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Review Article

The middle ear cleft-embryological and anatomical aspects: a review

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ABSTRACT

The air in the middle ear cleft serves as an air cushion with its tympano-ossicular system serving to match the impedance of the inner ear fluids and thus compensate for the loss of sound energy during transmission in media of different densities. The tympanic membrane on one side and the pressure equalizing eustachian tube on the other are the vital constituents of this cleft. The embryology and components developing from the ecto, meso and endoderm layers are elaborated upon.

Keywords: Innervation, Musculature, Middle ear cleft, Tympano-ossicular system, Vascularity

INTRODUCTION

The mastoid air cell system, middle ear and the eustachian tube constitute the middle ear cleft. The external ear collects the sound waves to funnel them on the tympanic membrane from where they are channelized through the malleus-incus and the stapes into the bony labyrinth. Here there is sequential transmission in various fluids, namely the peri, endo and the corti lymph to finally make the basilar and tectorial membranes vibrate and convert mechanical to electrical neural signals that finally reach the auditory cortex through the neural pathways in the brain stem. The middle ear muscles reflexly contract to prevent excessive sound pressures that might damage the middle and inner ear auditory pathways.

REVIEW OF LITERATURE

Embryology

Auricular development is initiated at the fourth week of the second half of the embryonic phase. The "Colliculi of His" are six hillocks that develop in less than two weeks. At 4 weeks the external ear begins to increase in size. The posterior hyoid arch and the anterior mandibular arch are formed at seven weeks when the six hillocks unite into two folds.

The union of these two folds creates the external ear. At about nine weeks mesoderm proliferates between the first pocket's endoderm and "meatal plate." thus creating a fibrous tympanic membrane layer. The outer portion of the "meatal plate." constitutes the epidermal tympanic membrane." During the ninth week, concurrently the "meatal plate," a bony structure develops.

In development of the middle ear cavity there are three distinct phases which merge into each other, namely primary tympanic cavity formation, tympanic atrium development to be followed by the antrum, mastoid cavity and the epitympanic recess.[1] At 9–22 weeks, the ossicles begin to grow. At 20 weeks of gestation ear drum, external auditory canal and ossicles are entirely formed.[2] The facial nerve is too positioned correctly.

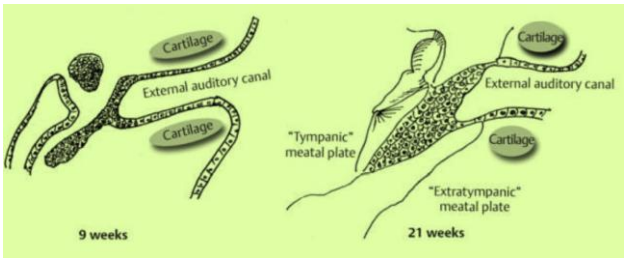

Figure 1: Embryonic development of eardrum from week 9th to week.[10]

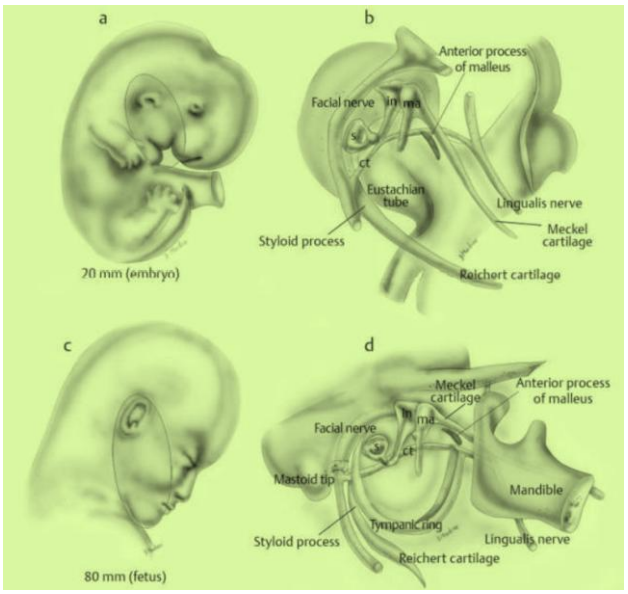

Figure 2: Derivatives of the branchial arches.[2]

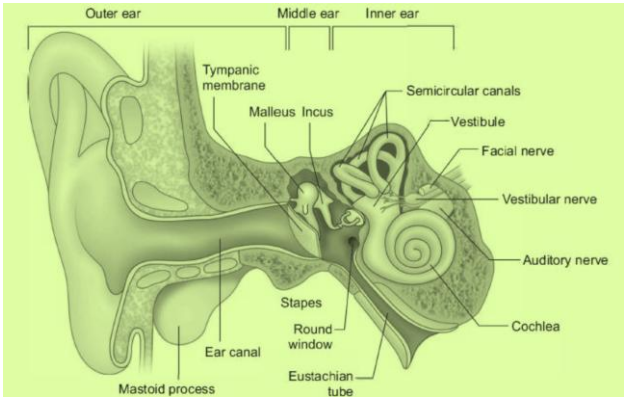

Figure 3: External, middle and the inner ear-Cross-sectional view.[8]

Formation of middle ear spaces and folds

Where the middle ear gaps begin to form between the third and seventh month, lies the eustachian tube opening. These gaps ultimately extend toward the middle ear cleft.

Four sacci or pouches, form from the terminal end of the first pharyngeal pouch, the *Saccus anticus*, Saccus medius, saccus superior and *Saccus posticus*.[3] *Saccus anticus*, the smallest saccus forms the anterior pouch of Von Tröltsch and is located anterior to the tensor tympani tendon.[4] Saccus medius forms the attic. There are three separate sacci. The anterior compartment of the attic may be formed by the anterior saccus. A posterior attic is formed by the medial saccus. The antrum and mastoid cells are formed by the posterior extension of the saccus posterior.[5] The superior saccus creates the posterior pouch of von Tröltsch and the Prussak space. Koerner's septum, a bony barrier, is the result of the fold in the antrum that continues to develop between the saccus medius and saccus superior.

Saccus posticus

This muscle extends inferiorly to the middle ear, forming the majority of the oval window niche, the sinus subtympanic us, the round window niche, the sinus tympani and the posterior tympanic sinus.[6]

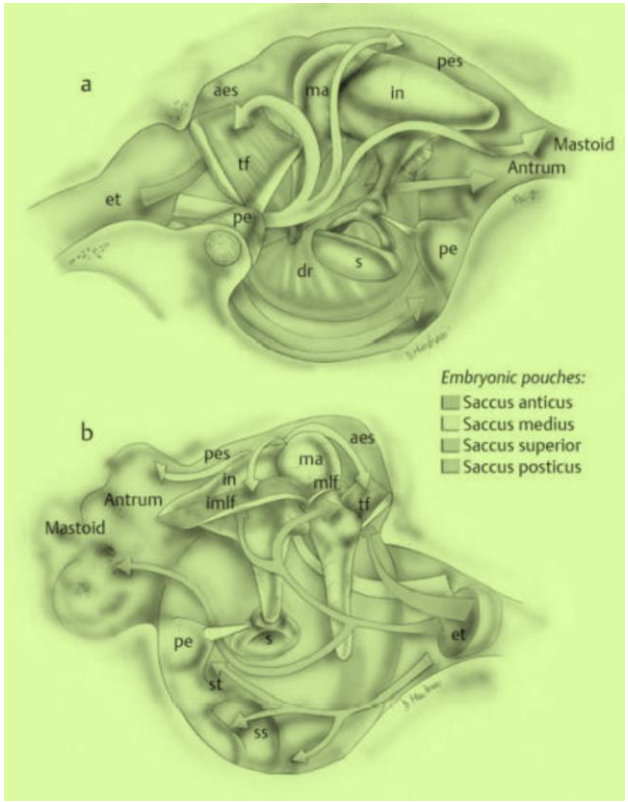

Figure 4: Tympanic cavity cavitations arising from the embryonic pouches.[7]

ANATOMY OF MIDDLE EAR CLEFT

The mastoid air cells, mastoid antrum, aditus, attic, middle ear cavity and the eustachian tube constitutes the middle ear cleft.

The eustachian tube

The eustachian tube joins the middle ear cavity to the pharynx and is lined by the ciliated columnar epithelium.

The pharyngeal orifice is situated 1.5 cm behind the lateral wall of the nasopharynx, at the level of the posterior end of the inferior turbinate and measures about 33 mm in length in normal adults. The three parts, bony, cartilaginous and the junctional measure 6.5 mm, 23.5 mm and 3 mm respectively.[8,9] This bony wall is dehiscent in 2% individuals, exposing thus the carotid artery.[10]

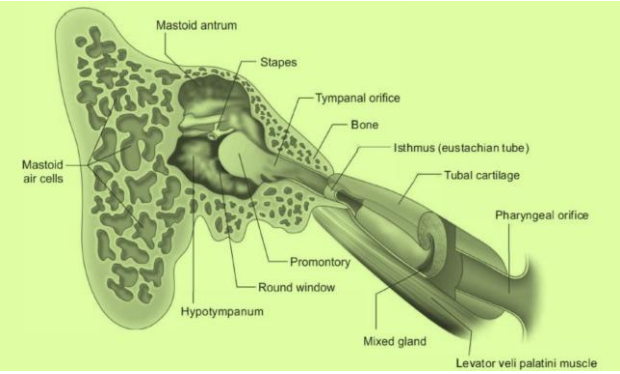

Figure 5: The middle ear cleft schematic representation.[8]

The middle ear cavity

The middle ear is six-sided chamber embedded between the inner ear medially and the tympanic membrane laterally.[1] The *Tegmen tympani*, that forms the roof is a thin plate of bone partially from the petrous and partially from the squamous part of the temporal bone. The tignum transversum, the main structural component that supports the legmen, is a bony log forms at the point where the petrous and squamous plates fuse. The cog is formed by the anterior extension of the tignum transversum. The legmen separates the middle ear air inferiorly and the cerebrospinal fluid superiorly.[11] The floor has a thin bone that constitutes the hollow of the jugular fossa, which lodges superior bulb of the internal jugular vein. The Jacobson's nerve, a branch of the glossopharyngeal nerve (CN IX) and the inferior tympanic artery are transmitted through the inferior tympanic canaliculus, a small canal located between the carotid artery and the jugular bulb close to the medial wall.[12]

The lateral wall is formed by the tympanic membrane in most of its part. However, the tympanic bone demarcates the tympanic cavity from the medial portion of the temporomandibular joint inferiorly. The superior scutum, also known as the outer attic wall, is a partition of bone.[13] The tympanic membrane, is an elliptical shaped thin, pearly grey membrane oriented at an angle of 45° with the floor of the external auditory canal and separates canal from the middle ear. The inferior most part of the malleus, the umbo, attaches to the ear drum, where the membrane peaks in convexity as it approaches the middle. It is 8 to 9 mm wide, 9 to 10 mm high and 0.1 mm in thickness. It is divided into pars flacida and the pars tensa.

Most of the tympanic membrane is called the pars tensa. It thickens at the periphery to produce the annulus tympanicus, which is firmly embedded in the tympanic sulcus, a bony groove. This groove has a deficiency superiorly in the shape of a notch known as the Rivinus notch.

The malleus is integrated in the middle layer of the membrane. There are three layers the. outer epidermal layer that extends in continuity with the squamous epithelium of the external auditory canal. There is a thicker keratinized layer in the postero-superior region. The middle fibrous layer has tangential fibers, inner circular (*Stratum circulare*) and outer radiating fibers (*Stratum radiatum*), related to the tympanic bone and the malleus handle.[14,15] The former are fixed to the manubrium, while the latter are attached to the manubrium in a concentric arrangement. The Inner mucosal layer, overlapping with middle ear mucosa. The superior portion of the tympanic membrane is called Pars Flacida or the Shrapnel's membrane' which is dull red in color. The anterior and posterior malleolar folds separate it from the pars tensa. The fibrous layer is minus in this area and facilitates moment of the malleus head. The lamina propria of the pars flaccida is composed of a modest number of collagenous and elastic fibers oriented in an irregular manner.[16]

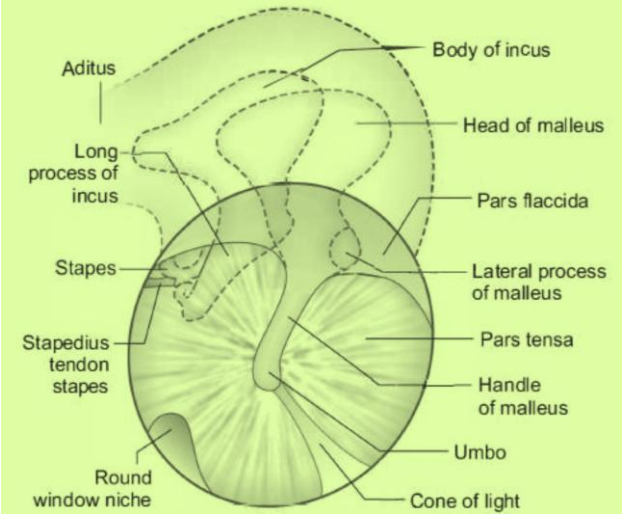

Figure 6: Lateral wall of tympanic cavity and relation to the middle ear ossicles (right ear).[13]

Nerve supply

The tympanic plexus innervates the inner, auriculotemporal nerve the outer anterior portion and the auricular branch of the vagus nerve the outer posterior surface. The anterior wall is narrow inferiorly where the internal carotid artery lies and the lower cavity is divided from the carotid canal by a thin plate of bone. The upper section of the anterior wall has two orifices. The eustachian tube orifice is inferior while the tensor tympani are superior. The two openings, the Gasserian

fissure, situated below, transmits the tympanic artery and the anterior ligament of the malleus and the Huguier canal above, transmits the chorda tympani from the middle ear.

The middle ear and inner ear are divided by the medial wall. The promontory is the protruding portion of the medial wall overlying the basal turn of the cochlea. The tympanic plexus, also known as Jacob's nerve, splits off the surface of the promontory and enters the temporal bone through the tympanic canaliculus, directly in front of the jugular foramen. The horizontal portion of the facial nerve travels in the fallopian canal antero posteriorly above the promontory. This canal extends from above the cochleariform process anteriorly down below and medial to the dome of the lateral semicircular canal, running obliquely over the promontory and above the oval window in antero-posterior direction. In the posterior wall of the tympanic cavity. It has its second genu at the intersection of the horizontal tympanic portion and the vertically descending mastoid portion. The bony facial canal in the medial wall may be dehiscent; leaving the nerve exposed covered merely by the sub mucosa or may prolapse over the oval window.

During otosurgery, this is quite vulnerable to trauma. In patients with an exposed facial nerve, facial palsy can even occur from infections of the middle ear mucosa. The processus cochleariformis is an anterior projection, a landmark to first genu of the facial nerve. Lateral semicircular canal lies in the medial wall of the attic just above the facial nerve canal. The dominant structure in the posterior epitympanum is the dome of the lateral semicircular canal, which extends lateral to the facial canal.

The ponticulus and subiculum are two bony ridges that divide the three depressions that make up the medial wall, also referred to as the surgical floor of the middle ear. The stapes footplate closes the oval window region or fenestra vestibule, located in the groove above the ponticulus. The secondary tympanic membrane, i.e., the round window membrane, seals the round window region or fenestra cochlea, which is the groove beneath the subiculum. The sinus tympani, is bordered medially by the medial wall of the tympanum and laterally by the mastoid section of the facial nerve. In fact, it is the space between the ponticulus superiorly and subiculum inferiorly.[13]

The fissula ante fenestram is an appendage of the perilymphatic labyrinth and is a strip of periotic connective tissue extending from the vestibule just anterior to the oval window through an irregular still-like space in the bony otic capsule to unite with the mucoperiosteum of the tympanic cavity below the pulley of the tensor tympani muscle. The oval window is a rene shaped opening on the medial wall closed by the footplate of the stapes. The oval window averages 3.25 mm long and 1.75 mm wide.

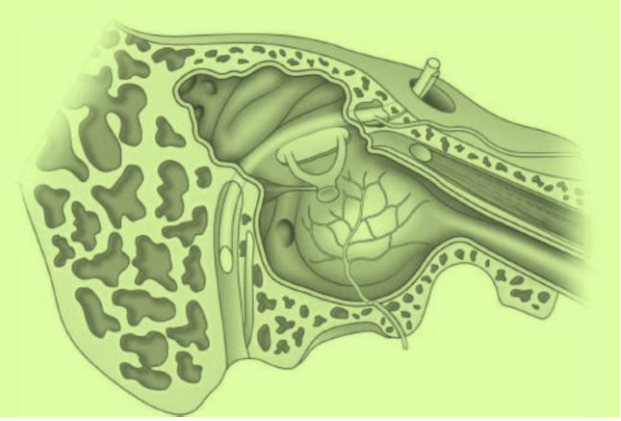

Figure 7: Medial wall of middle ear (Right ear).[8]

A point approximately one-third of the way between the oval window and the non-ampullated end of the lateral semicircular canal is recognised as the post-fenestram, where the periotic tissue evaginates into the otic capsule.[12] Positioned poster inferior on the promontory in the medial wall of the tympanic cavity, lies the round window that is the second opening of the bony labyrinth leading to the middle ear. A membrane closes the round window niche. The subiculum separates the round window niche from the promontory and is never more than 2 mm from the oval window.

The round window niche is typically triangular in shape with anterior, poster superior and poster inferior aspects and depth ranging up to 1 mm.[17] The posterior wall of the middle ear is the tallest measuring about 14 mm. At the aditus ad antrum area, it is absent and permits communication between the attic and the mastoid antrum, it develops from the petrous bone and demarcates the middle ear from the mastoid air cells. The posterior wall can be divided into two portions, the lower two thirds, which correspond to the posterior wall of the retro tympanum and the upper third, which marks the posterior limit of the epitympanum and the aditus ad antrum. Incudal buttress, is a compact bone extending from the tympanic ring laterally to the lateral semicircular canal medially, divides the two halves. Its upper surface contains the incudal fossa, where the short process of incus is seated.[12] The aditus ad antrum, that connects the mastoid antrum to the epitympanum, is located superiorly. The stapedius tendon is transmitted to its insertion at the stapes neck by the pyramidal process, a tiny conical projection just inferior to the aditus.

The chorda tympani nerve enters lateral to and beneath the pyramid. The facial recess is bounded medially by the vertical portion of the facial nerve, superiorly by the short process of incus in the fossa incudis and laterally by the postero-superior section of the tympanic annulus and the chorda tympani.[18] The pyramidal, chordal and styloid eminences are protrusions of the posterior wall. The chordal ridge of Proctor, the pyramidal ridge, the styloid

ridge, the ponticulus and the subiculum are ridges of on the posterior wall.[12]

CONTENTS OF THE MIDDLE EAR CAVITY

Ossicles

The largest ossicle is the malleus, with its head, neck and the handle, ad measures up to 9 mm. The epitympanum lodges the head. The chorda tympani cross the malleus handle on its medial aspect and the lateral process receives the anterior and posterior malleolar folds. The malleus handle has an umbo at its inferior end and traverses between the mucosal and fibrous layers of the tympanic membrane, downward, medially and somewhat backward.[8]

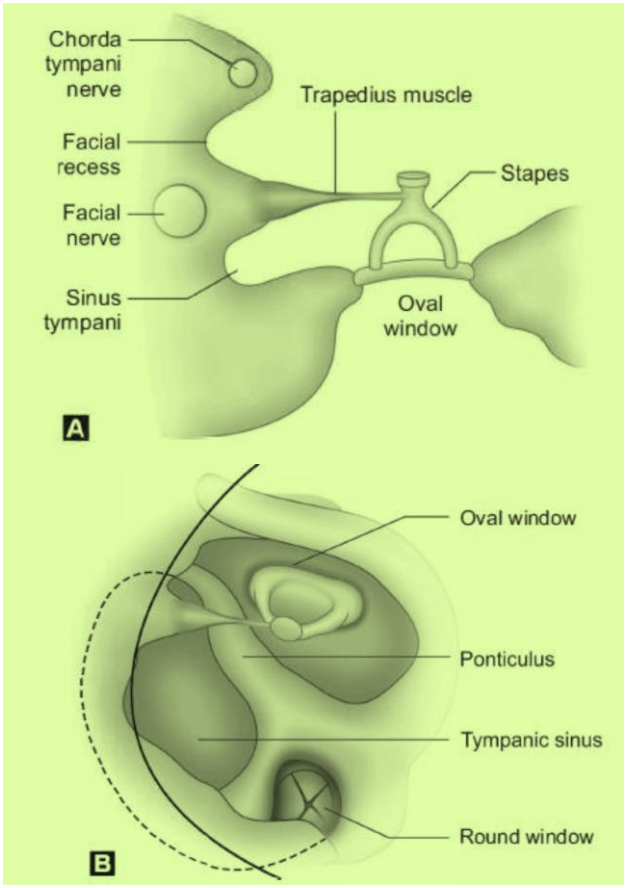

Figure 8 (A and B): Schematic representation of facial recess and sinus tympani.

There are two, the short and the long processes and a body of the incus. The lenticular process articulates with the head of the stapes head as it descends into the mesotympanum. Head, neck, the two crura and the footplate constitute the stirrup-shaped stapes with the stapedius tendon inserted on the neck. The annular ligament lines the oval window.

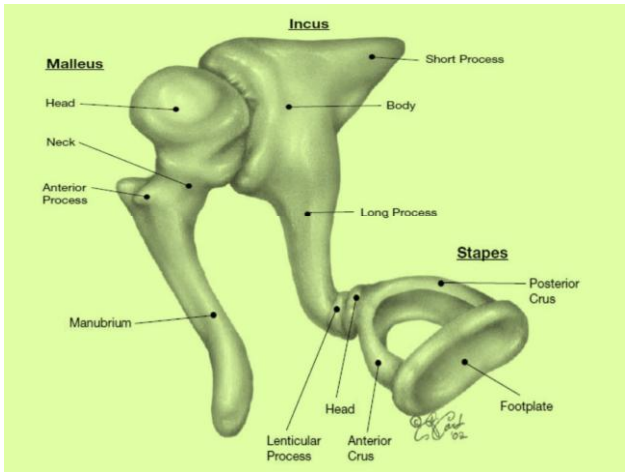

Figure 9: Ossicles of the ear.[9]

Muscles of middle ear

The stapedius muscle is attached to the head of stapes after exiting as a thin tendon from the top of the pyramidal process. The stapedius nerve, a branch of the facial nerve, innervates this muscle. The bony canal, the cartilaginous section of the eustachian tube and the greater wing of the sphenoid give origin to the tensor tympani muscle. It enters the middle ear and hinges on the medial wall prior to winding laterally around the processus cochleariformis and finally inserts on the upper end of the handle of the malleus. The mandibular nerve innervates this muscle.[9]

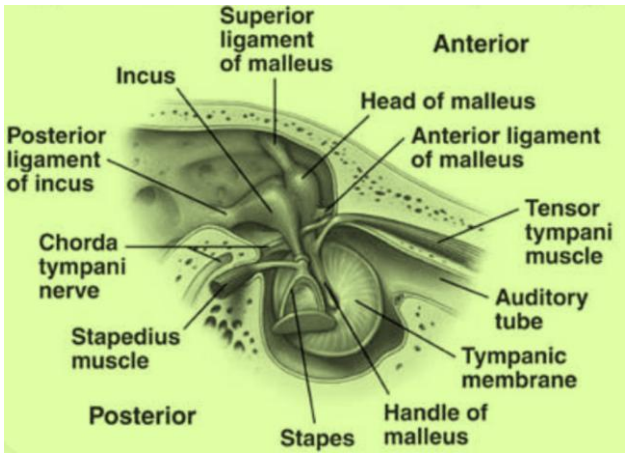

Figure 10: Auditory ossicles and their muscle attachments.[9]

The tympanic plexus

The carotico - tympanic nerves and the tympanic branch of the glossopharyngeal nerve, the Jacobson's nerve, intermingle to form the tympanic plexus. Mucous membrane lining the middle ear cleft is innervated by the nerves that form a plexus on the promontory.[19]

Table 1: Blood supply of middle ear.

S. no	Branches	Parent artery	Region supply
1.	Anterior tympanic	Maxillary artery	Tympanic membrane, malleus, Incus, anterior tympanic cavity
2.	Stylomastoid	Posterior auricular	Posterior part of tympanic cavity, stapedius muscle
3.	Mastoid	Stylomastoid	Mastoid air cells
4.	Petrosal	Middle meningeal	Roof of mastoid and roof of epitympanum
5.	Superior tympanic	Middle meningeal	Malleus, incus, tensor tympani
6.	Inferior tympanic	Ascending pharyngeal	Mesotympanum

Aditus is the communicating tunnel from the attic to the mastoid antrum is called the aditus. The floor and the medial wall of the canal form the horizontal semicircular canal. The short process of incus rests on the floor of the plane where the facial nerve is located, deep below the Aditus's entrance. Mastoid process is lies behind the tympanic part of the temporal bone. Pneumatization of the temporal bone results in a cellular mastoid in 80% of individuals. The diploeic mastoid bone marrow survives even post puberty, despite its continuous development. Air cells are completely absent in the acellular mastoid. Moreover, the petrous and squamous parts of the mastoid also contain air cells. Wrt their anatomical location, the air cells of a well-developed mastoid are categorized into multiple types.

The maximal volume of air lies within the petrous section of the temporal bone. A tangent traced to the posterior prolongation of the zygomatic arch, crossing the posterior border of the external auditory meatus, constitutes the Mac Ewan's triangle.[20]

CONCLUSION

On Vis a Vis the ecto, meso and endoderm layers develop into the middle ear air cleft with its tympano-ossicular system that matches the impedance during transmission in media of different densities. The tympanic membrane and the eustachian tube are the vital constituents of this cleft.

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