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MIDDLE EAR CLEFT : THE EVOLUTION OF MOST SOPHISTICATED PARANASAL SINUS INTO AN IMPEDANCE MATCHER!!

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ABSTRACT

Aims And Objective: Assess and analyse the feasibility to categorise and include middle ear cleft as fifth pair of paranasal sinuses. **Materials And Method:** This study was based on a retrospective review of the PNS and temporal bone CT scans which was obtained from the CT scan image archives of a tertiary medical care centre Patna medical college in the last 2 years (May 2018–June 2020). Analytical review of various publication on Pubmed, Cochrane review, Google scholar regarding embryology, anatomy, physiology, histology and pathology of middle ear cleft and para nasal sinuses. **Result:** Striking similarities and homogeneity was noted in our analytical review between middle ear cleft and para nasal sinuses pneumatisation p <.01. The degree and extent of pneumatisation of mastoid correlates with pneumatisation of sphenoid and ethmoid pneumatisation (p<.01) **Conclusion:** This study intends to give an insight into development and functioning of middle ear cleft, importance of these pneumatisation in craniofacial skeleton and unify the pneumatisation process of craniofacial skeleton to that of temporal bone.

KEYWORDS

mastoid, middle ear cleft, pneumatisation, sphenoid, ethmoid, mucosa, pseudostratified columnar epithelium, cilia

AIMS AND OBJECTIVE:

To assess and analyse categorisation and inclusion of middle ear cleft and mastoid as fifth pair of paranasal sinuses.

Background: Development of mastoid air cells and para nasal sinuses have been studied extensively but discretely as an exclusive event in embryology. We here propose a hypothesis that these two events are different faces of the same coin. Development of face is associated with fusion of some embryologic process and further its pneumatisation[1,2,3]. These air cells lined by mucosa makes the bone light, increases surface area for absorption of nutrients, and important for ventilation and drainage and thermoregulation. We tend to add one more function to sinus as an impedance matcher and amplifier for sound with inclusion of middle ear cleft in category of para nasal sinuses.

INTRODUCTION:

The development of face, branchial arch derivative, cranium and temporal bone derivatives are interlinked. A part of temporal bone styloid complex and tympanic bones is derived from pharyngeal arches similar to paranasal sinuses bone. The face develops from frontonasal process, paired maxillary process and mandibular processes around stomodeum which fuse in the midline to give face its shape[1].The maxilla, lateral ethmoturbinal and mandible are derived from first arch cartilage and are innervated by maxillary nerve and artery. Similarly, styloid complex including mastoid, eustachian tube cartilage, tympanic plate is derived from second arch cartilage and innervated by facial nerve and stapedial artery which involutes in course of time. These bones as child grows makes the skull heavy impeding cephalocaudal axis of head. To overcome this, nature makes an adaptation by pneumatising these bones which happens in different specific times during development[4,5,6]. We study middle ear cleft in relation to its function as transformer and impedance matcher in hearing mechanism, but in addition it ventilates , drain mucus and helps in thermoregulation simulating functioning of sinuses. Various theories of pneumatisation of mastoid have been proposed in literature like Whittmack, Bateman, Tumarkin, Diamant to name a few. These theories hypothesise genetics, infection, absorption of marrow, traction of bone by muscles as causes for pneumatisation[5,6,14] of mastoid. The mastoid similarly helps in thermoregulation , making the skull light & ventilation and drainage of mucus.

MATERIALS AND METHOD:

This study was based on a retrospective review of the PNS and temporal bone CT scans which was obtained from the CT scan image archives of a tertiary medical care centre Patna medical college in the last 2 years (May 2018–June 2020). A total of 30 HRCT scans of temporal bones and paranasal sinuses of patients evaluated and correlation of degree of pneumatisation noted . All patients CT were done due to some other cause and age ranged from 15 to 67 years. The maximum cross sectional width of mastoid cells at the level of basal turn of cochlea from posterior canal wall to sigmoid sinus is measured (m_{max}). Two parallel lines are drawn along anterior and posterior margin of sigmoid sinus in axial HRCT of temporal bone. On the basis of whether air cell is limited to the anterior line , between the two lines or beyond the posterior line, mastoid is defined as mild pneumatisation, moderate pneumatisation and hyperpneumatisation. Systematic review on Google scholar, PubMed, Science direct, Cochrane review about middle ear cleft AND paranasal sinuses done. Analytical observational studies of various publication and literature on similarities in, embryology, radiology, histology, anatomy, physiology and pathology of middle ear cleft and mastoid to that of paranasal sinuses is done.

Inclusion Criteria: 30 HRCT scan of temporal bone of patient with no pathology or lesion of mastoid and para nasal sinus were studied.

Exclusion Criteria: Patients who have mastoid or sinus lesion or have undergone surgery for the same were excluded

RESULT:

On evaluation striking homology was noted between pneumatisation of Petro mastoid and paranasal sinuses[18].

Radiology: There was statistically significant positive correlation between mastoid pneumatisation and Fronto-ethmo-sphenoid pneumatisation p<.01). Two lines parallel to each other are drawn along anterior and posterior margin of sigmoid sinus in axial HRCT of temporal bone. Mastoid air cell limited anterior to line passing through anterior margin of sigmoid are mildly pneumatised , those encroaching bone between the two lines are moderately pneumatised and those extending posterior to second line are highly pneumatised. Mastoid air cell system was highly pneumatised in 19% of scan with highly developed ethmosphenoid (post sellar) (18%) and sellar (21%) pneumatisation. Mastoid air cell was moderately pneumatised in 74% having sellar type sphenoid (49%). Sclerotic and less pneumatised Mastoid (7%) with conchal (5%) type sphenoid forms a minority in our study. Similarly, degree of pneumatisation of frontal correlated with mastoid pneumatisation. (p<.01) and average no. of ethmoid cells were in direct proportion to pneumatisation of mastoid.

Mastoid	Sphenoid	Avg. No. of Ethmoid cell (axial view)	Frontal cell	P value
Highly pneumatised (19%)	Post Sellar (18%) sellar(7%)	12-15	Highly pneumatised	P<.01
Moderately pneumatised (74%)	Presellar (21%), Sellar (49%)	10-13	Moderately pneumatised	P<.01

Less pneumatised (7%)	Conchal (5%)	9-10	Less pneumatised	P<.01

Volume Of Sinuses And Mastoid In Different Age Group[18]

Age	R mast. Vol.	L mast vol.	Sphenoid vol.	Frontal sinus vol.
15-20 n Mean-SD	12 5.5-+2.2	12 5.6+-2.1	12 5.4+-2.09	12 3.6+-1.8
21-25 n Mean- SD	10 7.8+-3.3	10 7.5+-3.1	10 8.6+-2.3	10 3.5+-2.1
>25 n Mean- SD	9 8.1+-3.1	9 7.4+-2.9	9 7.88+-2.7	9 3.5+-2.3
P value	<.01	<.01	<.08	<.4

Correlation Of Mastoid Volume To Paranasal Sinuses Volume[18]

	r	p
Total mast. Vol- sphenoid vol	.398	.006
Total mastoid vol.-maxillary sinus vol.	.227	.125
Total mastoid vol. -ethmoid cell vol.	.272	.081
Total mast. Vol- frontal cell vol.	.228	.156

DISCUSSION:

Karakas S et al in there morphometric study of temporal bone and para nasal sinuses have beautifully correlated different air cells in anterior and lateral skull base[18]. Our study result shows that that there are some correlation between pattern and extent of pneumatisation of mastoid and paranasal sinuses. The degree of pneumatisation of mastoid air cell is in direct proportion to degree of pneumatisation of sphenoid and ethmoid. Sphenoid and posterior ethmoids being derived from same embryologic ethmoturbinal derivative and lying in relatively close proximity to eustachian tube correlated better than frontal or maxillary pneumatisation.

Evolution: Tucker A S et al. Takechi M et al. have studied the evolution of middle ear in great detail. The pneumatisation of frontal, ethmoid, maxillary and sphenoid is similar and correlates to pneumatisation of Petro mastoid temporal bone[1,7,14]. It is an adaptation, as animals became terrestrial from aquatic life and attained bipedal erect posture. In aquatic organism sound is conducted via bone and there is no middle ear for air conduction. In mammalian embryo too this is seen at early weeks echoing Ernst Haeckel's known dictum “ontogeny recapitulates phylogeny” . Sound dampening due to sound waves traversing from air in external ear to fluid in cochlea in terrestrial life needed to be amplified by impedance matching and transformer mechanism of middle ear ossicle. This is why otic placode arising just lateral to 2nd pharyngeal arch migrated upward backward and pharyngotympanic mucosal bud invaginates the solid mesenchyme around developing ossicles to create a cavity. Also sound transmission is enhanced by bone conduction as tympanomastoid part of temporal bone pneumatises[7,11,12,13,14].

Embryology: Hill M A online book review gives a great insight into vast fascinating ocean of embryology of middle ear and para nasal sinus development. A part of temporal bone styloid complex and tympanic bones are derived from pharyngeal arches similar to paranasal sinuses bone. The face develops from frontonasal process, paired maxillary process and mandibular processes around stomadeum which fuse in the midline to give face its shape[1].The maxilla, lateral ethmoturbinal and mandible are derived from first arch cartilage(Meckel's) and are innervated by maxillary nerve and artery. Similarly styloid complex including mastoid, eustachian tube cartilage, tympanic plate are derived from second arch cartilage(Reichert's) and innervated by facial nerve and stapedial artery which involutes in course of time. This is further substantiated by several congenital deformity like apert, crouzon syndrome etc where maxillofacial hypoplasia is associated with atresia or some deformity of ear.

The middle ear cleft is embryologically derived from tubotympanic recess formed by first pouch with small contribution from second making it a branchial derivative. The distal most part of tubotmpanic recess forms mastoid, the intermediate part forms tympanum and proximal part forms eustachian tube. At birth and during embryonic life middle ear cleft remains in close proximation to nasopharynx similar to para nasal sinus owing to shorter length of tube , but as the tube starts lengthening owing to differential growth of head the otic placode which was just lateral to second pharyngeal arch during early weeks of embryogenesis migrates upward ,backward and posteriorly.

Development of the Nasal Air Sinuses[19-26,28]

The nasal mucous membrane bud pushes its way through the lateral nasal cartilage into the maxillary process derived from first arch to form the Antrum of Highmore . The other air sinuses — the frontal, anterior, middle and posterior ethmoidal, and sphenoidal sinuses, arise in the same way as the antrum but at a much later date. Although they begin to bud out about the 3rd year, they assume their active growth in the earlier years of puberty, and reach their full size before the 30 th year. It will thus be seen that all the nasal air sinuses are produced primarily by a budding outwards of the nasal mucous membrane into the cartilaginous basis of the lateral nasal processes. The cartilaginous base is maxilla, frontonasal process and ethmoturbinal mass six in no. derived from 1st arch cartilage into which nasal mucosal bud invaginates and engulfs to form sinus or cavity. Interestingly sphenoid is derived embryologically from ethmoturbinal and is the 6th ethmotubinal draining into sphenoethmoidal recess.

The Eustachian Tube[19-26,28]

The Eustachian tube is derived from the proximal first inner cleft recess of the pharynx and retains through life the ciliated epithelial lining of the primitive pharynx. The part of the petro-mastoid which grows over it, is the tegmen tympani ; it also forms the roof of the tympanum and antrum of the mastoid. It forms the roof of all the cavities derived from the inner recess of the first cleft . The anterior edge of the tegmen tympani appears in the Glaserian fissure. The tensor tympani and tensor palati are developed on the mandibular side of the first cleft and are supplied from the nerve of the mandibular process through the otic ganglion.

The Tympanum[19-26,28]

The inner cleft recess ends in the jelly-like tissue containing the cartilaginous bases of the malleus and incus. As the pharyngotympanic recess buds and extends and widens outwards and backwards, the gelatinous tissue is absorbed, so that the malleus and incus and developing stapes, with the chorda tympani, become surrounded by the hypoblasts lining of the pharyngotympanic recess. The mucosal bud absorbs and engulfs gelatinous mass around 1st arch cartilage forming tympanic cleft filled with amniotic fluid

In carnivora and some other mammals the floor of the tympanum, formed by the tympanic plate, is inflated into a bulla, the tympanic bulla. Its meaning is unknown, but when a bulla is developed the antrum of the mastoid is small or, absent.

The Antrum of the Mastoid[19-26,28]

The antrum of the mastoid represents the extreme outer or posterior end of the first cleft recess . **It is formed at the same time and in the same manner as the tympanum.** At birth its outer wall is formed by the thin post-auditory part of the squamosal . The antrum opens in front into the attic of the tympanum. The tegmen tympani forms its roof and the petro-mastoid its floor and inner wall. The Fallopian canal runs down the inner wall of its mouth, and in its floor is located the lateral semi-circular canal.

Gross Anatomy: On gross endoscopic view the mucosa lining the cavity of paranasal sinus looks alike the mucosa of middle ear cleft . The ostia of paranasal sinuses are simulated with eustachian tube ostia for middle ear cleft[4,7].

Histology: The mucosa of para nasal sinuses is lined by **pseudostratified columnar ciliated** epithelium with thickness of .3-.5mm.columnar cells comprises three fourth of epithelium[9,10,11]. These columnar have 300-400 microvilli on their surface which helps in moisturising mucosa. The rest are ciliated columnar cells helping in mucociliary clearance. Goblet cells contributes 5-15% in respiratory mucosa which secretes shiny viscous mucus. The mucosa of middle ear cleft transits from **pseudostratified columnar epithelium** with plenty of goblet cells in protympanum to flat non keratinising squamous epithelium in mastoid[7,9,10]. **Dual epithelial origin** of middle ear cleft to explain the variation in mucosal lining of tympanum and mastoid has been rejected recently and both derive from endodermal lining of 1st pouch which adapts to need of local function

Physiology: Mucociliary clearance is about 200g or 2L/day at 5-10 mm/min[9]. Everyday 12,000 L airflow occurs through nose and gets hydrated[9]. The ventilation in paranasal sinus occurs during expiration. Ventilation in middle ear cleft occurs through eustachian tube which opens 2-3 times per min for .5 s during yawning or swallowing delivering .0001cc of air. The total ventilation is 1cc in a day. These ventilation process humidifies the air and helps in thermoregulation of sensitive inner ear fluid and to the lungs.

Pathology: The otitis media with effusion and mucocele shares same pathology of being an inflammatory disease. Polyps and granuloma are formed at both sites, though less common in middle ear cleft. **There are 19 primary cases of inverted papilloma in ear reported from around the world which can only be explained on histological similarity of epithelium**.

Autonomic Nervous Supply: A very striking feature of both these group of cavities is its mucosal nerve supply. **The topographic nerve innervating mucosa of middle ear cleft and paranasal sinuses is nerve of first arch.** General sensation and parasympathetic innervation of middle ear cleft mucosa is by tympanic branch of glossopharyngeal via tympanic plexus through mandibular branch and sympathetic supply caroticotympanic nerves, plexus around carotid artery. The nerve supply is through medial pterygoid branch of mandibular carrying glossopharyngeal parasympathetic and general sensory fibre and caroticosympathetic fibres.

Similarly, paranasal sinus mucosa is innervated by branches of maxillary nerve (topographic nerve) transmitting parasympathetic fibres of GSPN (facial N) through pterygopalatine ganglion and sympathetic plexus around carotid (caroticosympathetic plexus) via vidian nerve (functional nerves).

Blood Supply: The nose and paranasal sinuses are perfused by rich anastomosis between internal carotid artery (anterior and posterior ethmoidal artery) and external carotid via sphenopalatine artery. Similarly, tympanic plexus is formed over promontory between inferior tympanic branches of external carotid and caroticotympanic branch of internal carotid artery, though most prominent supply at both sites is by **branches of first arch artery that is maxillary artery.** Venous drainage is to pterygoid plexus from both the sites.

CONCLUSION:

The middle ear cleft is lined by mucocilia, non-keratinised epithelium, have ventilatory and drainage function through eustachian tube as its ostia, developed embryologically by pneumatisation of 2nd branchial arch cartilaginous derivatives, similar to other four pair of paranasal sinuses which develop by mucosal bud invaginating 1st arch cartilage. We propose to classify and categorise middle ear cleft as fifth pair of paranasal sinuses(fig1) which evolved into an impedance matcher during phylogeny. It would be further added that middle ear is the first but most sophisticated paranasal sinus to be developed. This study intends to give an insight into development and functioning of middle ear cleft, importance of these pneumatisation in craniofacial skeleton and unify the pneumatisation process of craniofacial skeleton to that of temporal bone. It is also inferred from this, how one of the paranasal sinuses adapted to need and evolved into an organ of hearing.

Similarities Between Middle Ear Cleft And Para Nasal Sinus [Table 1]

Table 1

features	Paranasal sinuses	Middle ear cleft	Mastoid
Gross anatomy	Location: Anterior and posterior nasal cavity, Pneumatisation of maxillary, ethmoid sphenoid and frontal bone	posterolateral to nasopharynx, pneumatisation of petrous part of temporal bone	Pneumatisation of mastoid part of temporal bone
Histology	Nonkeratinized pseudostratified columnar epithelium	Nonkeratinized pseudostratified columnar epithelium. 1st pouch endodermal lining	Dual epithelial origin rejected recently. Nonkeratinized squamous epithelium.1st pouch endodermal lining
Pathology	Sinusitis, polyp, mucocele, ringertz tumour, squamous cell carcinoma	Otitis media, aural polyp, effusion, ringertz, squamous cell carcinoma	Mastoiditis, polyp,squamous cell carcinoma
Physiology	Ventilation drainage absorption, thermoregulation	Ventilation drainage absorption, impedance matcher Thermoregulation of sensitive inner ear fluid.	Ventilation drainage absorption, thermoregulation
Embryology	Maxillary primordia,6 ethmoturbinals frontal process from 1st arch cartilage	Tubotympanic recess from first pharyngeal arch. Petro mastoid pneumatisation	Distal part of tubotympanic recess from 1st arch pneumatisation
Ostia drainage	Nasal cavity meatuses	nasopharynx	Aditus to tympanum
Pneumatisation	Maxilla, ethmoid, frontal, sphenoid bone	Petrous part of temporal bone	Mastoid part of temporal bone
Nerve supply	Topographic nerve: maxillary N (1ST arch) branches functional nerve: GSPN (facial) and caroticosympathetic plexus	Topographic nerve: mandibular(1st arch) functional: glossopharyngeal and caroticosympathetic plexus	
Blood supply[15]	Mostly by branches of first arch maxillary A. Anastomosis between external and internal carotid system	first arch maxillary A Anastomosis at tympanic plexus between external and internal carotid system	Stylomastoid artery
Venous[15] drainage	Pterygoid plexus	Pterygoid plexus, superior petrosal sinus	Mastoid emissary vein , pterygoid plexus

1.frontal sinus 2. ethmoid sinus 3. sphenoid sinus 4. maxillary sinus 5. middle ear cleft with mastoid

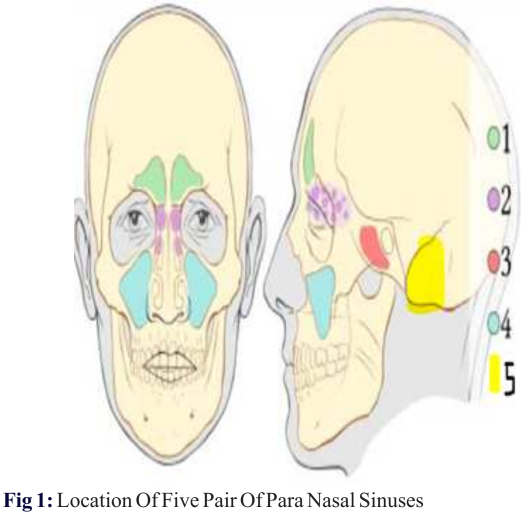

Fig 1: Location Of Five Pair Of Para Nasal Sinuses

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