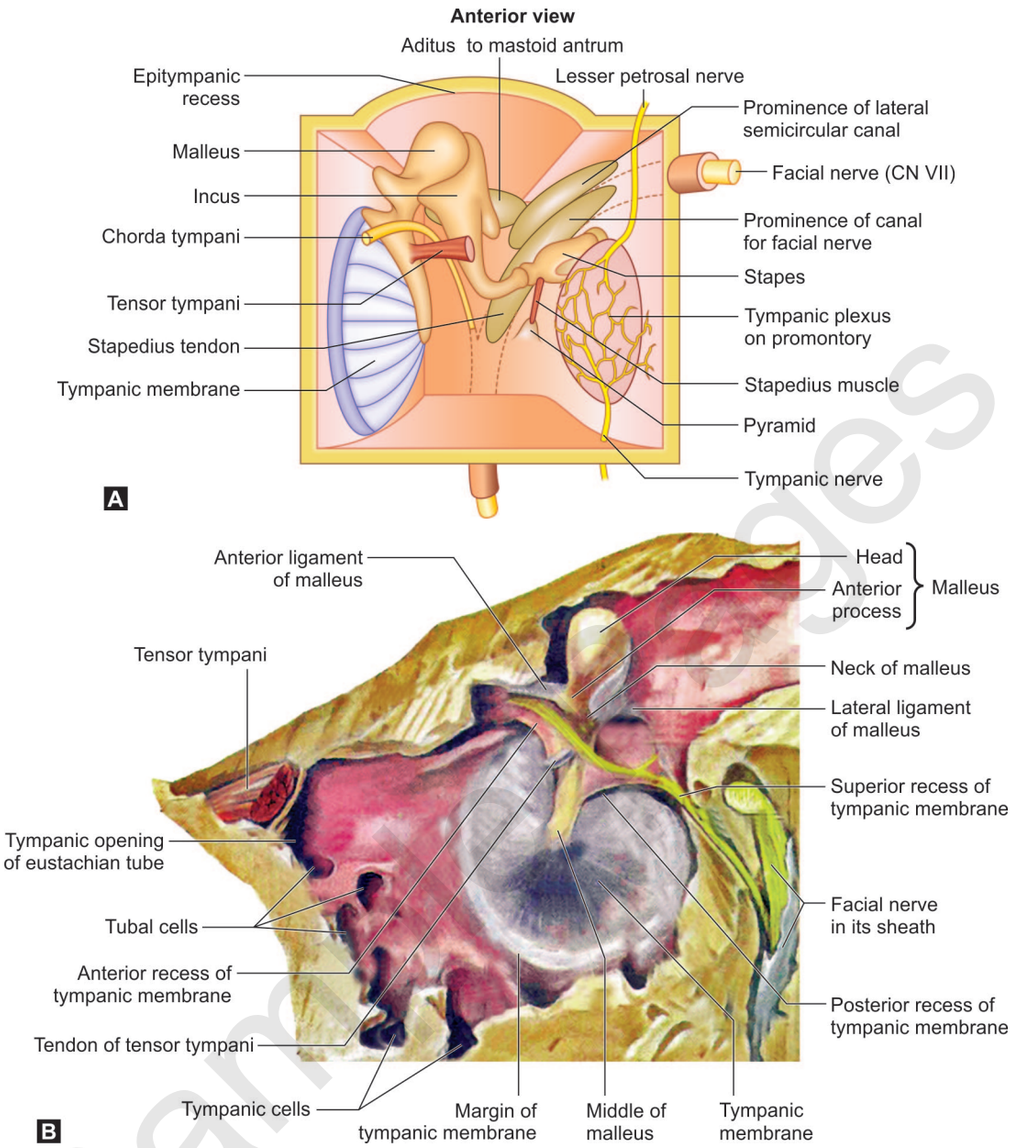


Fig. 2.10: Diagrammatic representation of middle ear cleft



Figs 2.11A and B: (A) Three-dimensional view of middle ear; (B) Lateral wall of middle ear

3. Mastoid antrum
4. Aditus ad antrum
5. Mastoid air cells.

EUSTACHIAN TUBE

Eustachian tube connects tympanic cavity to nasopharynx, it is approximately **3.6 cm long in average adult**. It runs upwards, laterally and backwards from the nasopharyngeal end in adults. The nasopharyngeal opening lies behind posterior end of inferior turbinate. Tympanic opening is higher than the pharyngeal opening. ***Tube is more horizontal and relatively wider, shorter in infants and young children***. The upper or postero-lateral one-third is bony, whereas lower or antero-medial two-thirds is cartilaginous. It is widest in entrance to tympanic cavity and narrow at its lower end, where tube is flattened at a diameter of 2 mm. Tubal tonsils are seen near the pharyngeal end of the tube which may at times cause eustachian tube obstruction because of hypertrophy.

There is also presence of fibrofatty tissue related to membranous part of cartilaginous tube specially in the region of nasopharynx which is known as **Ostmann's pad of fat**. This keeps the ET tube closed, thereby protecting the tube from **nasopharyngeal reflux**.

The fossa of Rosenmüller which lies behind the nasopharyngeal orifice is normally packed with small but well organized lymph nodes. It is the most common site for nasopharyngeal malignancy.

Blood Supply of Eustachian Tube

Arterial supply: Ascending pharyngeal and middle meningeal artery and also from artery of pterygoid canal.

Venous drainage: Pterygoid plexus.

Functions of Eustachian Tube

1. Ventilation of middle ear cleft—it plays a major role in equalizing middle ear pressure with atmospheric pressure.
2. Prevents reflux of nasopharyngeal secretion.
3. Clearance of middle ear secretions.

TYMPANIC CAVITY (THE MIDDLE EAR)

The tympanic cavity lies between the external and inner ear and shaped like a biconcave disc. The vertical and anteroposterior diameters are 15 mm, while the transverse diameter is 6 mm at the upper part, 2 mm at the center and 4 mm at the lower part (Fig. 2.12).

It is a six-sided cavity with a roof, floor, anterior, posterior, medial and lateral walls. The tympanic cavity is divided into three parts:

- Epitympanum
- Mesotympanum
- Hypotympanum

Epitympanum (Attic)

It is situated above the malleolar folds of the tympanic membrane. It contains the head of the malleus, incudomalleolar joint and body and short process of the incus. It connects the mastoid antrum via the aditus posterosuperiorly.

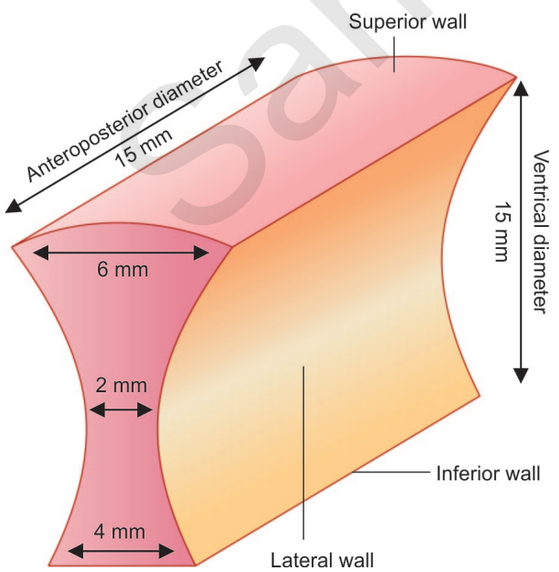


Fig. 2.12: Biconcave middle ear cavity

Mesotympanum

It is situated medial to the pars tensa of the tympanic membrane.

Hypotympanum

It is situated below the level of the tympanic membrane.

Anterior and inferior mesotympanum and hypotympanum are lined by columnar ciliated epithelium. The posterosuperior mesotympanum, epitympanum aditus and mastoid area are lined by pavement epithelium.

Lateral Wall

It is formed by the tympanic membrane and partly by a portion of squamous part of the temporal bone. This wall separates the middle ear from external ear.

Medial Wall (Fig. 2.13)

It separates the middle ear from the inner ear. It has several important structures:

a. Promontory is the most prominent and bulging part of the medial wall formed by the basal turn of the cochlea.
b. Bony lateral semicircular canal lies posterosuperior to the promontory above the oval window.
c. Oval window (fenestra vestibuli) lies between the middle ear and the scala vestibuli of the cochlea. It is closed by the footplate of stapes and the annular ligament.
d. Round window (fenestra cochleae) is situated below and behind the promontory. The niche of the round window is directed posteriorly. It is closed by the secondary tympanic membrane and separates the middle ear from the scala tympani of cochlea.
e. Facial nerve runs in the bony fallopian canal above the oval window.

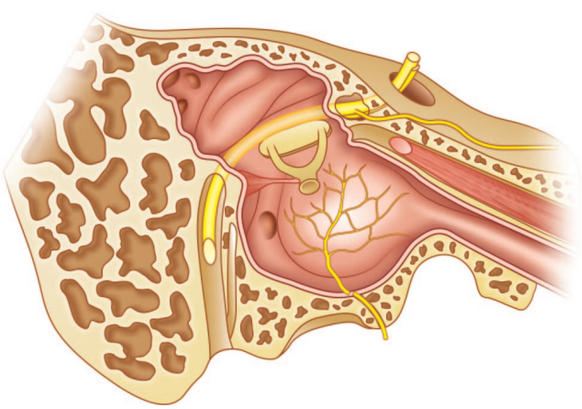


Fig. 2.13: Medial wall of middle ear

Anterior Wall

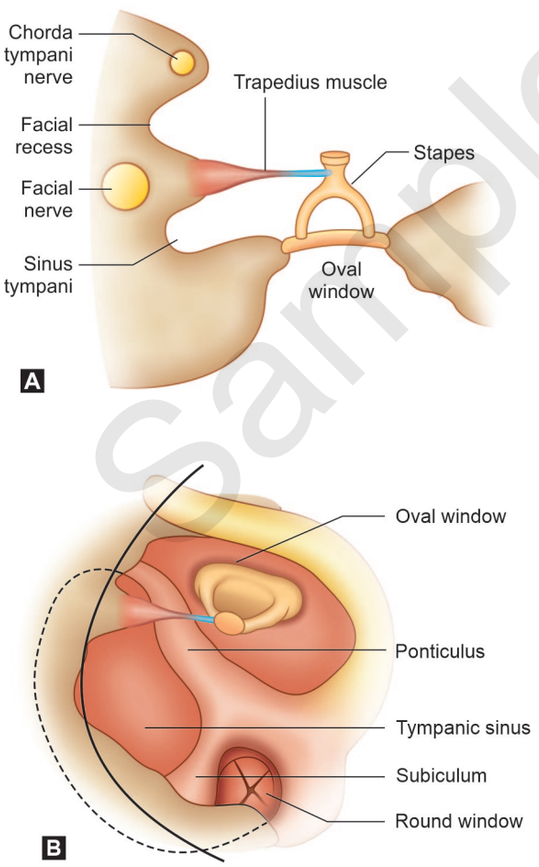
Anterior wall separates middle ear cavity from internal carotid artery. There are various structures passing through the anterior wall to the tympanic cavity. They are as follows:

a. Canal for chorda tympani nerve
b. Canal for tensor tympani muscle
c. Eustachian tube
d. Anterior malleolar ligament
e. Anterior tympanic artery

Posterior Wall

The upper part of the posterior wall shows the opening of aditus, which leads backwards from the posterior epitympanum to the mastoid antrum. Below the aditus there is a triangular bony projection known as processus pyramidalis. Stapedius tendon is transmitted through the apex of the processus pyramidalis. The vertical portion of facial nerve courses down the posterior wall to its exit in the stylomastoid foramen.

- Facial recess **(suprapyramidal recess)** and sinus tympani **(infrapyramidal recess)** (Fig. 2.14).



Figs 2.14A and B: Diagrammatic representation of facial recess and sinus tympani

Two recesses extend posteriorly from the mesotympanum that are often impossible to visualize directly. These spaces, the **facial recess and sinus tympani**, are the most common location for cholesteatoma persistence after ear surgery. The sinus tympani lies between the facial nerve and the medial wall of the mesotympanum and is very difficult to access surgically. The facial recess (suprapyramidal) is lateral to the facial nerve, bounded by the fossa incudis superiorly and the chorda tympani nerve inferiorly, posterosuperior meatal wall laterally and pyramid medially. It may be directly accessed via a posterior tympanotomy approach, through the mastoid (posterior tympanotomy or facial recess approach).

- **Sinus tympani** (infrapyramidal recess): The niche of two labyrinthine windows communicates at the posterior extremity with the deep recess which is known as sinus tympani. Laterally, it is separated from the facial recess by the pyramid.

It is bounded superiorly by subiculum and inferiorly by ponticulum.

Floor

It is formed by a thin plate of bone which separates the middle ear from the bulb of the internal jugular vein lodged in the jugular fossa. In the presence of a bony dehiscence in this area the jugular bulb may come into the middle ear to become a content of it.

Roof

The roof of the middle ear is separated from the middle cranial fossa by a thin plate of bone known as tegmen tympani and tegmen antri.

Ventilatory Anatomy

Normally the middle ear cleft is well ventilated. The air comes through the eustachian tube from the nasopharynx to the anterior mesotympanum. From here the air column goes up to the anterior epitympanum via the isthmus tympanic anticus and then goes backward to the posterior epitympanum. Part of this air passes through the aditus to ventilate the mastoid air cells and part of it comes down via isthmus tympanic posticus to ventilate the posterior mesotympanum. In a well pneumatized mastoid, ventilation of the posterior mesotympanum takes place also through the posterior wall. From the posterior mesotympanum, air percolates to the hypotympanum. Disorder of this ventilatory anatomy has a great bearing in the etiopathogenesis of various inflammatory diseases of the middle ear.

Contents of the Middle Ear (Figs 2.15 and 2.16)

a. **Ossicles:** Three tiny bones which conduct the sound from the eardrum to the oval window.
   - *Malleus* (*hammer*) is the largest and lateral most ossicle measuring 8 mm in length. It has a head,

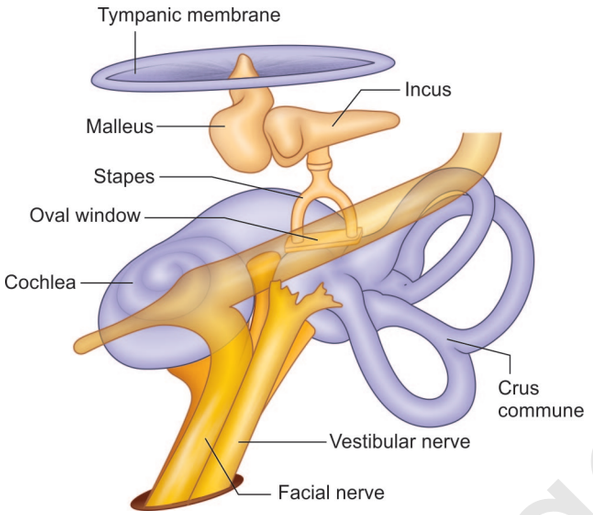
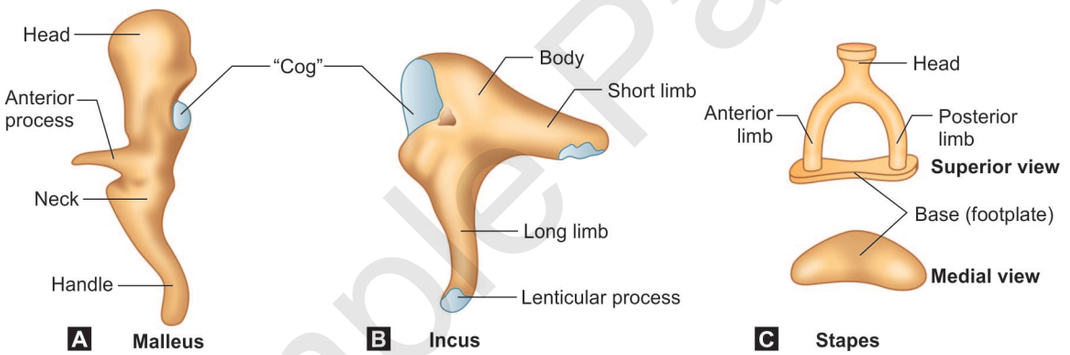


Fig. 2.15: Middle and inner ear with its nerve supply shown as single unit along with tympanic membrane and ossicular chain in relation to middle and inner ear



Figs 2.16A to C: Malleus, incus and stapes from left to right

neck, handle and anterior and lateral processes. The head is situated in the epitympanum. A lateral (short) process projects laterally from the neck while the handle is firmly fixed to the pars tensa of the eardrum.

- *Incus* (*anvil*) has a body, short process and long process. The body articulates with the head of malleus in the attic and the short process projects into the attic. The long process projects downwards behind the handle of malleus, running parallel to it and articulates with the head of the stapes via the lenticular process.
- *Stapes* (*stirrup*) is the smallest ossicle measuring about 3.5 mm and consists of head, neck, footplate and anterior and posterior crura. The footplate of stapes is held to the oval window by the annular ligament.

b. **Muscles**

- The tensor tympani and stapedius muscles decrease the movement of the ossicles.
- The tensor tympani is inserted to the neck of malleus. It is the first arch muscle supplied by branch of mandibular nerve (V3).
- The stapedius is inserted to the neck of the stapes. It is the second arch muscle supplied by branch of facial nerve, i.e. nerve to stapedius.

c. **Mucosal folds and ligaments**—keep the ossicles in place.

d. **Nerves**

- Chorda tympani is a branch of the facial nerve which carries the sense of taste. It enters the middle ear cavity from the posterior wall, runs forwards and lateral to the incus and medial to the malleus, escaping out through the anterior wall.
- The tympanic plexus lies on the promontory. It is formed by the tympanic branch of glossopharyngeal nerve and sympathetic fibers from the plexus around the internal carotid artery. It also carries the secretomotor fibers to the parotid gland (GSP). Tympanic plexus innervates the medial surface

of tympanic membrane, tympanic cavity, mastoid air cells and the bony eustachian tube. Tympanic branch of glossopharyngeal nerve can be sectioned in middle ear for treating the Frey's syndrome.

e. **Vessels:** Plexus of vessels from the stylomastoid artery and caroticotympanic artery.

Mastoid

The mastoid consists of three parts:

1. **Aditus ad antrum** is a short canal connecting the epitympanum with the mastoid antrum. The short process of incus lies on its floor. The facial nerve runs in its canal in the floor, while the lateral semicircular canal lies in the medial wall. The bone lateral to the aditus appears like a bridge during ear operations (Fig. 2.17).
2. **Mastoid antrum** is the largest air cell in the mastoid bone. The antrum is an important landmark in the surgery of the mastoid bone, and is always present.
   - Anteriorly, the antrum receives the aditus. The facial nerve also lies anterior to the antrum.
   - Medially, it is related to the horizontal/posterior semicircular canal.
   - Roof is formed by the tegmen antri.
   - Lateral wall is formed by the cortex of the mastoid bone which lies medial to the suprameatal triangle. Its thickness can be up to 15 mm or 1.5 cm.

   Macewen's (*suprameatal*) *triangle* (Fig. 2.18): It forms bony surface marking of the antrum. It is bounded by the temporal line of supramastoid crest and the posterosuperior bony meatal wall and the line drawn connecting the suprameatal crest and the bony meatal wall.
   Posteroinferiorly, the antrum communicates with numerous mastoid air cells.

   Sinodural angle (*Citelli's angle*): Angle between tegmen antri and sigmoid sinus.
3. **Mastoid air cells** are variable in number, size and distribution. They communicate with the mastoid antrum.

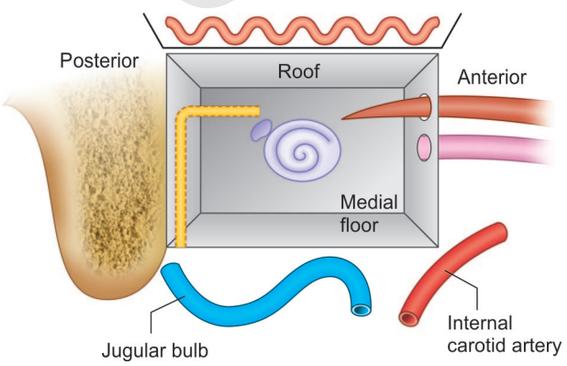


Fig. 2.17: Relation of mastoid with middle ear cavity

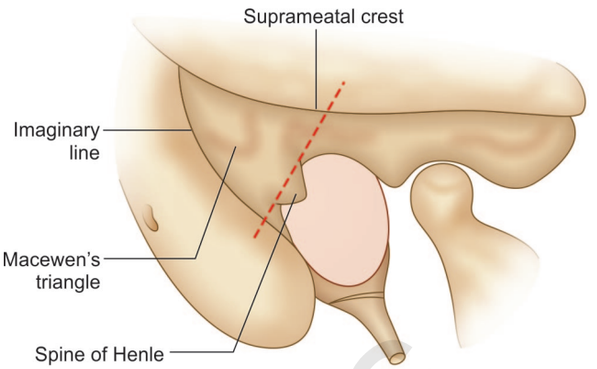
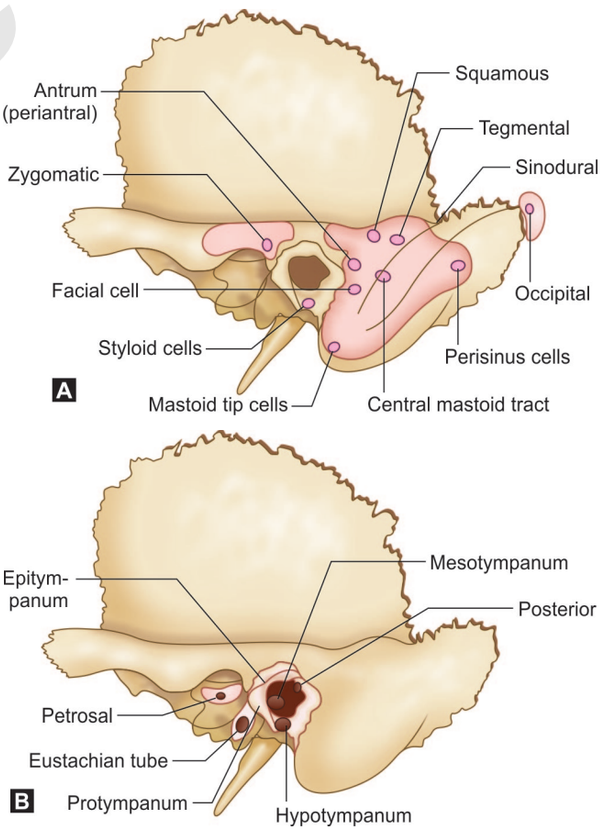


Fig. 2.18: Macewen's triangle

There are three types of mastoid process:

a. Cellular, with large and numerous air cells.
b. Diploic, with small and less numerous air cells.
c. Sclerotic, with air cells practically absent.
   - The cellular mastoid account in about 80% of subjects and is considered to be normal. The diploic and sclerotic types may be due to the blockage of the eustachian tube. The air cells are located mainly in petromastoid and squamous parts of the temporal bone. In a well developed mastoid they are grouped as follows (Fig. 2.19).



Figs 2.19A and B: Different groups of mastoid air cells

2

- **Central group**
  Periantral cells
- **Peripheral group**
  - Dural
  - Perisinus
  - Sinodural
  - Tip
  - Retrofacial
- Labyrinthine group
  Supra and infralabyrinthine cells
- Petrous group: Apical cells
- Accessory group
  - Squamous
  - Occipital
  - Zygomatic
  - Peritubal
  - Styloid

Development of Mastoid

Mastoid develops from squamous and petrous bone. The persistent petrosquamosal lamina (bony plate)—the ***Korner's septum***, is surgically important as it may cause difficulty in locating the antrum. It divides mastoid air cells into medial and lateral groups. Mastoid antrum lies medial to the septum which may be difficult to reach or may lead to incomplete removal of disease during mastoidectomy. So, to reach postero-superior antrum, Korner's septum has to be removed.

Development of mastoid process depends entirely on development of sternocleidomastoid muscle. Hence, its development does not begin until the end of first year of life, when the infants begin to hold their head erect. It does not form a definite elevation until the end of the second year and achieves its definite size only at puberty. So, there is no actual mastoid process at birth and mastoid portion of temporal bone remains flat and stylomastoid foramen remains in surface of mastoid process. The facial nerve will be lying very superficial and may be injured in conventional postauricular mastoid incision. So, to avoid injury to the nerve, postauricular incision has to be done more horizontally.

Relations of the Middle Ear Cleft (Fig. 2.20)

External ear lies lateral to the eardrum.

Temporal lobe of the brain and meninges are above the antrum, aditus and epitympanum. The tegmen plate separates the middle ear cleft from the structures in the middle cranial fossa.

Cerebellum is posteromedial to the mastoid air cells.

Inner ear is medial to the antrum, aditus and tympanum.

Horizontal semicircular canal is an important landmark which lies posterosuperior to the facial nerve.

Fifth and sixth cranial nerves lie close to the apex of the petrous pyramid.

Facial nerve: The horizontal part runs downward in the medial wall of the tympanum. The vertical part runs downward behind the tympanum and in front of the mastoid cells and emerges out through the stylomastoid foramen.

Lateral sinus is posterior to the mastoid cells.

Jugular bulb is in close contact with the floor of the tympanum.

Internal carotid artery is anterior to the tympanum.

Blood Supply (Fig. 2.21)

The blood supply of middle ear is from the branches of

- Middle meningeal artery
- Maxillary artery
- Ascending pharyngeal artery
- Stylomastoid branch of the posterior auricular artery.

Nerve Supply (Fig. 2.21)

Sensory: Tympanic branch of the ninth cranial nerve (Jacobson's nerve) supplies through the tympanic plexus.

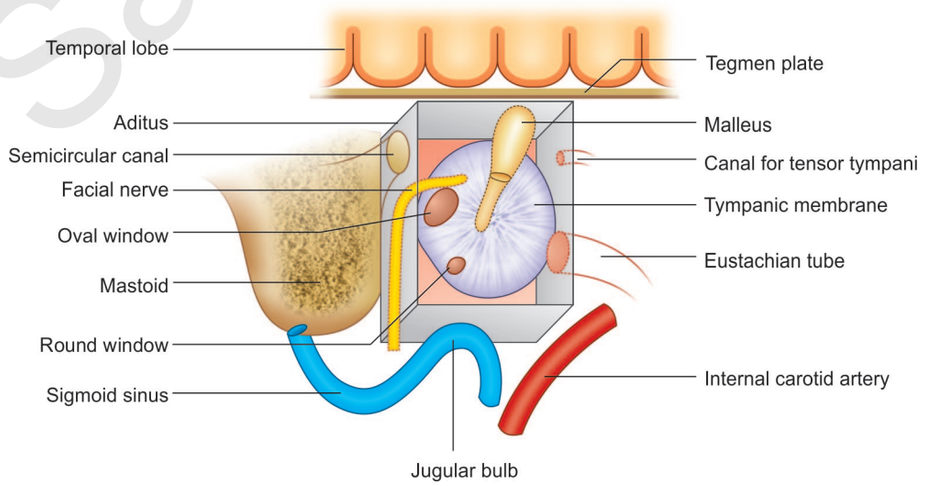


Fig. 2.20: Relation of middle ear cleft

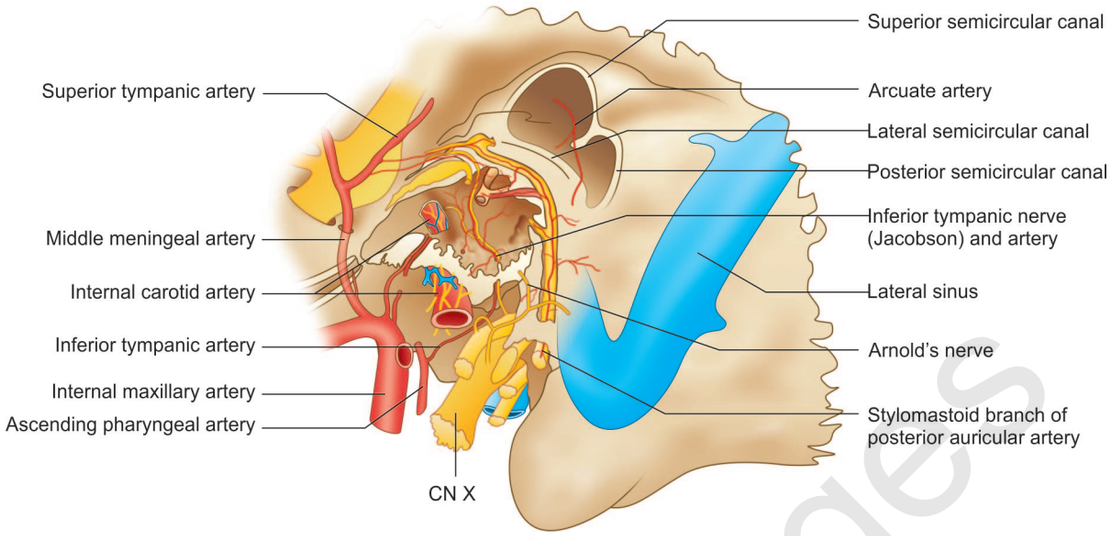


Fig. 2.21: Blood and nerve supply of middle ear

Motor: Tensor tympani muscle is supplied by the mandibular division of the trigeminal nerve and the stapedius muscle is supplied by the facial nerve.

Lymphatic Drainage

The lymphatics drain to the preauricular and the retropharyngeal lymph nodes.

INNER EAR

Development (Refer chapter-1 for details)

It starts in the 3rd week of the intrauterine life and is completed by the 16th week of the intrauterine life.

Membranous labyrinth develops from the otic capsule. This differentiates into various structures, like sensory end organ of hearing and equilibrium.

Bony labyrinth develops from the otic capsule. This is a mesenchymal condensation surrounding the membranous labyrinth. Soon this is converted into cartilage. Between the cartilage and the labyrinth is loose periotic tissue. This tissue disappears around the utricle and saccule to form the vestibule. It also disappears around the semicircular ducts to form the semicircular canals.

In the cochlea, two spaces are formed on either side of the cochlear duct known as scala vestibuli and scala tympani.

Anatomy

The inner ear is well protected and lies inside the petrous temporal bone, between the medial wall of the middle ear and the internal auditory canal. It is composed of:

1. The bony labyrinth has a central part called bony vestibule which is connected anteriorly to the bony cochlea and posteriorly to the three bony semicircular canals (Fig. 2.22).
2. The membranous labyrinth has structures with similar nomenclature as that of bony labyrinth. It floats within the perilymph and contains endolymph within (Fig. 2.23).

Anatomy of the Bony Labyrinth (Fig. 2.22)

Divided into 3 parts

a. Bony vestibule
b. Semicircular canals.
c. Cochlea

a. **Bony vestibule:** Vestibule is the central part of the bony labyrinth and is compared to a standard aspirin tablet (5 mm). It lies between the medial wall of the middle ear and lateral to the internal acoustic meatus, anterior to the semicircular canal and posterior to the cochlea.

On the lateral wall of the vestibule there is a bean-shaped opening called **fenestra vestibuli (oval window)** occupied by the footplate of the stapes and surrounded by annular ligament. On the front half of the medial wall there is a marked depression called **spherical recess**. This is a space for saccule. This wall is perforated by minute holes called **macula cribrosa media** for the passage of the inferior vestibular nerve filaments. Behind is another depression called the elliptical recess **containing utricle**. The two recesses are separated by a **vestibular crest**, the anterior end being the vestibular pyramid. Vestibular crest splits inferiorly to enclose the **cochlear recess** for cochlear nerve filaments. The pyramid and elliptical recess are perforated by small holes called **macula cribrosa**

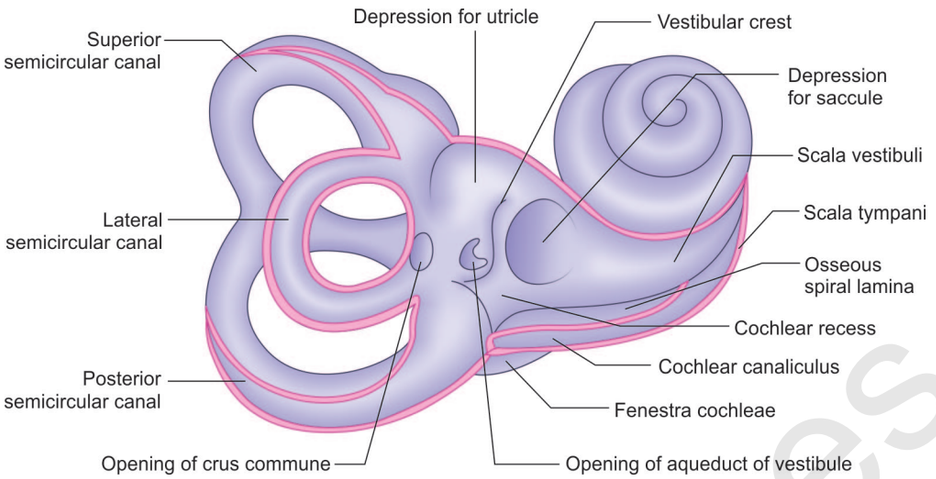


Fig. 2.22: Diagrammatic representation of bony labyrinth

superior, also called **Mike's dot** (it is an important landmark in translabyrinthine approach), for nerves to utricle and ampulla of superior and lateral semicircular canals respectively. Below the elliptical recess, there is a diverticulum called **aqueduct of vestibule** plugged in life by the endolymphatic duct and one or two small veins.

b. **Semicircular canals**

They are three in number:

1. Superior
2. Posterior or vertical
3. Lateral or horizontal semicircular canals.

Each occupies two-thirds of a circle and is unequal in length. The diameter is 0.8 mm. All three canals show dilatation at one end called ampulla containing vestibular sensory epithelium.

Superior semicircular canals length 15 to 20 mm lies transverse to the bony axis of the petrous portion of temporal bone. Anterolateral end is ampullated and opens in the upper lateral part of the vestibule. The other end fuses with the superior limb of the posterior vertical canal to form crus commune, 4 mm length, which opens in the medial part of the vestibule.

The lateral semicircular canal projects as a rounded bulge into aditus and antrum of the middle ear cleft. It is 12 to 15 mm long, lies at an angle of 30° to the horizontal plane. The ampullary end opens into the upper part of the vestibule, posterior end into the lower part below the orifice of the crus commune.

Posterior semicircular canal 18 to 22 mm long lies parallel and very close to the posterior surface of the petrous portion of the temporal bone. Lower ampullated limb opens into the lower part of the vestibule and the upper limb joins the crus commune. The angle formed by three semicircular canal is solid angle, whereas the triangle bounded by the bony labyrinth anteriorly, sigmoid sinus posteriorly and dura superiorly is known as Trautmann's triangle, which is a weakest part.

c. **Cochlea:** Cochlea resembles a common snail. It forms the anterior portion of the bony labyrinth.

It is 5 mm from base to apex and 9 mm around its base, length of the tube is 30 mm. It is a hollow tube having two and three-fourths turns around a conical central axis called 'modiolus'. The base of modiolus is directive toward internal auditory meatus and is perforated for the passage of cochlear nerve. The cochlea and the semicanal of the tensor tympani muscle are located just above the genu of the internal carotid artery. The osseous spiral lamina winds around modiolus and along the basilar membrane, it separates the scala media (cochlear duct) from scala tympani. Within this bony canal lies the membranous cochlear duct. There are three longitudinal channels within the cochlea: Scala vestibuli above, scala tympani below and scala media in between. Scala vestibuli communicates with scala tympani at the apex of the cochlea called helicotrema.

Scala vestibuli is in continuity with the vestibule at the oval window closed by the stapes footplate. Scala tympani is separated from the tympanic cavity by the secondary tympani membrane at the fenestra cochleae. The modiolus is a central structure with a perforated bony core that accommodates nerve fibers from the hair cells, as well as blood vessels.

It is continuous with the internal auditory meatus at the medial end. The nerve for the first turn and three-fourths of the cochlear tube pass through the peripheral tractus spiralis foraminosa. At once the nerves pair off towards the margin of ganglion and from here nerves communicate via the osseous spiral lamina with the organ of Corti.

Anatomy of the Membranous Labyrinth
(Figs 2.23 and 2.24)

The membranous labyrinth can be broadly divided into three parts based on physiology:
1. Membranous vestibular labyrinth
2. Membranous semicircular canal
3. Membranous cochlear labyrinth

The membranous labyrinth contains endolymph and the specialized vestibular and cochlear receptors. It lies within the bony labyrinth, floating on the perilymph.

1. *Membranous Vestibular Labyrinth*

It consists of:
- Saccule
- Utricle
- The endolymphatic duct and sac.

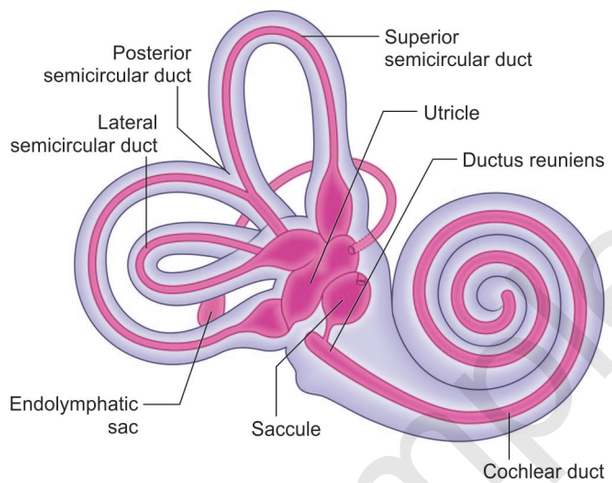


Fig. 2.23: Membranous labyrinth shown floating inside the bony labyrinth

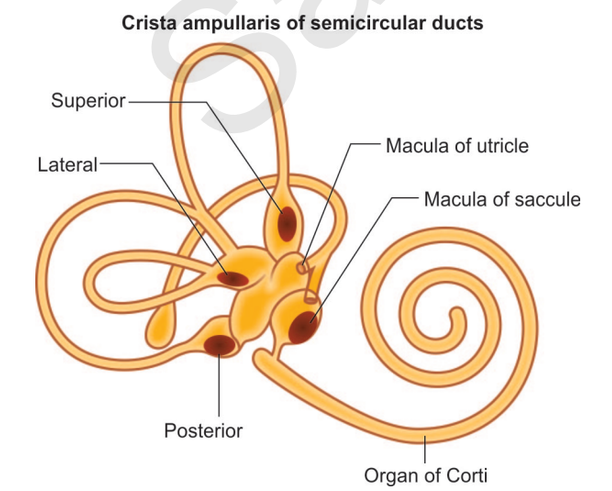


Fig. 2.24: Specialized epithelium in the membranous labyrinth

Saccule is connected to the cochlear labyrinth by the membranous cochlear reuniens. Saccule and utricle are connected to each other indirectly by the endolymphatic duct. Saccule occupies the spherical recess in the bony vestibule and it contains specialized vestibular epithelium. Utricle is bigger in size than the saccule and occupies the elliptical recess of the bony vestibule.

The three semicircular canals open into the posterior wall of the utricle by five openings. The utricle and saccule communicate with each other via the utriculosaccular duct to which the endolymphatic duct opens.

Vestibular receptor organs
- Macula (utricle and saccule)
- Cristae (ampulla of semicircular canals)

Macula
Vestibular receptor organs of the saccule and utricle are called macula. Macula of the saccule lies vertically in the medial surface of the saccule, whereas in the utricle it lies horizontally. These specialized vestibular receptor organs are composed of hair cells, supporting cells and gelatinous mass (Fig. 2.25).

This gelatinous mass is composed of mucopolysaccharides thought to be secreted by the supporting cells. Macular gelatinous mass contains additional materials made up of calcium carbonate crystals known as otolith or statoconia. Hence, the gelatinous mass is sometimes known as statoconial membrane.

2. *Membranous Semicircular Canal*

Cristae ampullaris: The membranous semicircular canal is suspended within the bony semicircular canals. It opens through the five openings into the posterior wall of the utricle (Fig. 2.24). Crista is a saddle-shaped ridge within each membranous ampulla which is seen in the dilated part of the bony semicircular canal. It is a sensory end organ covered by neuroepithelium with hair cells and sensory cells and gelatinous mass (Fig. 2.26). The gelatinous mass in the cristae is dome-shaped hence called cupula.

The hair cells are of two types (Fig. 2.27):

Type 1 cells are flask-shaped enclosed with nerve chalice. Type 1 cells are predominantly seen in the summit of the cristae.

Type 2 cells are cylindrical with no nerve chalice. Type 2 cells are found more towards the periphery in the cristae.

The hair cells consist of one kinocilium which is tall and prominent; many small cilia (60–110) known as steriocilia which are smaller than the kinocilium. The kinocilium in the macula is not uniformly

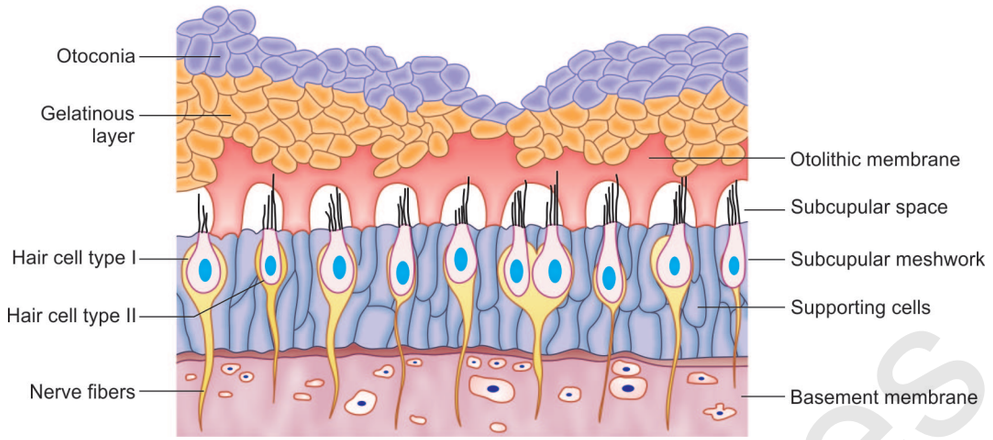


Fig. 2.25: Microscopic structure of macula

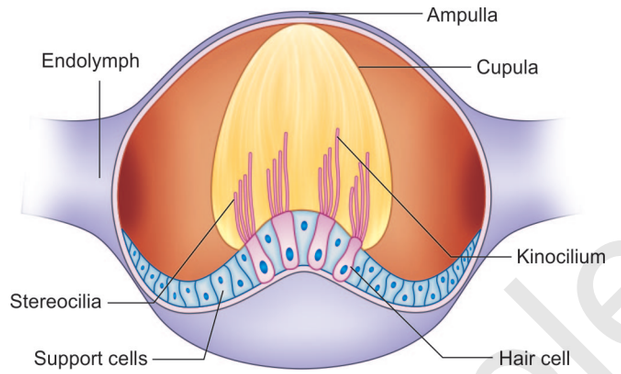


Fig. 2.26: Structure of ampullary end of semicircular duct over the crista lie sensory hair cells interspersed with supporting cells. Hair from sensory cells projects into the gelatinous substance of cupula

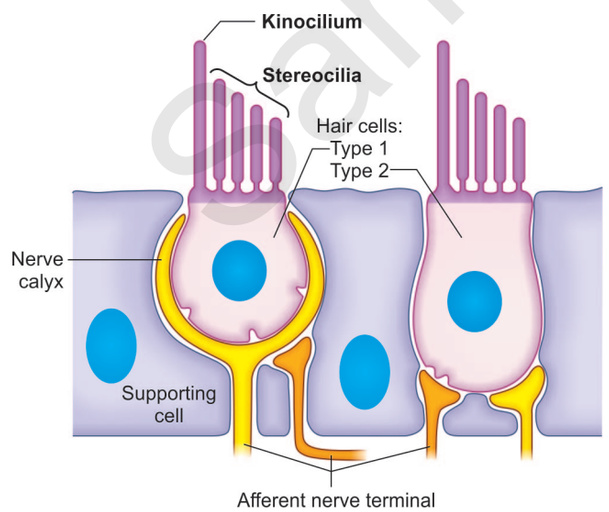


Fig. 2.27: Kinocilia and stereocilia type 1 (flask-shaped cell) and type 2 (cylindrical cell)

arranged. A curve line called striola divides each macula into medial and lateral halves.

3. *Membranous Cochlea*

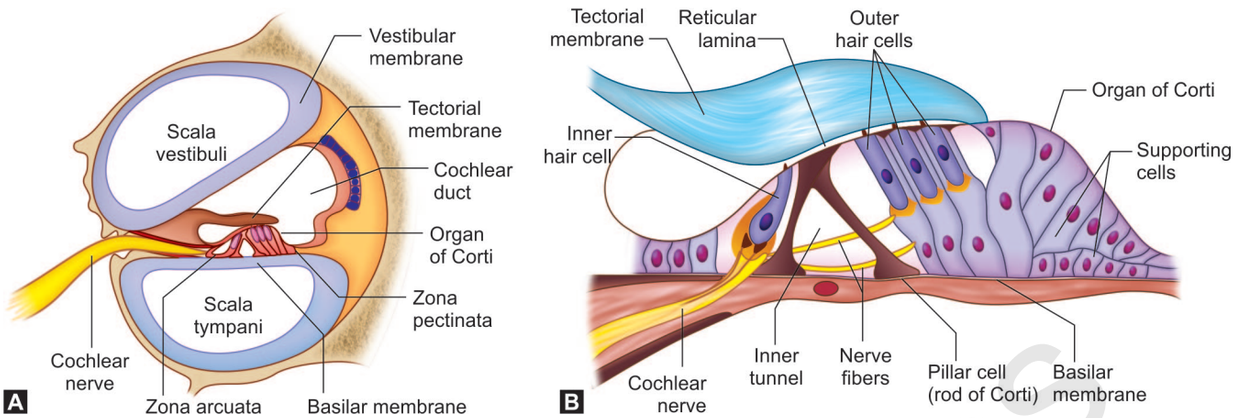
Cochlear duct (scala media): It occupies mid-portion of the cochlear canal and is triangular in cross-section. Floor is formed by basilar membrane, roof by Reissner's membrane and lateral wall by stria vascularis and bony wall of cochlea. Basilar membrane supports organ of Corti, containing the sound receptors.

The thin area of basilar membrane in its inner part is called zona arcuata, thicker outer part is zona pectinata.

Organ of Corti is spread like a ribbon along the entire basilar membrane. It consists of the tunnel of Corti which is composed of two rows of rods of inner and outer hair cells. It forms a triangle with the basilar membrane and contains cortilymph. There is one row of inner hair cells in contrast to the 3–4 rows of outer hair cells. Inner rods are 3500 and outer rods are 12000. Rods are expanded like a cap on top. Sensory cells arranged in two groups as inner and outer hair cells. In the fetus and newborn, there are 3500 inner hair cells and 13000 outer hair cells. As age advances there is generalized reduction in the number of hair cells. Hair cells are supported by pillar cells, Deiter's cells and Hensen's cells. The tips of the outer hair cells are attached to the undersurface of tectorial membrane (Figs 2.28A and B).

Tectorial membrane: It consists of gelatinous matrix with delicate fibers, that overlies the organ of Corti. The shearing force between the hair cells and tectorial membrane produces stimulus to hair cells.

Lateral wall 'stria vascularis': It is thought to play an active role in the maintenance of the ionic composition and electrical potential of the endolymph.



Figs 2.28A and B: (A) Structure of organ of Corti; (B) Diagrammatic microscopic view of organ of Corti

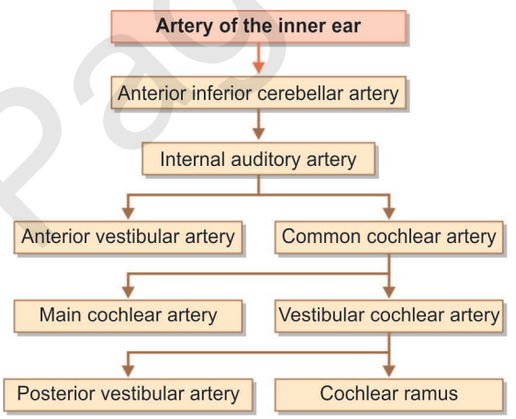
Blood Supply of Inner Ear

(Fig. 2.29 and Flowchart 2.1)

Internal auditory artery arises from the anterior inferior cerebellar artery (AICA). It accompanies the facial and vestibulocochlear nerves in the internal acoustic meatus and usually divides into three branches to supply the inner ear:

- Anterior vestibular artery to supply the macula of utricle and crista of superior and lateral semicircular canals.
- Vestibulocochlear branch to supply the posterior semicircular canal.
- Cochlear branch to supply the cochlea.

Flowchart 2.1: Blood supply of inner ear



AUDITORY PATHWAY

First order neurons are located in the spiral ganglion and are bipolar (Fig. 2.30). Peripheral processes innervate the organ of Corti and central processes terminate in the dorsal and ventral cochlear nuclei (Fig. 2.31).

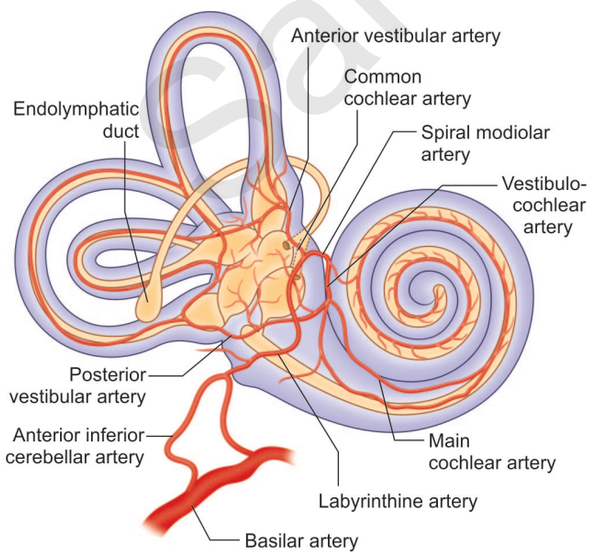


Fig. 2.29: Blood supply of inner ear

Second order neurons lie in the dorsal and ventral cochlear nuclei. Most of the axons crossover in the trapezoid body and terminate in the superior olivary nucleus. Many end in the trapezoid body or lateral lemniscus and some remain uncrossed.

Third order neurons lie in the superior olivary nucleus. The axons cross from lateral lemniscus and reach the inferior colliculus.

Fourth order neurons lie in the inferior colliculus. Their axons pass through the inferior brachium to reach the medial geniculate body (some fibers directly reach the medial geniculate body).

Fifth order neurons lie in the medial geniculate body. Their axons form the auditory radiation which passes through the part of the internal capsule to reach the auditory area in the temporal lobe.

Vestibular Pathway (Fig. 2.32)

Vestibular receptors are the macula of the saccule and utricle and the cristae of the ampullae. They are innervated by the peripheral processes of bipolar neurons of the vestibular ganglion which is situated in

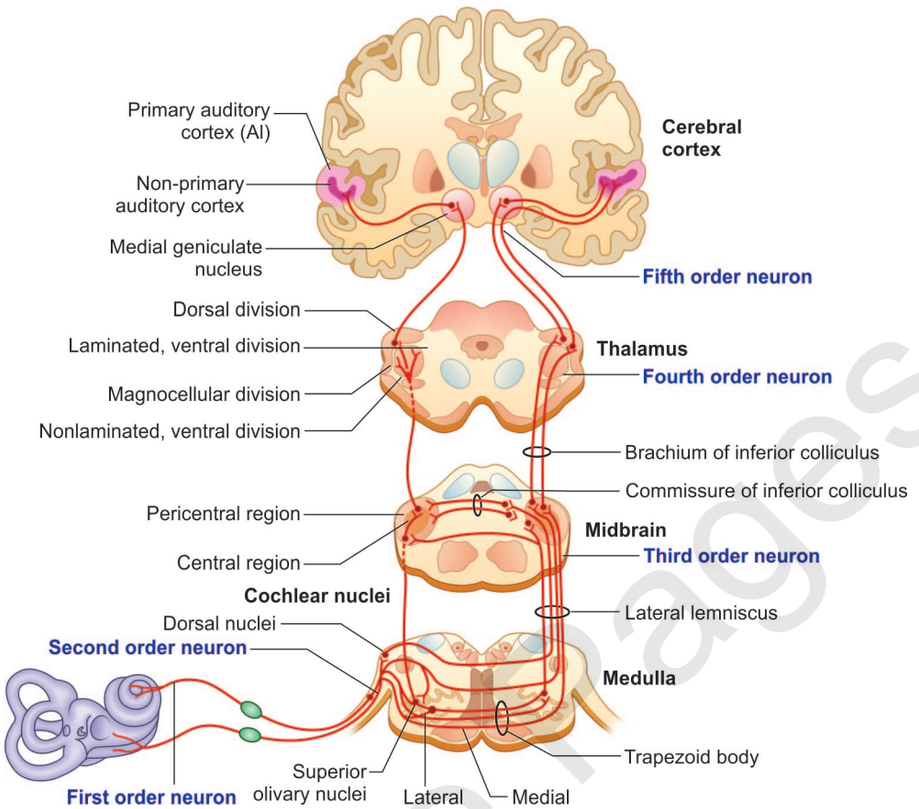


Fig. 2.30: The auditory pathway

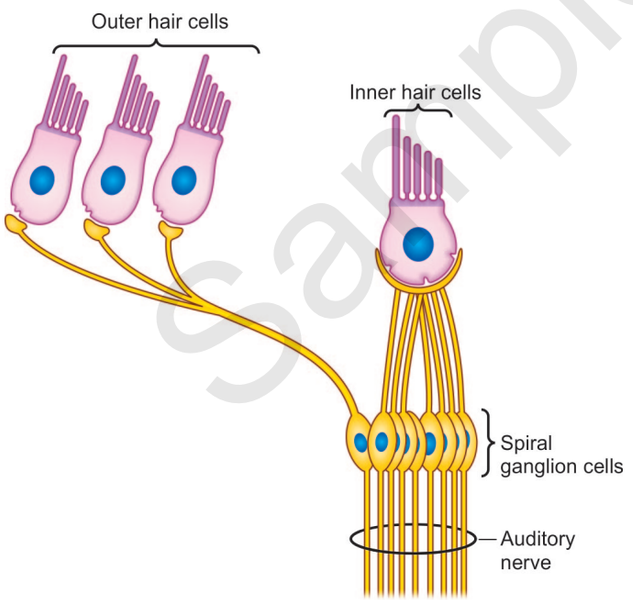


Fig. 2.31: First order neuron starting from hair cells to spiral ganglion cells and auditory nerve

the internal acoustic meatus. The central processes form the vestibular nerve which ends in the vestibular nuclei (Flowchart 2.2).

Second order neurons lie in the vestibular nuclei. These send fibers to the following:

1. Archicerebellum through inferior cerebellar peduncle (vestibulocerebellar tract).
2. Motor nuclei of brainstem (chiefly 3, 4 and 6) through the medial bundle.
3. The anterior horn cells of the spinal cord through the vestibulospinal tract. The impulses arising in the labyrinth can influence the movement of eyes, head, neck and trunk through the vestibular pathway.

Internal Auditory Canal (Fig. 2.33)

Internal auditory canal (IAC) is lined by dura. It is nearly 1 cm in length. It passes in the petrous temporal bone in lateral direction. The lateral end (fundus) of the canal is closed by cribriform plate having numerous apertures through which the auditory nerve, facial nerve, vestibular nerve, internal auditory artery and vein pass.

Fundus is divided by a vertical plate of bone which separates it from the inner ear. On the medial aspect, the plate is divided by transverse crest into smaller upper and larger lower area. Anteriorly above the crest is opening of facial canal, behind this and separated from it by a vertical ridge called Bill's bar is the superior vestibular area. It shows a small depression containing

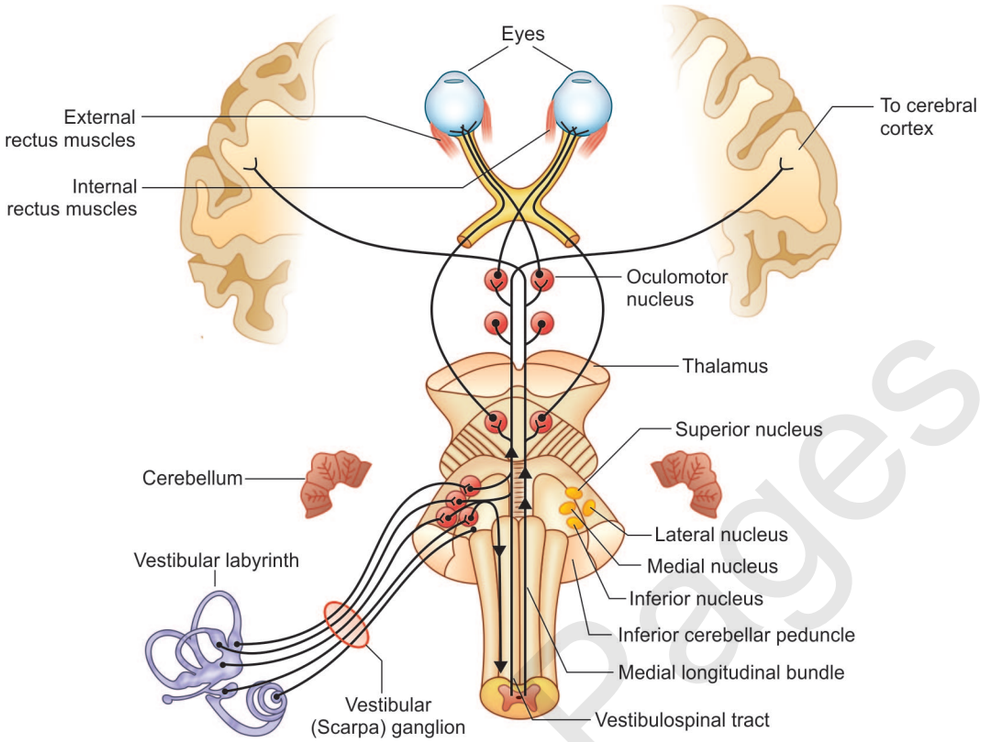
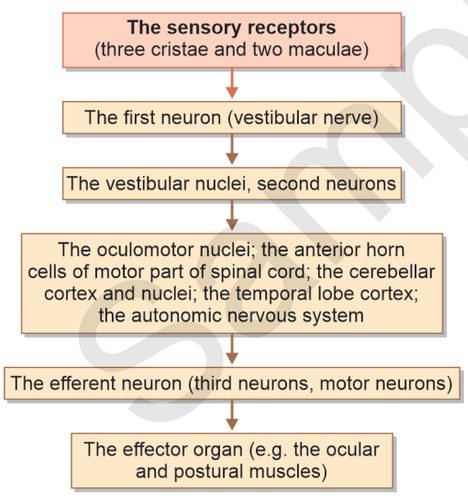


Fig. 2.32: The central connection of the vestibular nerve

Flowchart 2.2: The multisynaptic vestibular arc



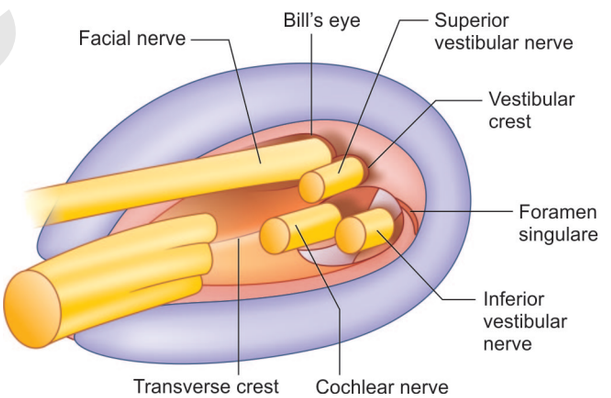


Fig. 2.33: Cross-section of internal auditory canal

numerous opening for the passage of filaments of vestibular nerve to utricle, saccule and superior, lateral semicircular canal. Below the transverse crest anteriorly lies the cochlear nerve. Inferior vestibular nerve lies behind cochlear nerve which carries fibers to the saccule. Foramen singulare lying behind and slightly below the inferior vestibular nerve through which singular nerve passes to supply posterior semicircular canal.

Points to Remember

1. Incisura terminalis in situated between the crus of helix and tragus, and is devoid of cartilage.
2. The skin on the outer surface of the pinna is firmly adherent to the perichondrium of the cartilage.
3. The malleolar folds separate the pars tensa from the pars flaccida.
4. The tympanic membrane is pearly white in color and lies at an angle of 55° with the floor of the meatus.
5. Middle ear cleft consists of eustachian tube, tympanic cavity and mastoid air cell system.
6. The eustachian tube is more horizontal and relatively wider and shorter in children.
7. Macewen's triangle is a surgical landmark for the mastoid antrum.

Textbook of
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