Chapter 1

Paranasal Sinus Anatomy: What the Surgeon Needs to Know

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Additional information is available at the end of the chapter

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Abstract

Performing a smooth and clean sinus surgery goes hand in hand with a perfect understanding of the nasal and paranasal anatomy. Within this chapter, the paranasal and related structures surgical anatomy will be extensively reviewed, with emphasis on the anatomical landmarks and the normal anatomical variations, which have a significant impact on the function, pathology, and surgical procedures of the paranasal sinuses.

Keywords: paranasal sinuses, anatomy, maxillary, ethmoid, frontal, sphenoid, endoscopic sinus surgery

1. Introduction

The solid knowledge of the surgical anatomy and normal development of the paranasal sinuses is the key element behind achieving superb end results, whether the target is to accomplish a therapeutic surgical procedure or to conduct a clinical trial or research. Understanding the surgical landmarks and the anatomical variants of the paranasal sinuses will guide surgeons to a safe, uncomplicated, and successful endoscopic sinus surgery.

2. Histology of the nose and paranasal sinuses

The nasal cavity and all paranasal sinuses are lined by respiratory pseudostratified epithelium except areas of the roof of the cavity, most superior part of nasal septum, and the medial part of superior turbinate are lined by mucosa that contains receptors for the smell sensation known as olfactory area. On the lateral wall and within the sinuses, the mucosa is highly vascularized and adherent to the periosteum of the underlying bone.

Respiratory epithelium contains four types of cells:

1. **Columnar cells:** Divided into ciliated and non-ciliated. The anterior part of the nasal cavity has non-ciliated columnar cells, and the ciliated cells start from the head of inferior turbinate and posteriorly. Mucosa of the paranasal sinuses is high in the concentration of the ciliated columnar cells. Each ciliated cell contains around 100 cilia. Concentration of the ciliated cells varies within the nasal and paranasal mucosa. Giving the fact that cold, dry, and high airflow decreases the number of ciliated cells within the mucosa, which explains why the anterior nasal mucosa has less ciliated cells comparing with the posterior mucosa. And in cases of deviated nasal septum, the narrower sides have higher concentration of ciliated cells than the wider sides.
2. **Goblet cells:** The number of goblet cells varies within the nasal and sinuses mucosa, the posterior we go, the higher number of goblet cells we find. They are sensitive to mechanical and chemical stimulus; however, their contribution to nasal secretion is minimum.
3. **Basal cells:** They are the progenitors of the other type of cells. They are located deep on the basement membrane and not reaching the surface.
4. **Basement membrane:** The deepest layer of the epithelium, which consists of collagen fibrils. It became thicker in individuals with rhinitis [1].

3. Nasal cavity

Nasal cavity is divided by the nasal septum into two halves, so the septum forms the medial wall of these two nasal cavities. The lateral wall of each cavity contains three projections called turbinates or conchae (occasionally four turbinates) and contains passages under these turbinates as well. The roof formed by a sieve-like bone called cribriform plate of the ethmoid, which separates the nasal cavity from anterior cranial fossa. Olfactory nerves pierce through the cribriform plate on each side. Anteriorly, the roof is sloping downward in form of nasal spine of the frontal bone and nasal bone. Posteriorly, it is sloping downward as the face of sphenoid sinus. The floor of the nasal cavity, which is wider than the roof, is formed by the palatine process of the maxilla anteriorly and the horizontal process of the palatine bone posterior to it. In adult individual, the average surface area is about 150 cm^2 and the average volume is about 15 ml for both nasal cavities [1, 2].

3.1. Nasal septum

The nasal septum consists of three parts: (1) the cartilaginous septum (quadrangular cartilage), anteriorly; (2) the bony septum posteriorly, which comprises two bones (the upper one is the perpendicular plate of the ethmoid and the lower one is the vomer); (3) the membranous septum, which is the smallest and the most caudal part, is located between the quadrangular cartilage and the columella. It is not unusual to have a deviated septum toward either sides, making one side narrower than the other [3].

3.2. Lateral nasal wall

The lateral wall of the nasal cavity is a complex structure formed by the inferior, middle, and superior turbinates and, occasionally, the supreme turbinate, the fourth turbinate. Lateral to these turbinates are the corresponding meatuses. The paranasal sinuses are divided per their drainage systems into anterior sinuses group (maxillary, anterior ethmoid, and frontal sinuses) which drains into the middle meatus through the anterior ostiomeatal unit. And the posterior sinuses group (posterior ethmoid and sphenoid sinuses) drains into the sphenoethmoidal recess (aka posterior ostiomeatal unit) (**Figure 1**). The lateral wall also has the drainage of nasolacrimal apparatus via the nasolacrimal duct to the inferior meatus. In addition, it has the sphenopalatine foramen, which connects the nasal cavity to pterygopalatine fossa.

3.3. Turbinates and meatuses

3.3.1. Inferior turbinate and meatus

Unlike the superior and middle turbinates, which are parts of the ethmoid bone, the inferior turbinate is an independent bone. It is the largest one among them and it extends along the

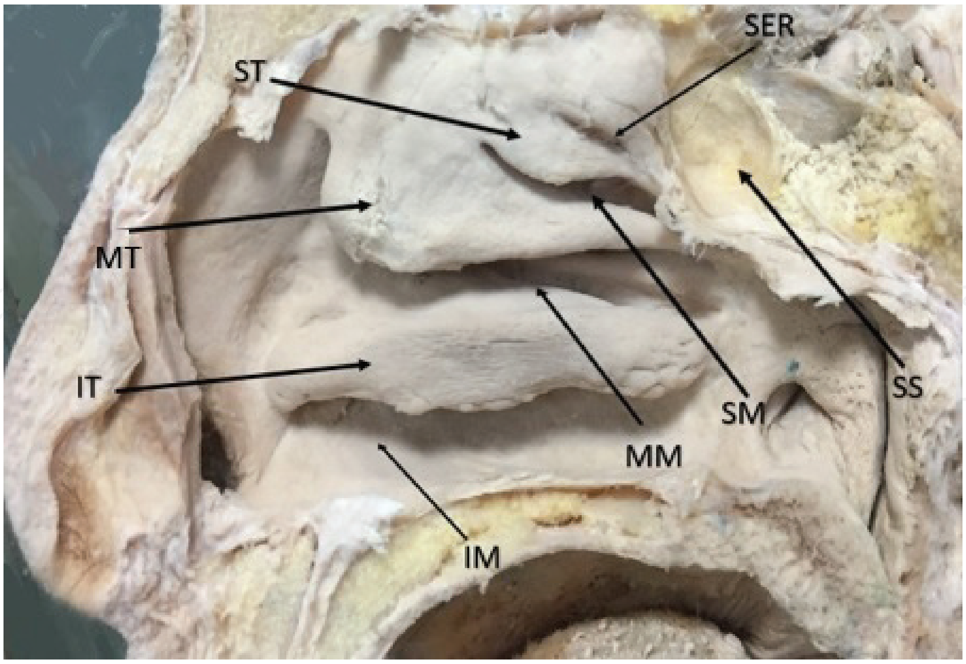

Figure 1. Gross picture of a parasagittal view of the lateral nasal wall. IT, inferior turbinate; MT, middle turbinate; ST, superior turbinate; IM, inferior meatus; MM, middle meatus; SM, superior meatus; SER, sphenoethmoidal recess; SS, sphenoid sinus.

entire length of the nasal floor. Anteriorly, it articulates with the conchal crest of the maxilla, the middle part of the turbinate covers the lower portion of the medial wall of maxillary sinus. Posteriorly, inferior turbinate articulates with the conchal crest of palatine bone. In the inferior meatus, the nasolacrimal duct opens about 2 cm behind the nostril.

3.3.2. Middle turbinate and meatus

The middle turbinate extends along the middle and posterior parts of the nasal cavity. It has three attachments which make it a very stable structure.

- Anterior attachment is vertically oriented and attached superiorly to the lateral border of cribriform plate.
- Second attachment is obliquely oriented, forming the basal lamella or "ground lamella" (which is the most important one in providing the stability of the middle turbinate); it is attached to the lamina papyracea (medial wall of the orbit).
- Posterior attachment is attached to the medial wall of maxillary sinus, and it is horizontally oriented.

The basal lamella divides the ethmoid sinus into anterior and posterior air cells. Immediately behind the posterior part of the middle turbinate underneath the mucosa is the sphenopalatine foramen. The middle meatus receives drainage of the anterior sinuses group as a component of the anterior ostiomeatal unit.

3.3.3. Superior turbinate and meatus

Superior turbinate occupies only the upper part of nasal cavity. Occasionally, there is a fourth turbinate called the supreme turbinate, and the corresponding meatus is the supreme meatus. The posterior ethmoid cells drain into the superior meatus. The supreme meatus "if present" drains the most posterior ethmoid cells.

3.3.4. Anatomical variations of the turbinates

- **Concha bullosa:** It is a pneumatization of the inferior bulbous part of middle turbinate. Occurs in approximately 24–55% of the population and often bilateral. Usually pneumatization originates from the frontal recess or the agger nasi cell [4, 5] (**Figure 2**).
- **Interlamellar cell of Grunwald:** Also called lamellar bulla or conchal neck air cell. It occurs when the pneumatization is limited to the vertical part of middle turbinate. Usually not causing narrowing of the ostiomeatal unit [6] (**Figure 3**).
- **Paradoxic middle turbinate:** Present in about 26% of the population. Occasionally, it can affect the patency of the ostiomeatal unit [6] (**Figure 4**).
- **Pneumatized basal lamella:** Can be falsely considered as a posterior ethmoid air cell during endoscopic sinus surgery.

Figure 2. Coronal computed tomography "CT" scan showing pneumatization of the bulbous portion of middle turbinate bilaterally "concha bullosa" (arrows).

Figure 3. Coronal CT scan showing pneumatization that is restricted to the vertical lamella of the right middle turbinate "interlamellar cell of Grunwald" (arrows).

- **Missed basal lamella:** When the basal lamella does not attach to the lamina papyracea, it attaches to the lateral maxillary sinus wall.
- Rare variations like pneumatization of inferior turbinate, bifid inferior turbinate, and second middle turbinate have been reported in the literature [7–9].

3.4. Ostiomeatal unit

The anterior ostiomeatal unit drains the maxillary, anterior ethmoid, and frontal sinuses. It is formed by (1) ethmoid infundibulum, (2) middle meatus, (3) hiatus semilunaris, (4) maxillary ostium, (5) ethmoid bulla, (6) frontal recess, and (7) uncinate process (**Figure 5**). Occasionally, abnormalities or anatomical variations could affect the patency of this unit. The other draining ostiomeatal unit, located posterior in the nasal cavity, is the sphenoethmoidal recess. It drains the posterior ethmoid sinus lateral to the superior turbinate and drains the sphenoid sinus medial to the superior turbinate [6, 10].

3.4.1. Uncinate process

The uncinate process is a crescent-shaped, thin individual bone. Inferiorly, it is attached to the ethmoidal process of inferior turbinate. The anterior attachment of uncinate process is to the lacrimal bone. Posteriorly, uncinate process forms the anteroinferior border of the hiatus semilunaris. Medial to the uncinate is the ethmoid infundibulum, and laterally is the middle meatus. The superior attachment of the uncinate process is the most interesting one, that is, because of its variability and its direct effect on frontal sinus drainage pathway. There are three patterns of attachment of the superior portion of the uncinate:

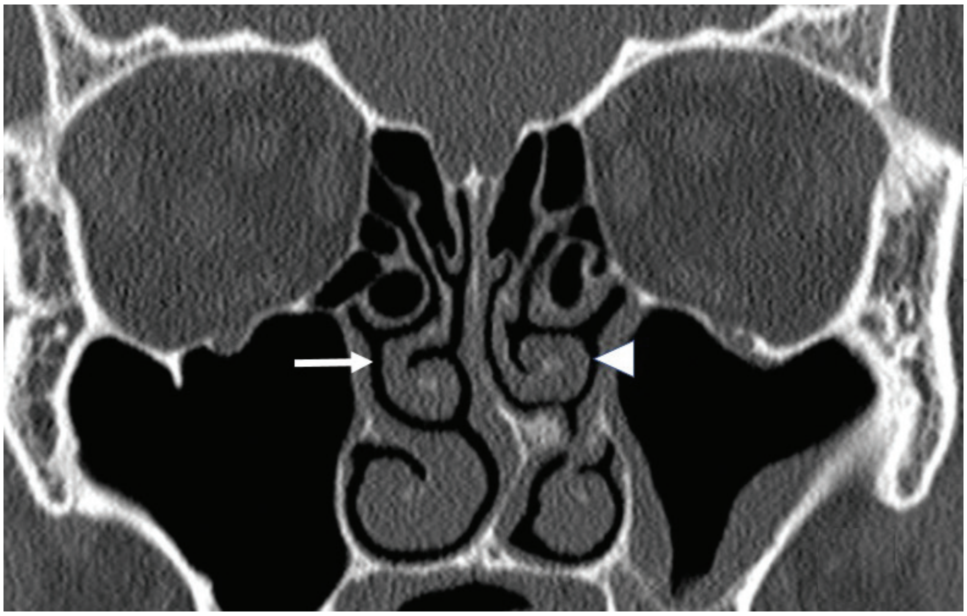

Figure 4. Coronal CT scan demonstrating paradoxical right middle turbinate (arrow). Left middle turbinate is indicated (arrowhead) for comparison, showing the normal orientation.

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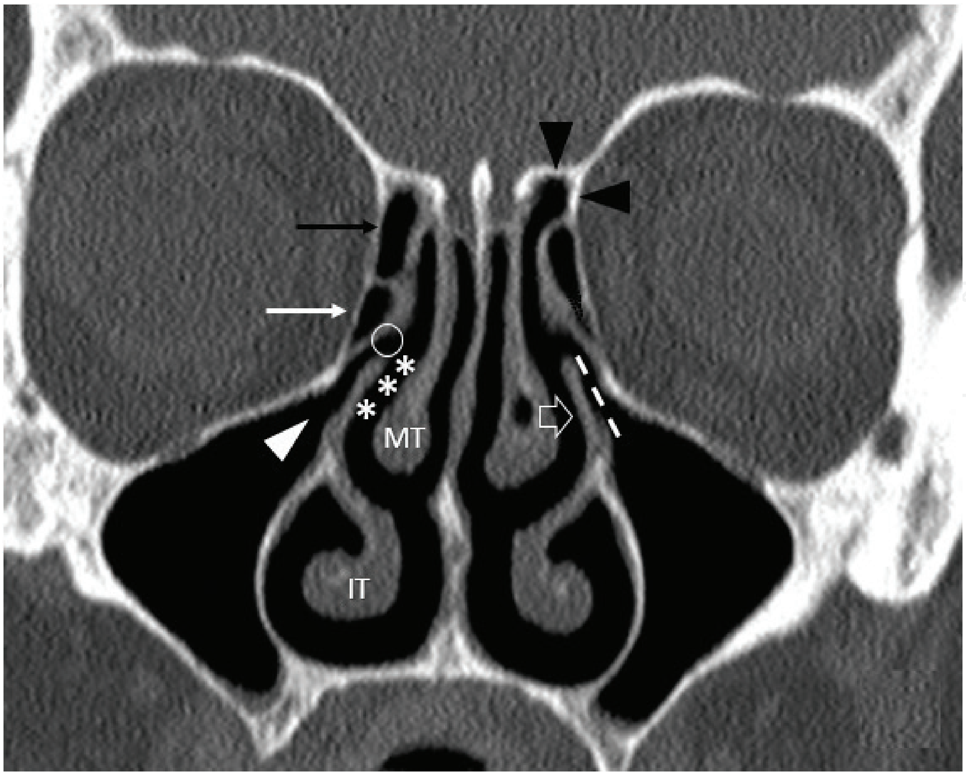

Figure 5. Coronal CT scan showing the components of the ostiomeatal unit: ethmoid bulla (white arrow); maxillary sinus ostium (white arrowhead); middle meatus (asterisks); uncinate process (hollow arrow); hiatus semilunaris "the space between the uncinate process and ethmoid bulla" (white circle); ethmoid infundibulum (dashed line). Frontal recess is part of the ostiomeatal unit (not shown in this coronal level, seen on more anterior view). Note the suprabullar recess on the left side (black arrowheads), which is the space created above the ethmoid bulla when the roof of bulla does not reach up to the skull base, superiorly. On the right side, suprabullar air cell (black arrow) "covered in later sections within this article." MT, middle turbinate; IT, inferior turbinate.

1. **Attachment to the lamina papyracea:** The most common site, found in about 50% of individuals. In this case, frontal sinus drainage pathway drains into the middle meatus. A lateral blind pouch will be formed between the uncinate and the lamina papyracea called the terminal recess or "recessus terminalis" (**Figure 6A**).

2. **Attachment to the middle turbinate:** The uncinate process displaced medially by the large agger nasi air cell and attached to the middle turbinate. Frontal sinus drains into the ethmoid infundibulum with this type (**Figure 6B**).

3. **Attachment to the skull base:** The least often site of attachment. The uncinate process extends superiorly to the skull base without contacting the agger nasi air cell. Here, frontal sinus drains into the ethmoid infundibulum as well (**Figure 6C**).

3.4.1.1. Anatomical variations of uncinate process

- **Pneumatized uncinate process (Uncinate bulla):** Literature reports a rate of about 0.4–2.5% of pneumatized uncinate process. If it is large enough, this could affect the patency of ostiomeatal unit [11, 12] (**Figure 7**).

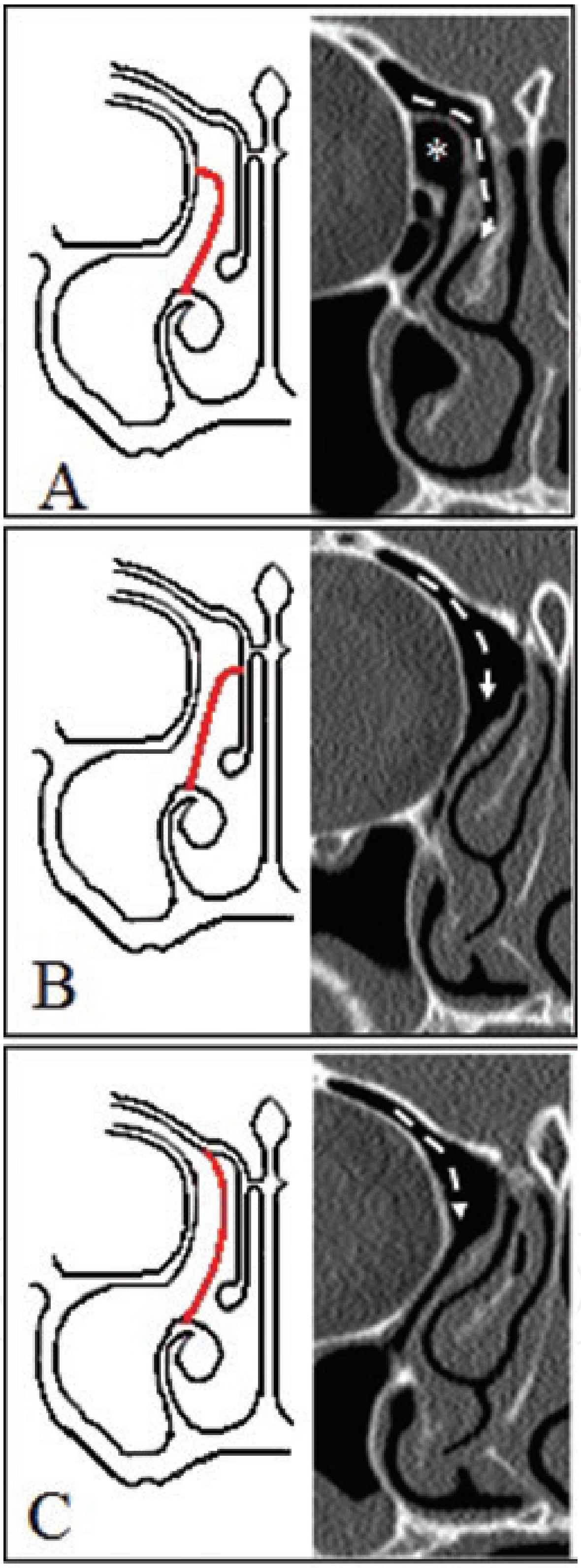

Figure 6. Variant attachments of the uncinate process (red). (A) Attachment to lamina papyracea. Note the blind pouch created between the uncinate and lamina papyracea "recess terminalis (asterisk)." Frontal sinus drains medial to the uncinate into the middle meatus (dashed arrow). (B) Attachment to middle turbinate. Frontal sinus drains into the ethmoid infundibulum. (C) Attachment to skull base. Also, the frontal sinus drainage pathway ends into the ethmoid infundibulum with this type.

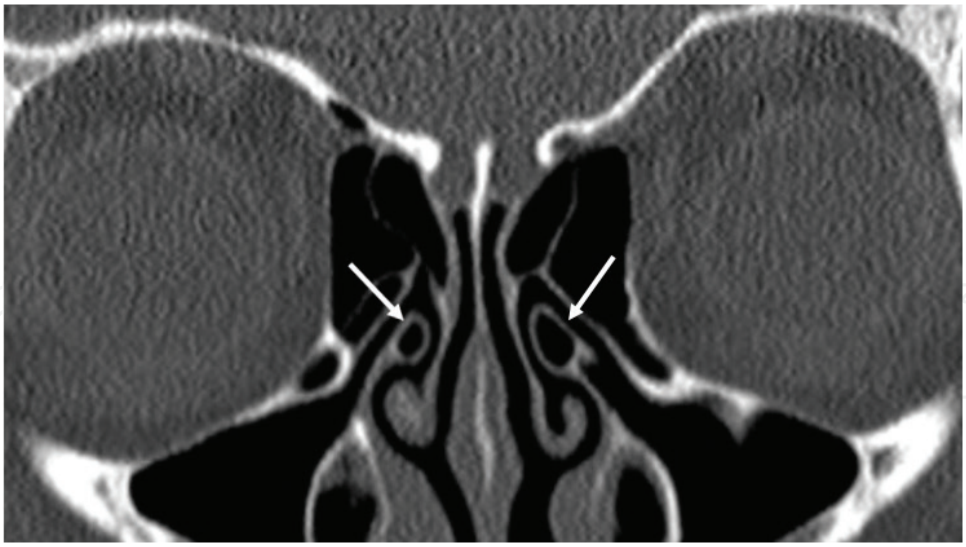

Figure 7. Coronal CT scan showing bilateral pneumatized uncinate process "uncinate bulla" (arrows). Note that ostiomeatal units are patent bilaterally; however, extensive pneumatization might compromise it.

- **Atelectatic uncinate process:** The uncinate will be adherent to the inferomedial wall of the orbit. Often seen in maxillary sinus hypoplasia or silent sinus syndrome. This condition increases the risk of inadvertent violation of the orbit during endoscopic sinus surgery.
- **Horizontal uncinate process:** Almost always associated with large ethmoid bulla. Rarely the uncinate process could be totally absent.

3.4.2. Hiatus semilunaris and ethmoid infundibulum

The space between the anterior wall of ethmoid bulla and the free edge of uncinate process is called the hiatus semilunaris; it opens anterosuperiorly into a cavity called the ethmoid infundibulum. The ethmoid infundibulum is the space between the uncinate process and the inferomedial wall of the orbit (**Figure 5**). Hiatus semilunaris receives drainage from the ethmoid bulla. The maxillary sinus and often the frontal sinus, depending on the superior attachment of the uncinate process, drain into the ethmoid infundibulum.

3.5. Olfactory fossa

The olfactory fossa contains olfactory bulbs and blood vessels. Its boundaries are inferiorly the cribriform plate of the ethmoid and medially the crista galli. Laterally it is bounded by the thinnest bone in the anterior skull base "the lateral lamella of the cribriform plate." Superiorly it communicates with the anterior cranial fossa.

Keros in 1962 classified the depth of olfactory fossa into three types based on the length of the lateral lamella [13]:

- **Type 1:** The length of the lateral lamella is 1–3 mm, suggesting a shallow olfactory fossa seen in 12% of the population.

- **Type 2:** The length of the lateral lamella is 4–7 mm, means a moderately deep olfactory fossa seen in 70% of the population.
- **Type 3:** The lateral lamella is longer, measuring 8–16 mm indicating a deep olfactory fossa seen in 18% of the population (**Figure 8**).

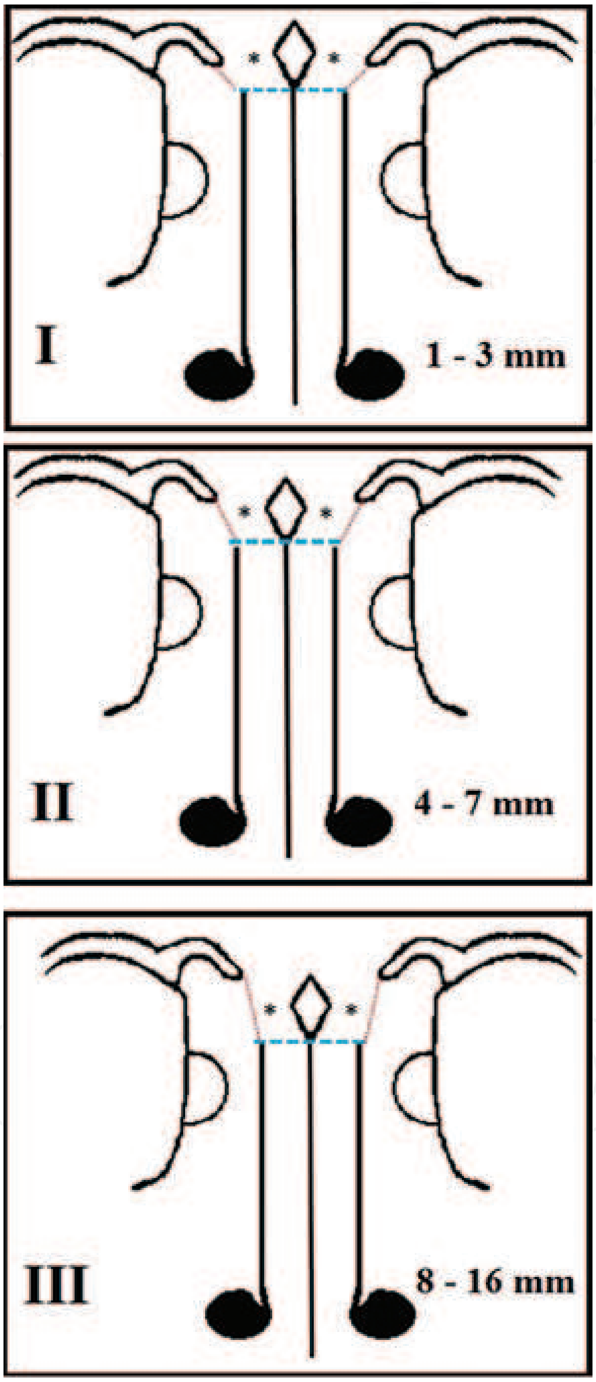

Figure 8. Coronal view of the olfactory fossa (asterisks) and its variations of depth. Thick dashed line represents the cribriform plate of the ethmoid. Thin dashed lines represent the thin lateral lamella of the cribriform. The depth of the olfactory fossa classified based on the length of the lateral lamella. Type I: lateral lamella length 1–3 mm; type II: lateral lamella length 4–7 mm; and type III: lateral lamella length 8–16 mm.

An anatomical variation of asymmetry in the depth of olfactory fossa had been reported in literature in up to 10–30% of the population [14].

Both type 1 and type 3 olfactory fossae are at increased risk for injury during endoscopic sinus surgery because in type 1 the angle between the medial and lateral lamellae of the cribriform plate is greater, and in type 3 the olfactory fossa is lower.

3.6. Blood supply, innervation, and lymphatic drainage of the nasal cavity

The nasal cavity is supplied by circulation derived from the internal and external carotid arteries, namely anterior and posterior ethmoidal arteries, sphenopalatine artery, septal branch of the superior labial artery, and the greater and ascending palatine arteries. Sphenopalatine artery is the main supplier of the nasal cavity.

In the lateral nasal wall, sphenopalatine artery after entering the nasal cavity through the sphenopalatine foramen gives off its posterior lateral nasal branches to supply the lateral wall. And it crosses the face of sphenoid sinus toward the posterior end of nasal septum as the posterior septal artery.

Veins accompany the arteries and drain to pterygoid plexus, facial vein, ophthalmic, and inferior cerebral veins [15].

Lateral nasal wall receives innervation from many nerves. Infraorbital nerves supply the vestibular area. The anterior ethmoidal nerve supplies the superior part of lateral wall. And the anterior superior alveolar nerve innervates the mucosa at the level of the wall of the maxillary sinus. The upper back mucosa is supplied by the lateral posterior superior nasal nerve. And the lower back mucosa innervated by the posterior inferior nasal nerve. The parasympathetic fibers reach the nasal cavity in the vidian nerve, and sympathetic fibers follow the blood vessels.

Lymphatic drainage of nasal cavity is to the submandibular, deep cervical, and retropharyngeal nodes.

4. Maxillary sinus

Maxillary sinus occupies the body of the maxillary bone. It is pyramidal in shape, with the base facing medially. The roof of the sinus is the orbital floor, and sinus's floor is formed by the alveolar process of the maxilla.

The medial wall of the maxilla is a large bony defect, known as "the fontanelle," in which the lateral nasal wall mucosa lies directly over the maxillary sinus medial wall mucosa. However, the bony defect is made much smaller by the contribution of the surrounding bones like lacrimal bone, ethmoid bone, inferior turbinate, and perpendicular plate of the palatine bone. This fontanelle is crossed by the uncinate process which divided it into a small anterior fontanelle and larger posterior fontanelle [16].

In adult individual, the maxillary sinus may extend from the area of the premolar teeth to the third molar, with a volume of approximately 15–22 ml [17].

In hyperpneumatized sinus, the apices of the molars or premolars are separated by a thin bone from the floor of the maxillary sinus or even project into the sinus floor. Occasionally, this bone is very thin or even absent, making extraction of such a tooth risky to leave a fistula by tearing of the mucous membrane. However, these types of fistulae often end with spontaneous healing [18].

Immediately posterior to the maxillary sinus lie the infratemporal fossa laterally and the pterygopalatine fossa medially.

4.1. Infraorbital nerve

The infraorbital nerve, a branch of the maxillary division "V2" of the trigeminal nerve, crosses the roof of maxillary sinus within a bony canal that opens as the infraorbital foramen, about 1 cm below the infraorbital rim (**Figure 9A**).

The inferior wall of the infraorbital canal can be extremely thin, with an average thickness of 0.2 mm or it may be completely dehiscent in between 12 and 16% of cases. It can be abnormally protruded within the maxillary sinus as well [19] (**Figures 9B** and **C** and **12**). In these situations, surgeon must identify these variants if present and pay extra attention during the procedure not to injure the nerve.

4.2. Maxillary sinus natural ostium

Ostium of the maxillary sinus is located in the upper portion of the medial wall of the sinus, and it opens at the posterior end of the hiatus semilunaris below the ethmoid bulla. The diameter of the ostium is about 2–4 mm, but it can be as wide as 10 mm. Mostly, the ostium existed as a canal with inferolateral orientation toward the sinus; however, it might be only an opening in some cases [20].

4.3. Development of maxillary sinus

Although the development of maxillary sinus starts in the intrauterine period, at birth it is not more than a shallow sac below the medial side of the orbital floor.

The growth of maxillary sinus is characterized by biphasic rapid growth, first phase during the first 3 years of life and the second phase from 7 to 12 years of age. A slow pneumatization continues until the age of 20 years as well.

- By the age of four, the lateral wall of the sinus reaches the infraorbital canal.
- By the age of seven, the floor reaches the level of inferior turbinate.
- By the age of nine, the floor of maxillary sinus reaches the level of the floor of nasal cavity.
- In adult individual, the floor of the sinus extends about 1 cm below the level of the floor of nasal cavity [21].

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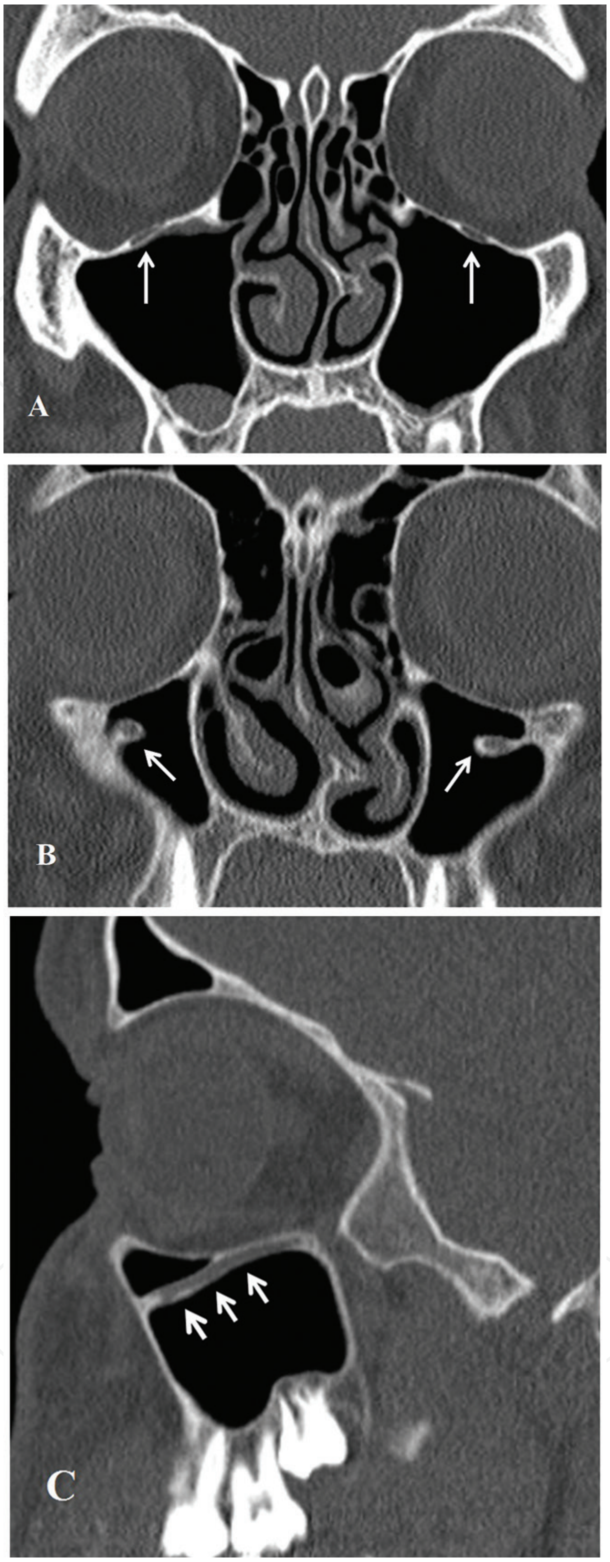

Figure 9. Coronal and sagittal CT scan. (A) Normal infraorbital bony canal (arrows) note the thin bony walls of the canal. (B) Bilateral aberrant locations of the infraorbital canals (arrows). They are protruded into the sinus which put the nerves at risk of traumatic injury during endoscopic maxillary sinus surgery. (C) Sagittal view for the left maxillary sinus of same patient in (B), demonstrating how the infraorbital canal is abnormally crossing the maxillary sinus (small arrows).

4.4. Anatomical variations of maxillary sinus

- **Accessory sinus ostium:** Any maxillary sinus opening outside the hiatus semilunaris is considered an accessory ostium. Its incidence is about 10–16%; however, some literature report a higher rate [22]. It is located in the posterior fontanelle, posterior to natural ostium (**Figure 10**). Typically, it is smaller than the natural ostium with an average diameter of 1.5 mm. The clinical significance of the presence of an accessory ostium is that occasionally a circular flow of mucus between the natural and the accessory ostia could occur, leading to recurrent sinusitis. If an accessory ostium is encountered intraoperatively, it should be surgically connected with the natural ostium.
- **Maxillary sinus hypoplasia:** It could be a genuine variant in about 10% of the population [4]. However, it might be secondary to other conditions like silent sinus syndrome, post-operated, or post-traumatic sinus. It carries a higher risk of orbital penetration during endoscopic sinus surgery.
- **Maxillary sinus septum:** Maxillary sinus septum is defined as a ridge that is 2.5 mm or more in height. It can be bony or fibrous septum [23]. Usually extends from the infraorbital canal to the lateral wall of the sinus. Occasionally it can impair the drainage of the sinus (**Figure 11**).
- **Infraorbital cell (Haller cell):** Any extension of the anterior ethmoid air cells along the orbital floor and lateral to the lamina papyracea is considered an infraorbital cell (**Figure 12**). The incidence of this variation ranges from 10 to 18% in the literature. It might compromise the patency of the maxillary ostium [24].

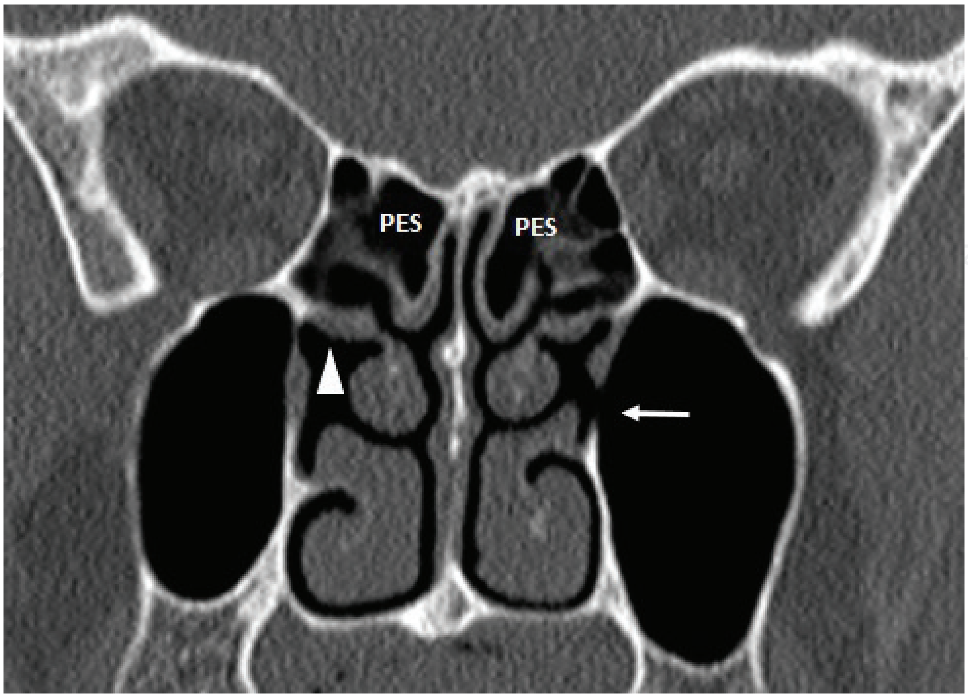

Figure 10. Coronal CT scan showing an accessory maxillary sinus ostium at the left maxillary sinus (arrow). It is located posterior to natural ostium, note the presence of the horizontal "third" part of middle turbinate (arrowhead), and the posterior ethmoid air cells (PES) indicate a posterior level of the view.

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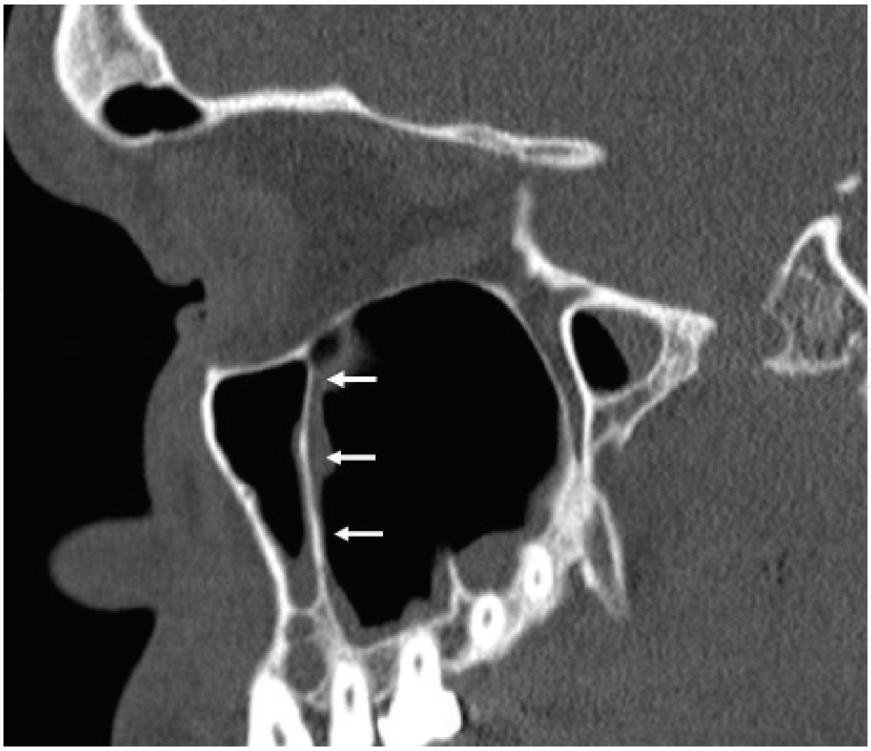

Figure 11. Parasagittal CT scan at the level of left maxillary sinus, showing a bony maxillary sinus septum (arrows). Large sinus septum could compromise the drainage of the sinus.

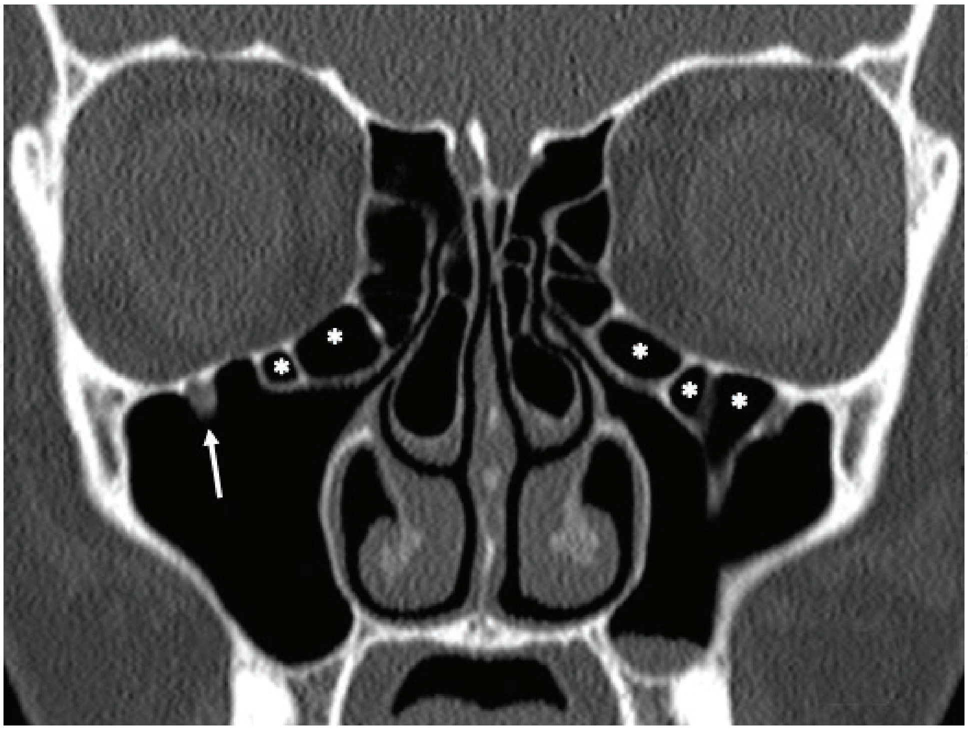

Figure 12. Coronal CT scan illustrates multiple bilateral infraorbital air cells "Haller cells" (asterisks). Any extension of ethmoid pneumatization at the orbital floor and lateral to lamina papyracea is labeled as Haller cell. Note how these cells significantly narrow the maxillary ostia bilaterally. Also, the infraorbital nerve canal on the right side is in the normal position; however, there is a complete dehiscence of its inferior bony wall (arrow). Patient is having large bilateral concha bullosa as well, which can further affect the ostiomeatal unit patency.

4.5. Blood supply, innervation, and lymphatic drainage

Maxillary sinus receives its blood supply by small arteries from the sphenopalatine, infraorbital, greater palatine, facial, pterygopalatine, posterior lateral nasal, and posterior superior alveolar arteries. Veins accompany these vessels drain to the facial vein and to the pterygoid plexus.

The innervations are from the maxillary division (V2) of trigeminal nerve through various branches, namely superior alveolar (posterior, middle, and anterior), greater palatine, and infraorbital nerves. While the area of the ostium is the most sensitive portion, the main part of the sinus is being relatively insensitive.

The lymphatic drainage is through the infraorbital foramen or the ostium to the submandibular node.

5. Ethmoid sinus

The ethmoid bone consists of five components: crista galli, cribriform plate, perpendicular plate, and two ethmoidal labyrinths. Each ethmoid labyrinth projects laterally from the side of the perpendicular plate. Each ethmoidal labyrinth consists of middle and superior turbinates, ethmoid air cells, and a thin paper-like lateral surface called "the lamina papyracea." The lamina papyracea forms a large part of the medial orbital wall as well.

The ethmoid air cells are divided by the basal lamella of middle turbinate into anterior and posterior ethmoid sinuses. The ethmoidal labyrinth does not have its own roof, and the roof of the sinus is formed by the orbital plate of frontal bone "Fovea ethmoidalis" [25].

Unlike the other sinuses, ethmoid sinus is not formed by a single air cell, instead it is divided by bony septa into variable number of air cells. Anterior ethmoid contains more air cells than the posterior ethmoid; however, the posterior ethmoid air cells are larger. In adult individual, the average number is 3–7 air cells in the anterior ethmoid sinus, and 2–4 in the posterior ethmoid. Each air cell drains through its own ostium, with anterior ethmoid air cells drain into the middle meatus and the posterior ones drain into the superior meatus [26].

5.1. Ethmoid bulla

The ethmoid bulla is the largest air cell of anterior ethmoid sinus. It extends from the lamina papyracea laterally and bulges medially into the middle meatus. The ostium of the ethmoid bulla often located on the upper margin of the posterior wall and drains into the middle meatus. Ethmoid bulla can be of variable sizes; however, occasionally "about 8% of the population," it might be underdeveloped [27].

A rare anatomical variation of the ethmoid bulla, when it is non-pneumatized. In this case, there will be a bony projection from the lamina papyracea known as "torus lateralis." Surgeon must be aware of this anatomical variant during endoscopic sinus surgery to prevent any unintentional orbital penetration [28].

5.2. Anterior ethmoidal artery

The anterior ethmoidal artery is one of the critical structures within the ethmoid sinus. After branching from the ophthalmic artery within the orbit, it pierces the upper portion of the lamina, then crosses the roof of anterior ethmoid sinus within a bony canal (approximately 2–3 mm behind the face of the ethmoid bulla). After crossing the sinus, it pierces the lateral lamella to enter the olfactory fossa. Then descends into nasal cavity through a slit on the side of the crista galli (**Figure 13A**).

The anterior ethmoidal artery foramen in the lamina papyracea is located about 24 mm posterior to the anterior lacrimal crest. The ophthalmic artery gives off another branch "the posterior ethmoidal artery" as well, which enters the posterior ethmoidal foramen 36 mm posterior to the anterior lacrimal crest [29].

Occasionally, the anterior ethmoidal artery bony canal might be dehiscent or totally absent, and the artery is suspended on the mucosa of the sinus (**Figure 13B**). The importance of preoperative identification of this condition cannot be stressed enough to avoid injuring the artery during operating endoscopically on the ethmoid sinus.

5.3. Development of the ethmoid sinus

Formation of the ethmoid sinus starts in fetal life. At birth, the sinus is present and can be identified radiologically. There is a rapid pneumatization between the first year and the age

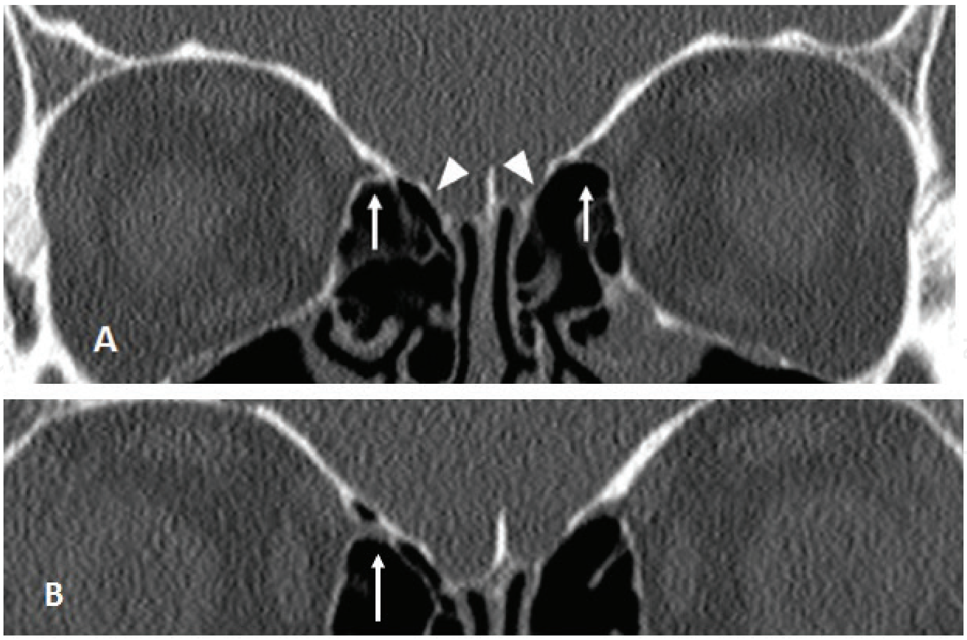

Figure 13. Coronal CT scan showing (A) the anterior ethmoidal artery canals while crossing the roof of ethmoid sinuses (arrows). The anterior ethmoidal artery foramen can be identified on the radiological imaging as a beak at the medial orbital wall. (B) Dehiscence of the bony canal and the anterior ethmoidal artery is suspended within the sinus on right side (arrow). Note the dehiscence of the inferior wall of the bony canal on the left side (arrowheads) indicate the thin lateral lamellae of the cribriform plate.

of four. Then it grows slowly till reaching the adult appearance by the age of 12. The clinical implication of the ethmoid sinus course of development is that the sinus could be the source of orbital infection in pediatric age group. And it is amenable to be surgically drained in this age group as well [30].

5.4. Anatomical variations of the ethmoid sinus

- **Agger nasi cell:** Makes the most anterior ethmoid air cells. Formed by an extension of the ethmoid air cell pneumatization into the lacrimal bone, and it is found as a prominence anterior to the vertical (anterior) attachment of middle turbinate (**Figure 14**). Their incidence is high, seen in about 93% of the population. Its size has a direct effect on the drainage of frontal sinus [31].

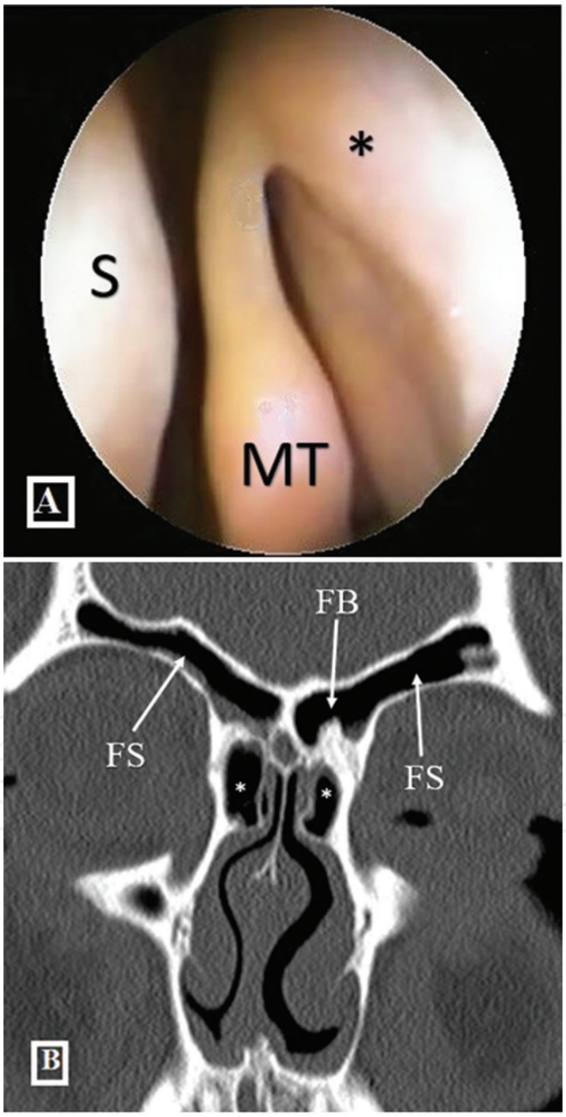

Figure 14. (A) Endoscopic picture showing the left agger nasi air cell as a prominence just anterior to the neck of the middle turbinate (asterisk). S, nasal septum; MT, middle turbinate. (B) Coronal CT scan at anterior level, showing bilateral agger nasi air cells (asterisk). Note the frontal sinuses (FS) and the frontal beak (FB) which corresponds to the frontal sinus ostium "refer to frontal sinus section".

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- **Suprabullar recess and retrobullar recess:** When the upper border of the ethmoid bulla is not reaching the skull base, the space formed between them is referred to as "suprabullar recess." And when there is a space between the posterior wall of the bulla and the basal lamella, posteriorly, this space is called "retrobullar recess" (**Figure 15**).
- **Suprabullar cell:** An ethmoid air cell lies above the ethmoid bulla, so the superior border is related to the anterior cranial fossa. This cell is limited to the posterior portion of the frontal recess and does not extend to the frontal sinus (which differentiates it from the frontal bullar cell, the latter does extend to the frontal sinus). So, the anterior border of the suprabullar cell is made by the frontal recess (**Figure 5**).
- **Supraorbital cell:** A lateral extension of pneumatization from the suprabullar recess into the orbital plate of frontal bone over the orbit (**Figure 16**). Literature report 15% as an incidence of the supraorbital cell occurrence in the population.

  The anatomical significance of the supraorbital cell is that if it is large it can displace the anterior ethmoidal artery posteriorly. In addition, during endoscopic sinus surgery, it can be mistaken as the frontal sinus [32].
- Occasionally, small focal corticated defects in the lamina papyracea can be seen in up to 0.5–10% of the population; however, they are not clinically significant [33].
- **Sphenoethmoidal cell (Onodi's cell):** When the posterior ethmoid air cells pneumatized further posteriorly, and extend superiorly and laterally to sphenoid sinus, it is called the sphenoethmoidal cell or Onodi's cell. This can be explained by the fact that the ethmoid air cells are developed and pneumatized earlier than the sphenoid sinus, so they have a room

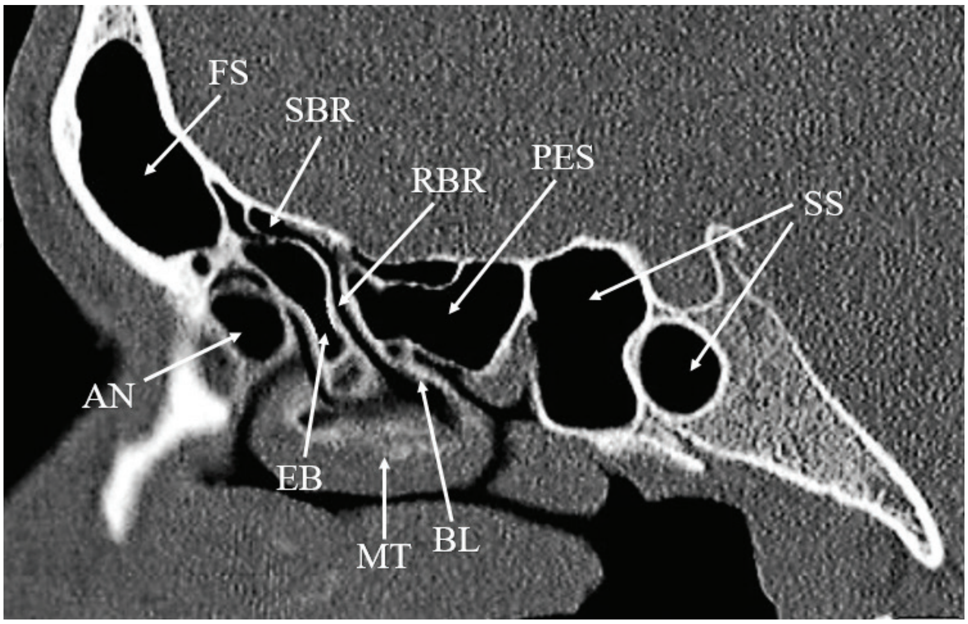

Figure 15. Parasagittal CT scan showing an ethmoid bulla (EB) that is not extending superiorly to the skull base, the gap created between it and the skull base is known as the suprabullar recess (SBR). Also, note that there is a gap between the posterior bullar wall and the basal lamella (BL), which is referred to as the retrobullar recess (RBR). FS, frontal sinus; AN, Agger nasi air cell; MT, middle turbinate; SS, right and left sphenoid sinuses. PES, posterior ethoid sinus.

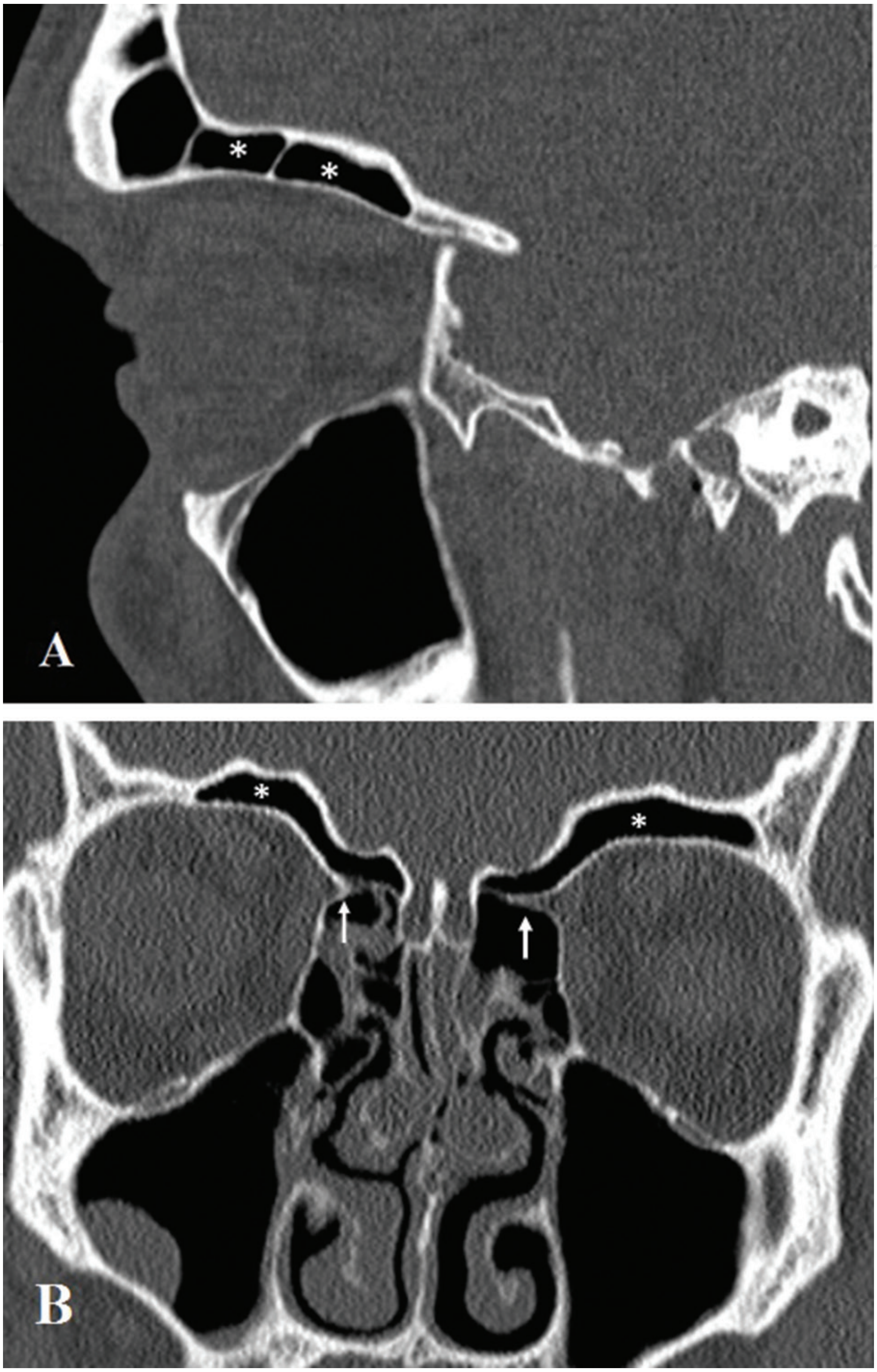

Figure 16. (A) Parasagittal CT scan showing an extension of pneumatization over the orbit (asterisks). (B) Coronal image of same study, showing bilateral supraorbital air cell (asterisks), note the anterior ethmoidal artery canal "arrows" is crossing between the anterior ethmoid sinus and the supraorbital air cell, which subjected the artery to a great risk during endoscopic sinus surgery while approaching these air cells.

to extend posteriorly. The incidence of the sphenoethmoidal cell ranges from 3.4 to 14% in the literature [34]. The significance of this air cell is that it is closely related to the optic nerve on its superolateral wall, and the nerve can even be engulfed within the air cell as well (**Figure 17**).

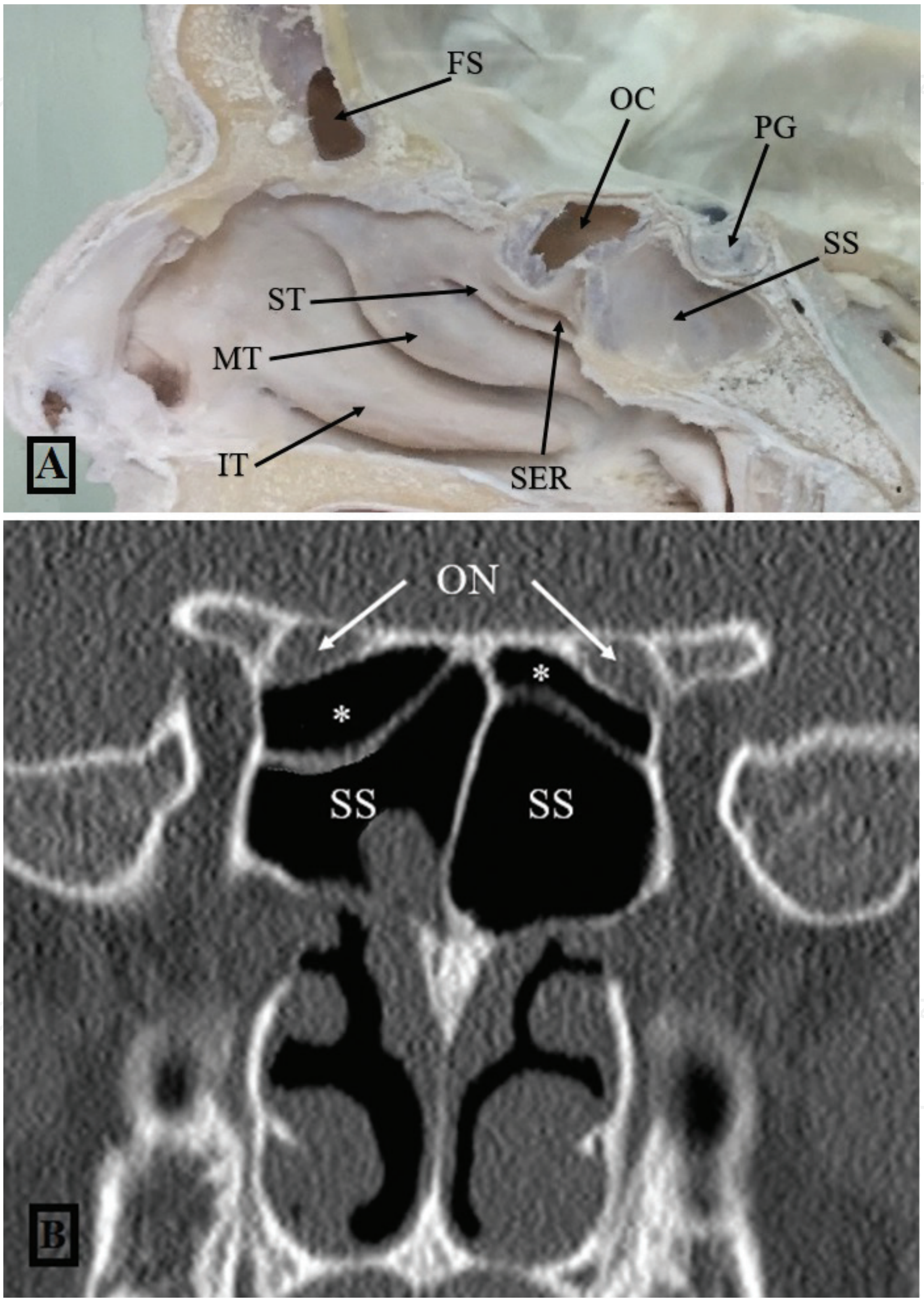

Figure 17. (A) Parasagittal gross picture showing how the Onodi's cell (OC) is extending posteriorly over the sphenoid sinus (SS). Note that Onodi's cell drains into the superior meatus, in contrary to the sphenoid sinus which drains into the sphenoethmoid recess (SER) lateral to the superior turbinate (ST). IT, inferior turbinate; MT, middle turbinate; FS, frontal sinus; PG, pituitary gland. (B) Coronal CT scan view at posterior level showing bilateral Onodi's cells (asterisks). Note how the optic nerve canals (ON) are closely related to the superolateral walls of the Onodi's cells. SS, sphenoid sinus.

- **Pneumatized crista galli:** Seen in 13% of individuals. The pneumatization extends from the frontal sinuses. Rarely can obstruct the frontal ostium [35].

5.5. Blood supply, innervation, and lymphatic drainage

Anterior and posterior ethmoid sinuses receive blood supply by branches from the supraorbital, anterior, and posterior ethmoidal and sphenopalatine arteries. The venous drainage is via the accompanying veins to the superior ophthalmic vein or pterygopalatine plexus.

The innervation is by anterior and posterior ethmoidal nerves of the ophthalmic division (V1) and the posterior nasal branch of the maxillary division (V2) of the trigeminal nerve.

The lymphatic drainage of the anterior ethmoid sinus is to the submandibular nodes, and the posterior ethmoid sinus drains to the retropharyngeal nodes.

6. Frontal sinus

There are two sinuses extending in the squamous part of the frontal bone. They are separated by bony septum because each sinus (right and left) develops independently; they are expected to be asymmetrically pneumatized. The larger sinus may pass across the midline and overlap the other.

Sinus's anterior and posterior walls are called outer and inner frontal table, respectively. The inner table is a relative thin bony plate that separates frontal sinus from the anterior cranial fossa posteriorly. On the other hand, the outer table is a considerable thick bony wall [36]. On the posterior wall (inner table) of the sinus, there are venous drainage channels called "foramina of Breschet." These foramina have clinical significance in their role in spreading the infection from the sinus toward intracranially. Also, these foramina act as sites of mucosal invagination within the bone, so failing to completely remove the mucosa in these sites during the sinus obliteration procedure may predispose to the development of mucocele. The floor of each frontal sinus forms the anterior roof of the orbit. The floor consisted of a thin bone which can be eroded by the mucocele.

6.1. Frontal ostium and frontal recess (frontal sinus drainage pathway)

Frontal sinus ostium is located at the posteromedial part of sinus's floor. The frontal sinus drainage pathway has an hour-glass shape, with the narrowest point of this pathway corresponds to "the frontal beak" which represents the frontal sinus ostium (**Figure 18**A). Therefore, what lies superior to the frontal beak is frontal sinus, and what lies inferior to the beak is frontal recess [37]. The thickness of the frontal beak (frontonasal process of the maxilla) will determine the size and patency the frontal sinus ostium.

Frontal recess is like an inverted funnel with its apex formed by the frontal sinus ostium. The frontal recess is not a structure by itself, rather it is formed by walls of the surrounding structures. Boundaries of frontal recess are as follows: from the anterior and inferior side, the posterior wall of agger nasi cell; from the posterior side, the face of ethmoid bulla;

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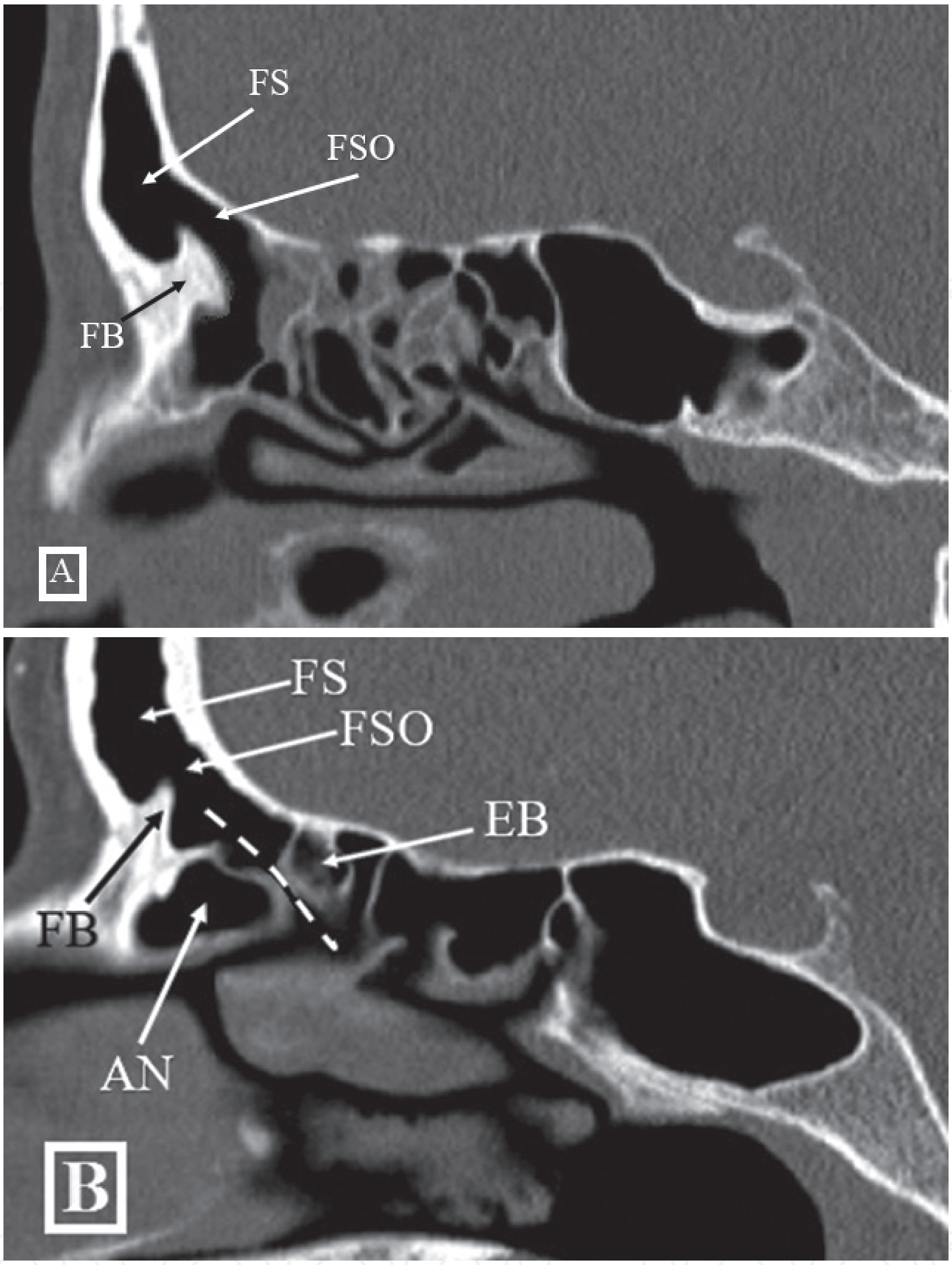

Figure 18. Parasagittal CT scan images. (A) Prominent frontal beak (FB) which corresponds to the level of the frontal sinus ostium (FSO). Superior to the beak is the frontal sinus (FS). (B) A relatively small frontal beak (FB), which is often associated with large agger nasi air cell (AN). Note that the large agger nasi cell causing a significant narrowing of the frontal recess (dashed line). As agger nasi cell forms the anterior wall of the recess, ethmoid bulla (EB) forms the posterior wall. So, any enlargement or pathology affecting either cells could compromise the patency of the frontal recess.

lateral boundary is formed by the lamina papyracea; medial side formed by the lateral wall of olfactory fossa and the upper portion of middle turbinate; and superiorly, comes the fovea ethmoidalis.

Depending on the superior attachment of the uncinate process, the frontal sinus drainage pathway drains into the middle meatus or the ethmoid infundibulum (as mentioned in the uncinate process section) [38].

6.2. The relationship between frontal beak and agger nasi cell size

When agger nasi cell is small, the frontal beak becomes prominent and narrows the ostium. In contrary, the large agger nasi cell results in a small frontal beak which means wider frontal sinus ostium. However, the large agger nasi cell might compromise the frontal sinus drainage pathway at the level of frontal recess, inferiorly (**Figure 18B**) [39].

6.3. Anatomical variations of frontal sinus

- Frontal sinus aplasia (totally absent) is found in 5% of the population (**Figure 19**). And hypoplastic frontal sinus is found in 4%.
- **Frontoethmoidal cells (Frontal cells):** Classification of frontal cells was first described by Kuhn [40]. However, later Wormald modified the frontal cells classification [41]. (This chapter reviews the modified classification by Wormald.) They were classified into four groups as follows:

  Type 1 frontal cell: Single frontal recess cell (above agger nasi cell and below the frontal ostium) (**Figure 20A**).

  Type 2 frontal cells: Two or more cells in frontal recess (above agger nasi cell and below the frontal ostium) (**Figure 20B**).

  Type 3 frontal cell: Single cell above the agger nasi with extension into the frontal sinus through the frontal ostium but not exceeding 50% of the vertical height of the ipsilateral frontal sinus (**Figure 20C**).

  Type 4 frontal cell: Either single cell above the agger nasi with extension into the frontal sinus through the frontal ostium, and exceeding 50% of the vertical height of the ipsilateral frontal sinus, or an isolated cell within the frontal sinus (above the frontal ostium) (**Figure 20D**).

- **Frontal bullar cell**: Single cell extends from the suprabullar region along the posterior wall of frontal recess and extends into the frontal sinus, superiorly. This differentiates it from

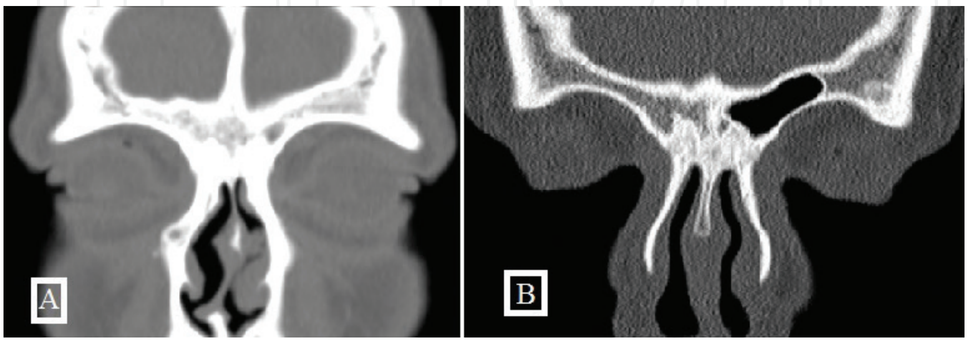

Figure 19. Coronal CT scan. (A) Bilateral aplastic frontal sinuses. (B) Because each frontal sinus develops independently, a variant like unilateral aplastic frontal sinus can occur.

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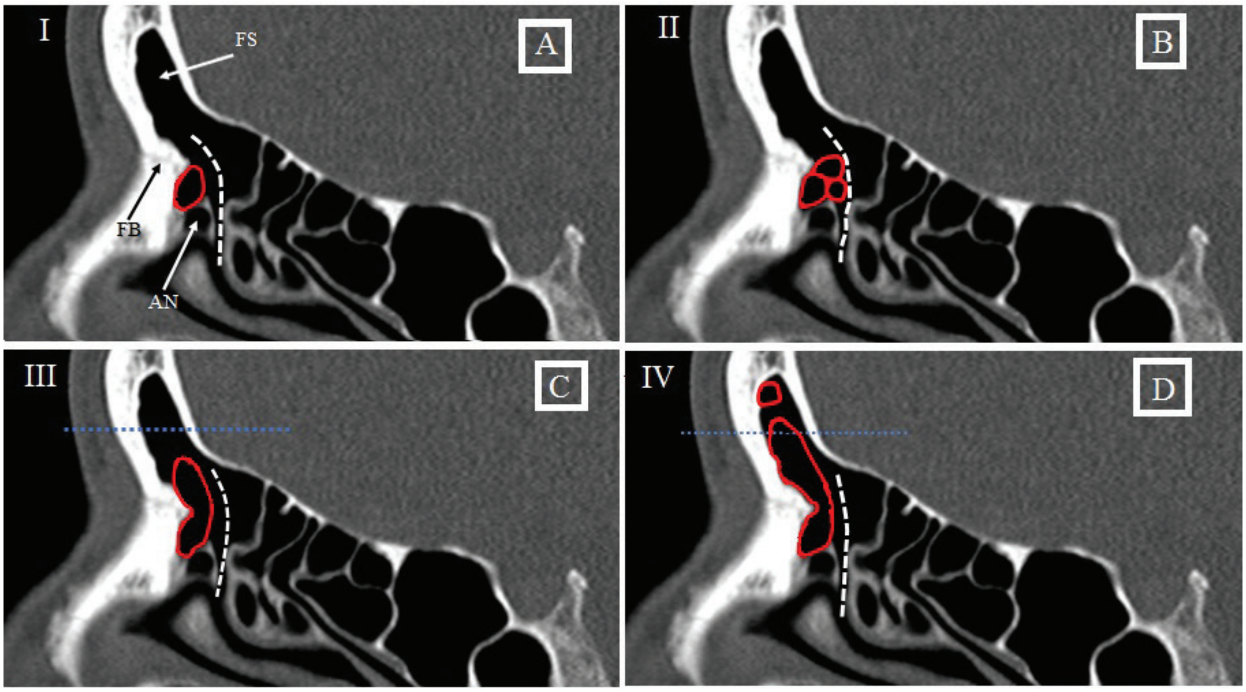

Figure 20. Parasagittal diagram demonstrating four types of the frontoethmoidal "frontal" cells (red). FS, frontal sinus; FB, frontal beak "corresponding to the frontal ostium"; AN, agger nasi cell; blue dashed line represents the midway of the frontal sinus vertical length.

the suprabullar cell, which does not extend into the frontal sinus. The posterior wall of the frontal bullar cell is related to anterior cranial fossa, and its anterior wall is related to frontal sinus (**Figure 21**). Caution must be taken during opening this cell not to cause unintentional trauma to anterior skull base.

- **Frontal intersinus septal cell:** Occasionally, the intersinus septum is pneumatized forming an intersinus air cell, which might be communicating with either one of the frontal sinuses or could be completely an isolated air cell. It might compromise the frontal sinus ostium patency [42] (**Figure 22**).

6.4. Air cells that might affect the patency of the frontal ostium or the recess

(1) Agger nasi cell; (2) Ethmoid bulla; (3) Suprabullar cell; (4) Frontal bullar cell; (5) Frontoethmoidal cells (Frontal cells); (6) Frontal intersinus septal cell (**Figure 23**).

6.5. Development of frontal sinus

Frontal sinuses are the only sinuses that are not present at birth. They start pneumatization by the age of two and reach the orbital roof by the age of 5–7. By age of 12, they reach the adult size [3]. The clinical application of the frontal sinus development process is that external trephination procedure is contraindicated before the developing sinus reaches the level of orbital roof because of the risk of intracranial penetration.

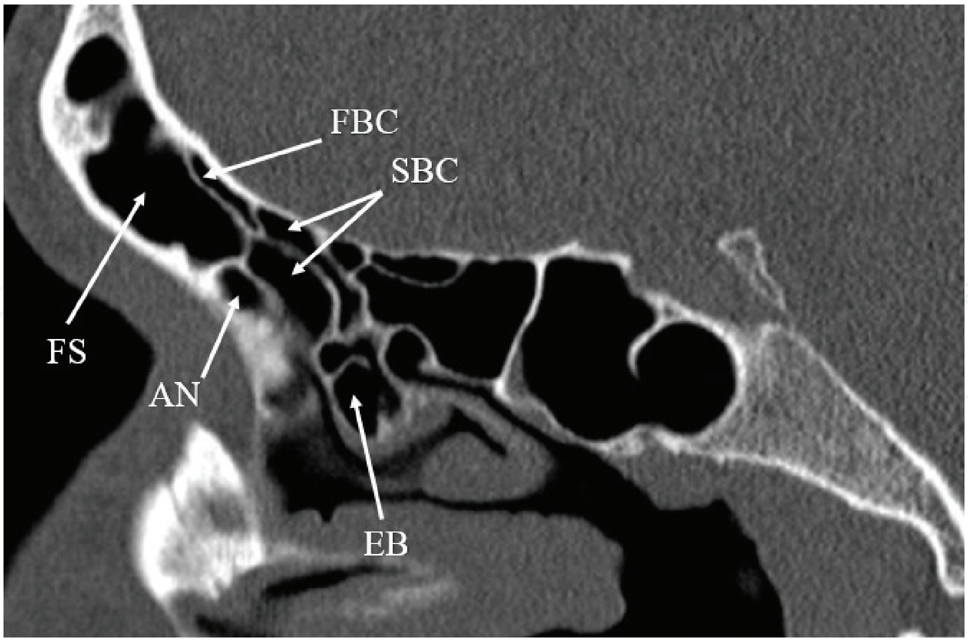

Figure 21. Parasagittal CT scan showing frontal bullar cell (FBC). Note that the posterior border of the cell is related to the anterior cranial fossa. And the frontal sinus (FS) is making the anterior border. The suprabullar cells (SBC) are limited to the frontal recess and are not extending to frontal sinus. AN, Agger nasi; EB, ethmoid bulla.

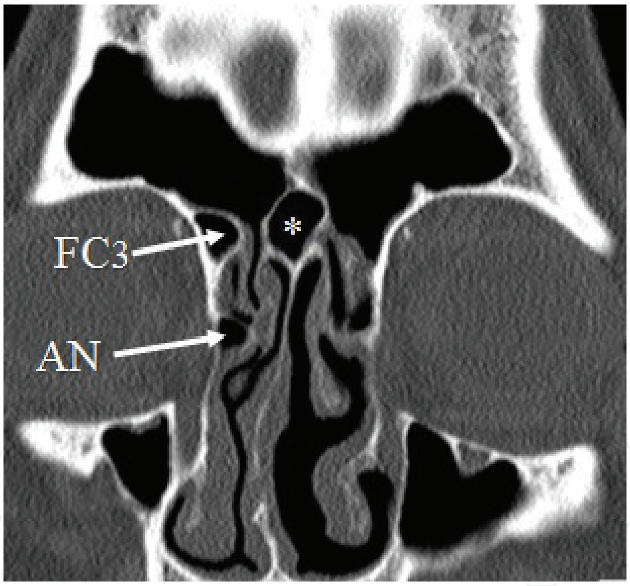

Figure 22. Coronal CT scan showing frontal intersinus septal air cell (asterisk). Note the frontal cell type 3 on the right frontal sinus (FC3). Frontal sinus ostium might be compromised because of the impact of either of these two cells. AN, Agger nasi cell.

6.6. Blood supply, innervation, and lymphatic drainage

Frontal sinus receives blood supply from the supratrochlear and supraorbital arteries (branching from ophthalmic artery). Venous drainage is by the superior ophthalmic and diploic veins. Lymph drainage is across the face to the submandibular nodes. Frontal sinus receives innervation from the supratrochlear and supraorbital nerves.

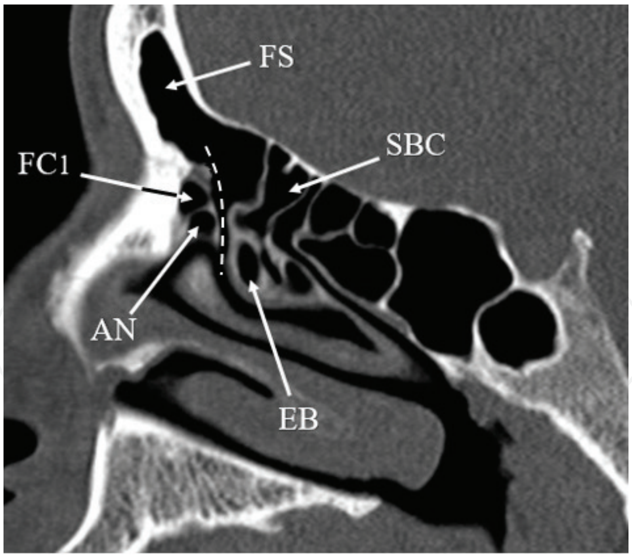

Figure 23. Parasagittal CT view of the frontal recess (dashed line). Note that anterior to the frontal recess are the agger nasi cell (AN) and frontoethmoidal cell "frontal cell" type 1 (FC1). And posterior to the recess are the ethmoid bulla (EB) and the suprabullar cell (SBC). Expanding of any of these air cells could have an impact on the patency of the frontal recess. Also, other air cells like frontal bullar cell or frontal intersinus septal cell could compromise frontal sinus drainage pathway at the ostium level.

7. Sphenoid sinus

Sphenoid sinuses occupy the body of sphenoid bone. Classically, there are two asymmetrical sinuses separated by off-midline intersphenoid bony septum.

7.1. Sphenoid sinus ostium and posterior septal artery

Sphenoid sinus drains into the sphenoethmoidal recess through a single sphenoid ostium in the sinus's anterior wall, which opens medial to superior turbinate. Typically, the ostium is located in the medial portion of sphenoidal face, about 10–12 mm superior to the upper border of the choana. Also, it can be located be measuring 7 cm from anterior nasal spine at an angle of 30° with the nasal floor. The posteroinferior end (the tail) of superior turbinate can be used to locate the ostium, which typically would be just superomedial to the tail of superior turbinate [43].

Inferior to sphenoid natural ostium, the posterior septal artery (a branch of sphenopalatine artery) crosses the sphenoid face from the lateral nasal wall to the posterior end of nasal septum. Either it bifurcates into superior and inferior branches before crossing (65%) or crosses as main artery then bifurcates (35%). Even if it bifurcates before crossing, both branches pass inferior to the ostium. The average distance between the sphenoid ostium and the posterior septal artery or its superior branch is about 5 mm. Because of that, during widening the ostium, it is safer to dissect and widen the sphenoid ostium horizontally and superiorly. Alternatively, to use the electrocautery if the ostium will be widening more than 5 mm inferiorly [44].

7.2. Vital structures surrounding the sphenoid sinus

Vital structures such as pituitary gland, optic nerves, cavernous sinuses and carotid arteries, maxillary divisions (V2) of the trigeminal nerves within the foramina rotundum, and vidian canals are closely related to the sphenoid body. Depending on the degree of pneumatization of the sinus, these structures could be seen as indentations on the sinus's roof and walls, internally.

Roof of the sinus is related to the pituitary gland and middle cranial fossa. Posteriorly lie the pons and the posterior cranial fossa. The optic nerve canal crosses the corner formed by the roof and the lateral wall on the posterior portion of the sinus on each side. On the posterolateral walls, internal carotid artery canals (cavernous segment) will be seen as bony prominences. Within the lateral sphenoid walls, the maxillary division of trigeminal nerves pass through the foramina rotundum toward the pterygopalatine fossae in both sides. Vidian nerves cross the lateral sides of the sinus floor within the vidian canals "pterygoid canals" (**Figure 24**).

7.3. Anatomical variations of sphenoid sinus

- **Sphenoid sinus pneumatization:** Depending on the degree of pneumatization, sphenoid sinus is classified into three types [45].
    - **Conchal type:** The degree of pneumatization is limited to the anterior portion of the sphenoid body and not reaching the level of the anterior wall of sella turcica. Seen in 1–4% of individuals (**Figure 25A**).
    - **Presellar type:** Pneumatization extends up to the vertical level of the anterior wall of sella turcica but not beyond that. Found in 35–40% of the population (**Figure 25B**).

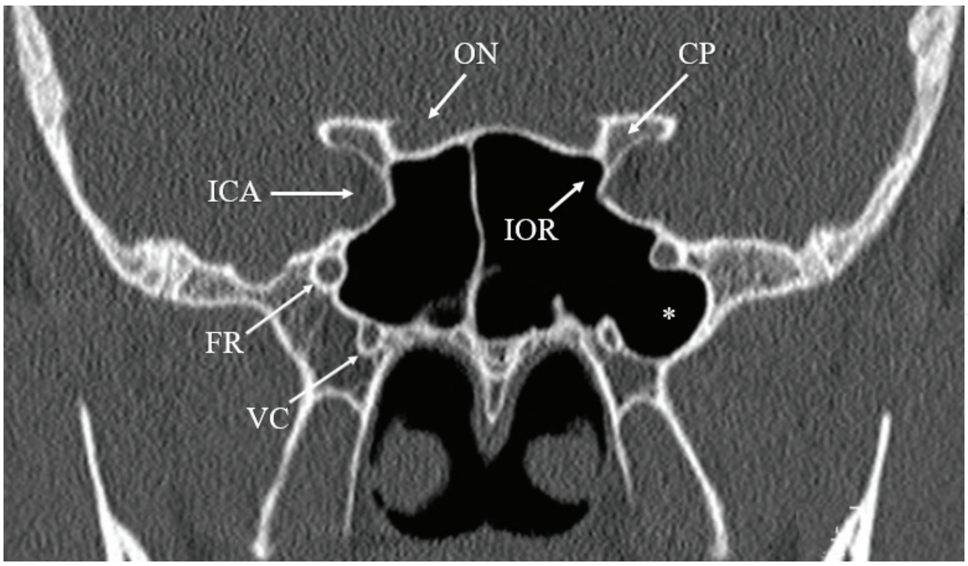

Figure 24. Coronal CT scan at the level of sphenoid sinus showing the critical structures neighboring the sinuses. ON, optic nerve; ICA, the cavernous segment of internal carotid artery; FR, foramen rotundum and V2 nerve; VC, vidian canal. In hyperpneumatized sinus, when pneumatization extends laterally between foramen rotundum and vidian canal, creating a recess known as the lateral recess (asterisk). When pneumatization extends below the optic canal "between optic canal and internal carotid artery" resulted in infraoptic "opticocarotid" recess (IOR). CP, anterior clinoid process.

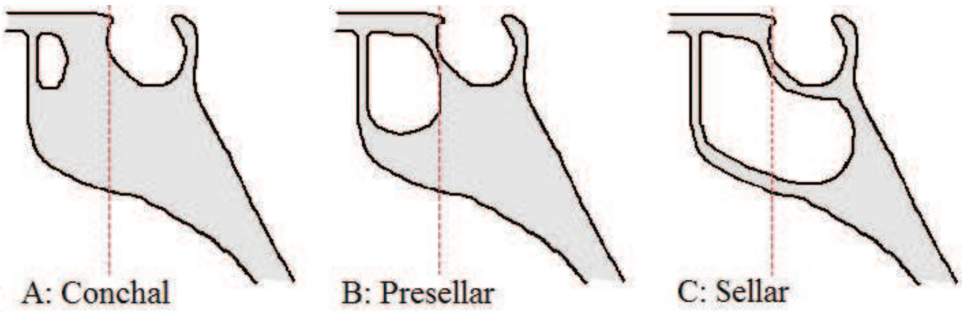

Figure 25. Sagittal view showing the types and degree of sphenoid sinus pneumatization related to the anterior wall of sella turcica (dashed line). (A) Conchal, when not reaching the vertical level of the anterior wall of sella turcica. (B) Presellar, when reaches but not beyond it. (C) Sellar, pneumatization beyond the anterior wall of sella turcica. Note the presence of a good density of cortical bone anterior to the pituitary fossa in conchal type, making procedures like endoscopic trans-sphenoid hypophysectomy, relatively contraindicated.

- **Sellar type:** Pneumatization extends beyond the level of the anterior wall of sella turcica below the pituitary fossa (**Figure 25C**) and might reach posterior to the sella turcica "occasionally called postsellar type" [46]. The sellar type is the most common one, seen in 55–60% of the population.

  Sphenoid sinus agenesis: When non-pneumatized sinus, it is found in less than 0.7% of the population.

  Sphenoid sinus agenesis or the conchal type are relative contraindications for endoscopic trans-sphenoid skull base approach.

- **Optic nerve canal dehiscence:** In 4% of cases, the bony canal is having a focal dehiscence and only sinus mucosa with neural sheath are separating the nerve from the sinus. In 78% of cases, the thickness of the wall of optic canal that separates it from the sinus is less than 0.5 mm [47] (**Figure 26B**).
- **Internal carotid artery canal dehiscence:** When areas of the medial side of bony canal separating the sinus from the artery are defected, putting the internal carotid artery at risk during the endoscopic sphenoid surgery. It was reported in literature a rate between 8 and 25% as the incidence of this variant [47, 48].

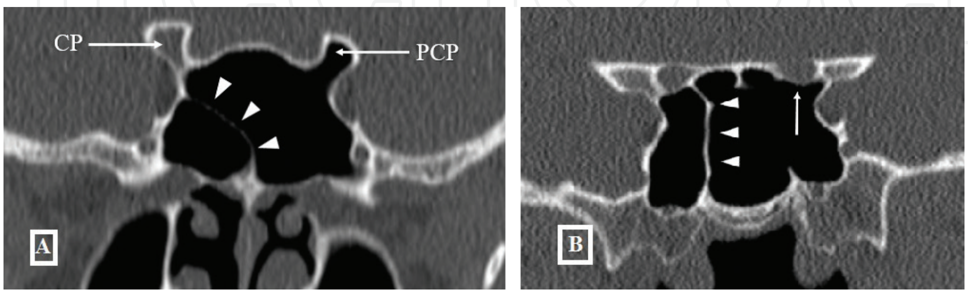

Figure 26. Coronal CT scan of the sphenoid sinus showing (A) Deviated sphenoid intersinus septum and attached to the right internal carotid artery canal (arrowheads). Also, note the extension of pneumatization to the left anterior clinoid process (PCP: Pneumatized clinoid process). Right normal anterior clinoid process (CP) indicated for comparison. (B) Deviated intersphenoid septum which attached to right optic canal (arrowheads). Note how thin can be the inferior bony wall of optic nerve canal, on the left side (arrow).

- The sphenoid intersinus septum occasionally deviates off the midline and has an insertion on the internal carotid artery bony canal or the optic canal. Excessive traction on the septum should be avoided, in these cases, not to cause avulsion of the bony wall (**Figure 26**).
- **Pneumatized posterior nasal septum:** Might be from an extension of air from the sphenoid sinus or crista galli. Rarely this cause narrowing of the sphenoethmoidal recess (**Figure 27**).
- **Supraoptic recess and infraoptic recess:** In hyperpneumatized sphenoid sinus, when pneumatization reaches superiorly and inferiorly to the optic canal, it will result in these two recesses, respectively. Because the infraoptic recess lies between the optic canal and internal carotid artery canal, also known as "opticocarotid recess" (**Figure 24**). In addition, pneumatization can extend from the infraoptic recess to the anterior clinoid process (**Figure 26A**).
- **Lateral recess:** When pneumatization extensively extends inferolaterally between the maxillary (V2) and vidian nerves, it creates this recess (**Figure 24**).

7.4. Development of the sphenoid sinus

At birth, it is not more than a small mucosal sac. Pneumatization starts around the third year of life. It gradually progresses until it reaches the adult size around the age of 14.

7.5. Blood supply, innervation, and lymphatic drainage

Arterial supply is from the posterior ethmoidal artery and posterior septal artery. Veins drain via the posterior ethmoidal vein to the superior ophthalmic vein. The sinus mucosa receives

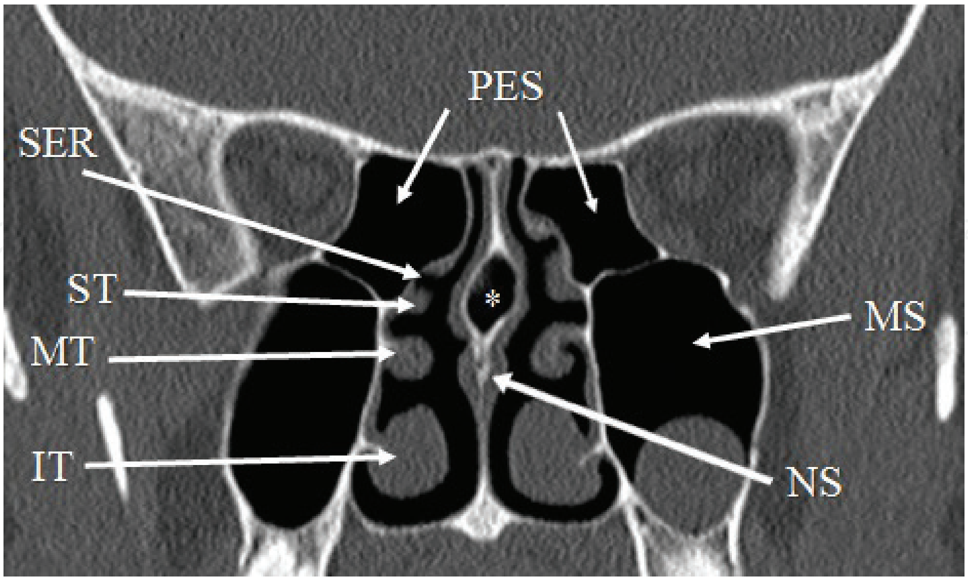

Figure 27. Coronal CT scan showing a pneumatized posterior nasal septum (asterisk). Note the proximity of sphenoethmoid recess (SER) to the pneumatized portion, which can be affected in extensive pneumatization. ST, tail of superior turbinate; NS, nasal septum; PES, posterior ethmoid sinus; MS, maxillary sinus; IT, inferior turbinate; MT, middle turbinate.

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innervation from the posterior ethmoidal nerve and the orbital branch of pterygopalatine ganglion. The Lymph drains to the retropharyngeal nodes.

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