REVIEW

Morphology and Variations of the Nose and Paranasal Sinuses: A Systematic Review

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Abstract

The anatomy of the nasal cavity and the paranasal sinuses are important to the clinicians not only for diagnosis but for treatment of diseases. Functional endoscopic sinus surgery (FESS) is a minimally invasive procedure used to treat chronic sinusitis, nasal polyps, and other sinus conditions and aims to restore normal sinus function. A sound knowledge in anatomy of the nose and paranasal sinuses is imperative to achieve better patient care. This review was conducted using PubMed database using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines 2020. Described literature includes morphology and variations of nasal septum, uncinate process, turbinates, maxillary sinus, ethmoid sinuses, frontal sinus, frontal recess, fronto-ethmoid cells and sphenoid sinuses. Studies done in different geographical regions have shown different prevalences of these variations This article underscores the morphology as well as variations with prevalences described the literature available in the PubMed and few selected articles on google scholar.

Key words – Anatomy of Nose; Paranasal sinuses; Nasal septum; Nasal turbinates; Uncinate process; Maxillary sinus; Frontal sinus; Ethmoid sinus; Sphenoid sinus; Crista galli; Skull base

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Introduction

The intricate anatomy of the nasal cavity and paranasal sinuses plays a critical role in maintaining optimal respiratory function and sinus drainage. Understanding the variations in these structures is paramount, not only for diagnosing and treating conditions like sinusitis but also to ensure the safety and success of surgical interventions in this region (1).

The nasal cavity communicates with the exterior through the nostril and with the nasopharynx through the posterior choana. It is divided by the nasal septum, which consists of cartilage, the vomer bone, and the perpendicular plate of the ethmoid bone. The floor of the nasal cavity is formed by hard palate which is formed by the palatine process of the maxilla and the horizontal plate of palatine bone. The roof has 3 parts. The anterior sloping part is formed by the nasal bones and the nasal process of the frontal bone. The middle horizontal part is by the cribriform plate of the ethmoid bone and the posterior sloping part is formed by the anterior surface of the body of the sphenoid bone, ala of the vomer and the vaginal process of the palatine bone (2).

Its lateral walls have a more complex structure, formed by bone, cartilage and soft tissues. Bones involved in forming the lateral wall are ethmoidal labyrinth including the uncinate process, perpendicular plate of the palatine bone, medial pterygoid plate of the sphenoid bone, medial surfaces of the lacrimal bone, maxillary bone and the inferior concha (2).

The lateral wall of the nose feature turbinates /conchae, which increase the surface area of the nasal cavity. The superior and middle turbinates derive from the ethmoid bone but the inferior turbinate is a separate bone. The spaces created by these turbinates are called the meatuses. Inferior meatus lies between the inferior turbinate and the floor of the nasal cavity. The nasolacrimal duct opens to it. The middle meatus lies between the inferior and middle turbinates and serves as a critical drainage pathway for the frontal, maxillary, and anterior ethmoid sinuses. The superior meatus lies between the middle and superior turbinates and the posterior ethmoid sinus drains to it. Spheno-ethmoidal recess lies posterosuperior to the superior turbinate (3).

The paranasal sinuses are air-filled spaces within the skull, comprising the frontal, maxillary, ethmoid, and sphenoid sinuses (4). The frontal sinuses are situated in the forehead within the frontal bone. The maxillary sinuses, situated in the maxillary bones, may extend into the palate or to the infraorbital area. The ethmoid sinuses, located between the nose and the bony orbit, are divided in to anterior and posterior groups of air cells. with the agger nasi cells being the most consistent of the anterior group (5). The sphenoid sinuses lie deep within the skull, behind the ethmoid sinuses and drain into the spheno-ethmoidal recess. These sinuses play significant roles in several functions. They help humidify and warm inhaled air, reduce the weight of the skull, contribute to voice resonance, sensation of smell and act as a buffer against facial trauma.

Anatomical variations in the nose and the paranasal sinuses may affect both airflow and sinus drainage, contributing to nasal obstruction and sinus disease. They can also complicate surgical procedures, highlighting the importance of accurate preoperative assessment. Advanced imaging techniques, particularly Computed Tomography (CT), have revolutionized our understanding of sinonasal anatomy, offering a more detailed and comprehensive view than traditional methods like anterior rhinoscopy. CT scans enable the identification of subtle variations that influence disease and treatment (4).

The main aim of this article is to describe the morphology and variations of the nasal cavity and paranasal sinuses. Understanding of these variations, will enable the clinicians to improve diagnostic accuracy and surgical decision-making. Ultimately, the findings will contribute to personalized treatment strategies, enhance clinical outcomes, and improve the quality of life for individuals with sinonasal pathologies.

Methods

Article identification was done using PubMed database. Additional articles were reviewed from google scholar where necessary. The key words used were Anatomy and variations of nose and paranasal sinuses.

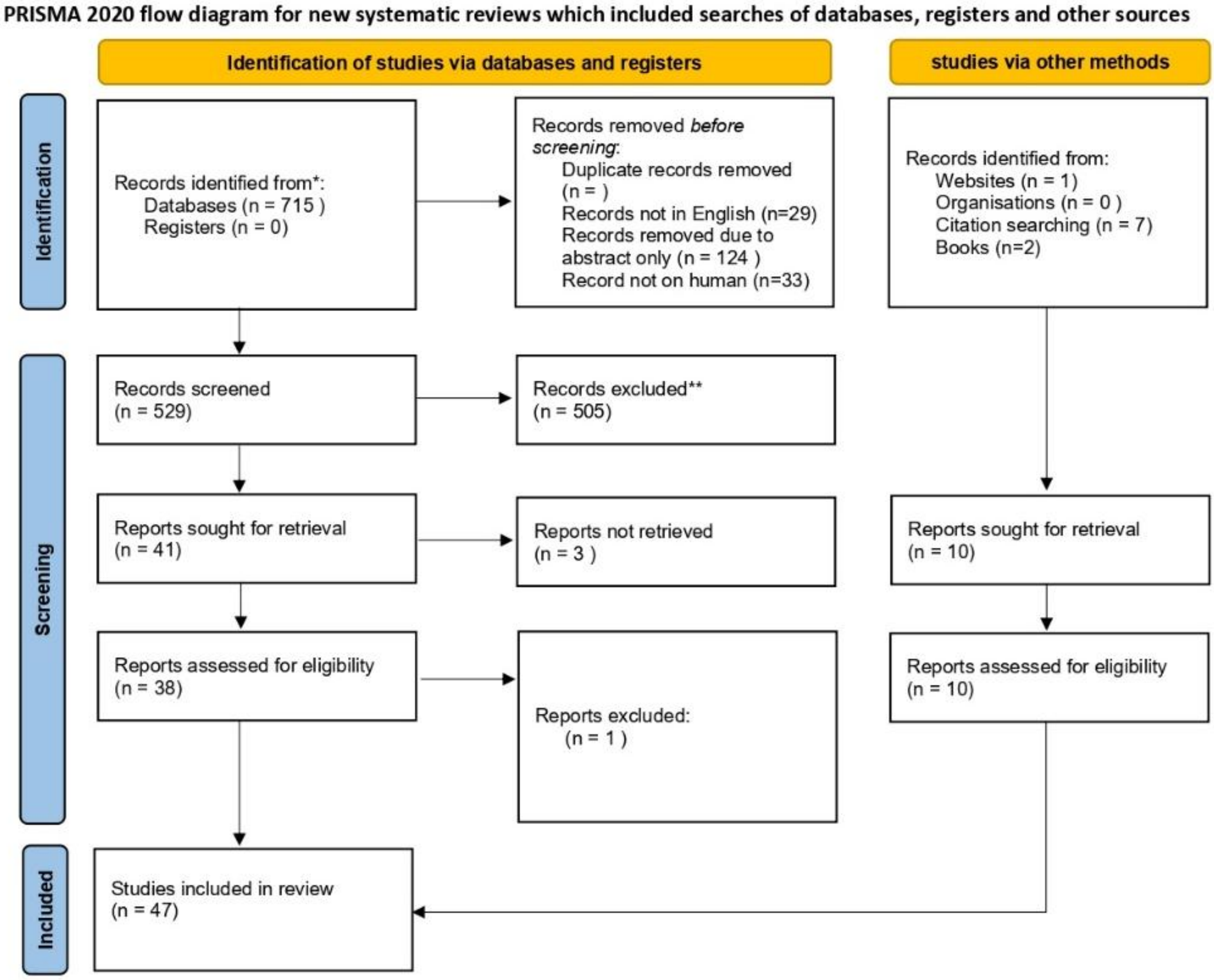

Figure 1: Flow Diagram for New Systematic Review PRISMA (6)

Variation involving the septum

Deviated nasal septum (DNS)

DNS is one of the most common anatomical variations of the nasal cavity, and it refers to the displacement of the nasal septum from the midline. This deviation can be either osseous or cartilaginous, or a combination of both (7). The reported prevalence of DNS varies widely across studies, likely due to the different definitions and study populations used. For example, a study in Saudi Arabia found DNS in 38.8% of scans whereas a study of 76 patients in Nepal found DNS in 64.5% of their sample (1, 8). Another study in Pakistan reported a rate of 56% in patients with chronic rhinosinusitis DNS can cause nasal obstruction and contribute to the development of rhinosinusitis, but some studies have failed to show a direct causal relationship (9). It is clinically important to be aware of the presence and severity of a DNS to appropriately manage symptoms, and to assess potential surgical implications.

Enlargement of the anterior septum (tumescentia septi nasi anterior)

This condition could lead to obstruction of the nasal airflow to varying degrees. This is also called nasal septal turbinate and prominence is made out of cartilage and surrounding erectile soft tissue. Excessive destruction of the nasal septal turbinate in surgery could lead to drying of the nasal mucosa and epistaxis (10)

Pneumatization of the nasal septum

This is the presence of air-filled spaces within the septum (10). An Indian study with 151 CT scans reported pneumatized septum in 27% (7).

Variations in the turbinates

Concha bullosa (CB)

CB is a common anatomical variation that refers to the pneumatization, or presence of air cells, within the nasal turbinates (11). The middle turbinate is the most common site for CB. The prevalence of CB varies across studies, with some reporting it in 49% of patients in India, 24.2% in Saudi Arabia (7, 12). A study in Turkey reported a total concha bullosa prevalence of 51%, with lamellar, bulbous, and extensive CB identified in 29%, 14%, and 8% of the sample respectively (13). CB can be unilateral or bilateral, and the size of the pneumatization can vary significantly. Another study in Turkey reported that 48.1% had concha bullosa and 61.6% of them were bilateral (14). Same study reported that concha bullosa involving the superior turbinate and inferior turbinates were 12.2% and 2.2% respectively (14). Knowledge of CB is important for clinicians because they can cause obstruction of the ostio-meatal complex, contribute to nasal obstruction, headaches and rhinosinusitis. However, a prospective radiological study in India evaluating the variations of the middle turbinates mentioned that there was no statistically significant association between the concha bullosa and development of chronic rhinosinusitis unless, it is an extensive type CB (15). A case report describes “Pneumo-concha dilatans” which is invasion of the aerated middle turbinate in to the maxillary sinus (16).

Paradoxical middle turbinate (PMT)

PMT is a variation where the middle turbinate curves laterally (11). It may cause narrowing of the middle meatus and potentially obstruct drainage. Studies have reported varying prevalences, with one study in Pakistan reporting a rate of 14.3%, while a study in Nepal found a rate of 2.6% (17, 1). This anatomical variation is not always considered a primary cause of sinus disease, but the severity of the curvature may impact drainage.

Secondary turbinate

Secondary turbinate is a developmental anomaly which arises from the lateral wall of the nose. Its precise origin is often inferior to the basal lamellar. It usually projects superomedially compared to the normal turbinate which projects inferomedially. While often asymptomatic, if it becomes hypertrophied (enlarged) or pneumatized (filled with air), it may narrow the ostio-meatal unit and cause chronic sinus issues. Its prevalence is reported as 2% (18). A case report describes occurrence of secondary and accessory turbinates on the same patient (19).

Accessory turbinate

Accessory turbinate origins from the uncinate process. When the uncinate process is folded more anteriorly and medially it appears as a turbinate, called accessory turbinate (18). Both secondary and accessory turbinates could be mistaken as polyps and could confuse the surgeon during endoscopic sinus surgery.

Bifid inferior turbinate

Bifurcation of inferior turbinates are described as case reports (20, 21). Interestingly, the uncinate process was absent in all cases reported and authors speculate that the bifurcation of the inferior turbinate could be due to rotation of the uncinate process during development (20).

Supreme turbinate (or supreme nasal concha)

Supreme turbinate is an inconstant, fourth, and highest bony structure located above the superior turbinate on the lateral wall of the nasal cavity. Present in 60-77% of individuals, it is part of the ethmoid bone, often aiding in the drainage of the posterior ethmoidal cells. When present it helps in identifying the sphenoid sinus osteum as the osteum lies immediately posterior to the posterior attachment of the superior turbinate (22).

Other variations

These include bifurcation and trifurcation of middle turbinates but not elaborated here due to its extreme rarity.

Morphology and Variations in the uncinate process

Uncinate process

It's a bony structure in the lateral nasal wall. It is a thin bone arising from the ethmoid bone and often described as sickle shaped. Its posterior margin runs parallel to the anterior surface of the bulla ethmoidalis. Its posterior attachment is to the ethmoidal process of the inferior turbinate and to the perpendicular process of the palatine bone. However, antero-superiorly, it has variable attachments to multiple structures. In a majority, its anterior attachment is to the lacrimal bone but, the attachment may extend to medial surface of the agger nasi cells and the middle turbinate. Its superior attachment could be exclusive or to a combination of following structures:

i) Attachment to lamina papyracea in a majority i.e. 52%. (23, 24, 25)
ii) Skull base
iii) Middle turbinate

Clinical implication of these variable attachments is that they may affect the drainage of the frontal sinus (25).

Pneumatization and deviations

Pneumatization of the uncinate process has been associated with poor sinus ventilation. The uncinate process can also have a deviated upper edge, which may appear as a second middle concha. Deviations can be medial, obstructing the middle meatus or lateral, obstructing the infundibulum. A study in Turkey reported a rate of medial deviation of 8.4% and lateral deviation of 5.7% (13). An Italian study reported 21% lateral deviations and 22.8% medial deviations (26).

Variations of the uncinate process can be a factor in narrowing the ostio-meatal complex, thus blocking the drainage and producing inflammation. In a study in Italy, medial deviation of the uncinate process was statistically associated with anterior ethmoid sinusitis (26).

Morphology and Variations of the maxillary sinuses

Maxillary sinus

Maxillary sinus is located in the maxillary bone and it is the largest of the paranasal sinuses. It is pyramidal in shape. The base of the maxillary sinus forms the lateral wall of the nasal cavity and the apex extends to the zygomatic process and forms the zygomatic recess of the maxilla. The base has a large defect and it is called the maxillary hiatus. This bony defect is filled by the uncinate process, ethmoid bulla, lacrimal bone, inferior turbinate and the palatine bone (4). Yet, there is an area of the maxillary hiatus, superior to the inferior turbinate which is not covered by any bony structures. This is called maxillary fontanelle and it is divided to anterior and posterior by the uncinate process (25). The floor of the maxillary sinus is involved in forming the alveolar recess of the maxillary sinus. Clinical importance is maxillary sinusitis could result from periodontal sepsis especially involving the last premolar and molar teeth (27).

Maxillary ostium opens to the hiatus semilunaris (crescent shaped space between the bulla ethmoidalis and the uncinate process) and it is located medial to the junction between the horizontal and vertical parts of the uncinate. If accessory ostia are present, they are located in the maxillary fontanelle or hiatus semilunaris (10). A retrospective study done in China studying the accessory ostia reported that 47% of the study population had an accessory maxillary osteum (28).

Aplasia and hypoplasia

Aplasia is extremely rare but a prevalence of hypoplasia unilaterally and bilaterally is reported as 7-8% and 2% respectively. In a study conducted in Turkey with 350 patients, 2.6% were found to have maxillary sinus hypoplasia (13). To classify maxillary sinus hypoplasia, location of the uncinate in relation to the orbit is important. Further to, hypoplasia may be associated with lateral protrusion of the anterior lateral nasal wall in to the maxilla (29). Hypoplasia is important to note, as it can be associated with orbital enlargement and thickening of the bony sinus wall, which may require careful surgical planning. Variations of the maxillary sinus include septations which are bony divisions within the sinus.

Haller cells

These are another important variation of the maxillary sinuses. Haller cells are ethmoid air cells extending into the floor of the orbit, are protruding to the maxillary sinus. These cells may block the ostium and affect its drainage pathways. A study in Nepal reported a 19.7% prevalence of Haller cells in a sample of 76 patients (1). Recognition of haller cells is crucial during surgical procedures such as middle meatal antrostomy. Further to, literature describe headaches caused by haller cells without any evidence of rhinosinusitis (30).

"Kissing antra"

This is a rare variation described in a case report where the aeration of palatine processes beneath the floor of the nasal cavity to the midline leading to meeting of two maxillary sinuses (31).

Morphology and Variations of the frontal sinuses

Frontal sinuses

The frontal sinus is located in the forehead above the orbits, are typically separated by a bony septum and drain into the nasal cavity via the frontal recess. The size and shape of the frontal sinuses are highly variable and may be absent either unilaterally or bilaterally (32). Frontal beak is formed by the nasal process of the frontal bone, frontal process of the maxilla and a small part from the nasal bone (25).

Variations of the frontal sinuses

Variations include agenesis (absence of the sinus), hypopneumatization (reduced air volume), and hyperpneumatization (increased air volume). Hyperpneumatization is classified in to hypersinus (extension of aeration beyond the margins of the normal frontal sinus), pneumosinus dilatans (extensive aeration encroaching surrounding structures and causing symptoms such as diplopia and frontal bossing) and pneumocoele (sinus overgrowth with thinning of the overlying bone) (32). In a study in Saudi Arabia involving 219 patients, 26.9% of participants showed signs of frontal sinus hypoplasia and 7.3% showed frontal agenesis (8). These variations are important to consider preoperatively, as they can influence the surgical approach and increase the risk of complications during endoscopic sinus surgery.

Morphology and Variations of the ethmoid sinuses

Ethmoid sinuses

The ethmoid sinus is located between the eyes, are a complex network of small, interconnected air cells within the ethmoid bone. These sinuses play a key role in the drainage pathways for other sinuses, particularly the frontal and maxillary sinuses.

Ethmoid sinuses are divided in to anterior and posterior by the ground lamellar of the middle turbinate. Ethmoidal bulla/Bulla ethmoidalis is formed by the anterior ethmoidal cells which are the largest ethmoid cells (25). Ethmoid bulla opens to the hiatus semilunaris, or retrobullar recess but rarely it may open into the ethmoidal infundibulum. When there are multiple openings of the ethmoid bulla one opening will open to the hiatus semilunaris. If the bulla is hypo or hyper pneumatized there is an increased risk of damage to medial wall of the orbit and the skull base (25).

Suprabullar recess

is the space between the roof of the ethmoid and the superior border of the bulla. Medially, it is bounded by the middle turbinate and laterally by the lamina papyracea. When the suprabullar recess extend above the orbit it is named as the supraorbital recess (25, 34).

Retrobullar recess

This is the space lies between the posterior border of the bulla and the basal lamellar of the middle turbinate. Similar to the suprabullar recess, its medial wall is formed by the middle turbinate and the lateral wall by the lamina papyracea (25, 3 4). A cadaveric study reported 93.8% occurrence retrobullar recess and 70.9% occurrence of a single discrete suprabullar recess (35).

Ethmoid labyrinth

This has four obliquely oriented lamellar. These lamellar are parallel to each other (36). The uncinate process is the first lamella. The ethmoid bulla forms the second lamella. The ethmoid sinus is divided to anterior and posterior by the third lamella/basal/ground lamella. The anterior vertical part inserts to the crista ethmoidalis of the palatine bone. The middle oblique part attaches to the lamina papyracea. The posterior horizontal part attaches to the lamina papyracea. The superior turbinate forms the fourth lamella (36).

Ethmoidal infundibulum

This is a space bounded laterally by the lamina papyracea, medially by the uncinate, anterosupeiriorly by the lacrimal bone and posteriorly by the anterior part of the ethmoidal bulla. The infundibulum may end blindly due to the to the acute angle created by the attachment of the uncinate to lamina papyracea. However, the infundibulum will be in continuity with the frontal recess if the uncinate attaches to the middle turbinate or the skull base (25).

Frontal recess

This is the space immediately inferior to the frontal opening. In a sagittal section on CT scan frontal sinus and the frontal recess is described to have an hourglass appearance and the narrowest part is the frontal ostium (37). The frontal recess is continuous with ethmoid infundibulum when uncinate attaches to the skull base. It is related anteriorly to the anterior wall of the ethmoidal bulla or suprabullar space.

Agger nasi cells

These lie anteroinferior to the frontal recess and lamina papyracea lies lateral to the recess. From a clinical point of view, the frontal recess lies medial to the attachment of the uncinate in a majority (25).

Due to the complex anatomy of the cells/pneumatized structures around the frontonasal recess, there are many classifications to categorize these cells. Initially Kuhn classification was proposed but later modified Kuhn was proposed (38, 39). In 2016, International Frontal sinus Anatomy Classification (IFAC) was introduced and it was widely accepted. The studies have evaluated the intra and inter-rater variability of IFAC and shown a very low variability suggesting that IFAC would be a better classification (40). European Position Paper on anatomical terminology of the internal nose and paranasal sinuses suggested classify frontoethmoidal cells in anterior, posterior, medial and lateral based on the relationship to the frontal recess but it was less specific hence, had limitation clinically (25).

International Frontal Sinus Anatomy Classification (IFAC) (41)

1. Anterior cells (push the drainage pathway of the frontal sinus medial, posterior or posteromedially)

- Agger nasi cell (ANC) - Cell that sits either anterior to the origin of the middle turbinate or sits directly above the most anterior insertion of the middle turbinate into the lateral nasal wall.
- Supra agger cell (SAC) - Anterior-lateral ethmoidal cell, located above the agger nasi cell (not pneumatizing into the frontal sinus).
- Supra agger frontal cell (SAFC) - Anterior-lateral ethmoidal cell that extends into the frontal sinus. A small SAFC will only extend into the floor of the frontal sinus, whereas a large SAFC may extend significantly into the frontal sinus and may even reach the roof of the frontal sinus.

2. Posterior cells (push the drainage pathway anteriorly)

- Supra bulla cell (SBC) - Cell above the bulla ethmoidalis that does not enter the frontal sinus.

- Supra bulla frontal cell (SBFC) - Cell that originates in the supra-bulla region and pneumatizes along the skull base into the posterior region of the frontal sinus. The skull base forms the posterior wall of the cell.
- Supraorbital ethmoid cell (SOEC)- An anterior ethmoid cell that pneumatizes around, anterior to, or posterior to the anterior ethmoidal artery over the roof of the orbit. It often forms part of the posterior wall of an extensively pneumatized frontal sinus and may only be separated from the frontal sinus by a bony septation.

3. Medial cells (push the drainage pathway laterally)

- Frontal septal cell (FSC)- Medially based cell of the anterior ethmoid or the inferior frontal sinus, attached to or located in the interfrontal sinus septum, associated with the medial aspect of the frontal sinus outflow tract, pushing the drainage pathway laterally and frequently posteriorly.

A study in Turkey found that 72% of patients had abnormal agger nasi cells (13). Similarly, a study in Nepal found that 18.4% of 76 patients had agger nasi cells (1). These cells, often located near the frontal recess, can obstruct drainage pathways. Other common variations include a large ethmoidal bulla, which may narrow the ostiomeatal complex and cause obstruction, and variations in the uncinate process, which can deviate medially or laterally.

These variations are clinically significant because they can affect sinus drainage and contribute to recurrent sinusitis, highlighting the need for awareness during surgical planning.

Morphology and Variations of the sphenoid sinuses

The sphenoid sinuses are located deep within the skull, posterior to the ethmoid sinuses, and are closely related to vital structures such as the optic nerve and internal carotid artery. The sphenoid sinuses can extend laterally into the greater and lesser wings of the sphenoid. A notable variation is asymmetric pneumatization, where the sinus may extend into the clinoid process. Sphenoid sinuses could have different patterns of pneumatization, which could affect surgical access and exposure of the sella turcica These variations are classified as conchal, pre-sellar, sellar, and post-sellar types (42).

Another significant variation is the presence of Onodi cells, which are sphenoethmoidal air cells that extend posteriorly and laterally to the sphenoid sinus. In other words, it is the most posterior ethmoid cell. These cells are located near the optic nerve and can increase the risk of optic neuropathy, especially during sinus surgery. A study in Saudi Arabia found that 31.4% of 293 patients had Onodi cells (12), and a study in Iraq found that 18% patients had Onodi cells (43). However, a study done in United states of America reported that the prevalence among Asians is high as 83.3% (44). Other variations in the sphenoid region include protrusion of the internal carotid artery or the optic nerve into the sphenoid sinus, both of which carry a high risk of iatrogenic injury during sinus surgery. Pneumatization of the anterior clinoid process and dehiscence of the Vidian nerve into the sphenoid sinus are additional variations that require attention to avoid surgical complications. A study done in Sri Lanka reported 24% and 20% pneumatization of anterior and posterior clinoid processes respectively. (45) These variations are clinically significant due to their proximity to critical neurovascular structures, making preoperative awareness essential to prevent injury.

Variations of the Skull base

These can be well explained by the Kero's classification. In Kero's classification, skull base is divided to 3 types based on the depth of the olfactory fossa. It is measured radiologically by measuring the height of the lateral lamella of the cribriform plate (46).

- **type 1:** has a depth of 1-3 mm
- **type 2:** has a depth of 4-7 mm
- **type 3:** has a depth of 8-16 mm

A study based on cone-beam computed tomography revealed Keros types 1, 2, and 3 was 20.43%, 66.26%, and 13.31%, respectively (47). Out of above, asymmetrical skull base or type 3 is more vulnerable to iatrogenic trauma.

Variation in the crista galli pneumatization

Crista galli pneumatization is another, less common variation, where the crista galli, a bony projection in the midline of the anterior cranial fossa, contains air. A study in Saudi Arabia found it in 73% of the scans (8) while another study in Turkey found 40.3% to have this variation (26). Pneumatized crista galli can communicate with the frontal sinus, and obstruction of its drainage can lead to infection and mucocele development.

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