

## CT OF THE PARANASAL SINUSES : NORMAL ANATOMY, VARIANTS AND PATHOLOGY

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The place of computed tomography in the pre-operative assessment of patients prior to functional endoscopic sinus surgery is well established. A good knowledge of the anatomy of the paranasal sinuses, the clinical significance of anatomical variants, and the terminology used in functional endoscopic sinus surgery is basic to the correct interpretation of imaging studies. This article will review the anatomy of paranasal sinuses, Jami Karise the reader with the common terminology used in functional endoscopic sinus surgery and describe the patterns of inflammatory changes.

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### 1. Introduction

During fetal development, the paranasal sinuses originate as invagination of the nasal mucosa into the lateral nasal wall, frontal, ethmoid, maxilla and the sphenoid bones. This unique development explains the enormous amount of anatomical variation. Computed tomography (CT) is an excellent means of providing anatomical information of this region, assessing disease extent, assisting endoscopic evaluation and guiding treatment. The role of magnetic resonance imaging is limited but may provide further information on fungal infection and differentiating thickened mucosa from fluid retention.<sup>1</sup>

### 2. Frontal sinuses

The frontal sinuses are funnel-shaped cavities that show marked individual variation. There is usually a central septum dividing the frontal sinus into two parts but several septa may also be seen. The frontal recess, the drainage pathway of the frontal sinus, usually drains into the middle meatus (62%) or into the ethmoid infundibulum (38%).<sup>2</sup> This pathway is bordered by the agger nasi cell anteriorly, lamina papyracea laterally and middle turbinate medially. On coronal CT, the frontal recess is seen superior and medial to the agger nasi cell (Figure 1). This drainage pathway measures on the average 13mm (range 2-20mm).

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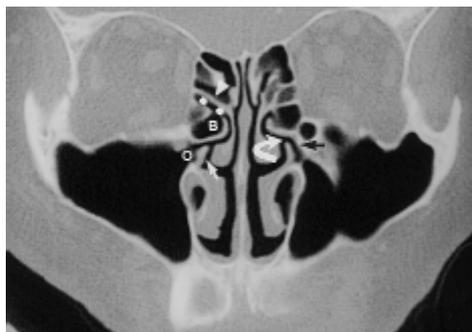
*Fig. 1. Coronal CT shows localised mucosal thickening in the left frontal recess (arrow) as well as in the right frontal recess. Note the relationship of the left frontal recess with the lamina papyracea (white arrow), the opacified agger nasi (A) and the middle turbinate (arrowhead).*

### **Agger nasi cells**

Anterior and inferior to the frontal recess are the agger nasi cells (Latin for "nasal mound"). The agger nasi cells are extramural cells and represent the most anterior ethmoid cells. On coronal CT, they appear inferior to the frontal recess and lateral to the middle turbinate (Figure 1). Thus, the agger nasi cells are important surgical landmarks and opening these cells usually provides an excellent view of the frontal recess.

### **The ostio-meatal unit**

The ostio-meatal unit (OMU) comprises the maxillary sinus ostium, the ethmoid infundibulum, anterior ethmoid cells and the frontal recess. The ethmoid infundibulum is bounded laterally by the inferomedial wall of the orbit, superiorly by the hiatus semilunaris and ethmoid bulla, and medially by the uncinate process (Figure 2). The maxillary sinus ostium and ethmoid infundibulum constitute the common drainage for the anterior paranasal sinuses. One of the aims of FESS is to re-establish the normal ventilation and the sinus drainage in the OMU.



*Fig. 2. Coronal CT shows the ostium of the right maxillary sinus (O), ethmoid bulla (B), uncinate process (white arrow), basal lamella (arrowhead) and sinus lateralis (asterisks). Note the left ethmoid infundibulum (black arrow). The gap between the tip of the uncinate process and the ethmoid bulla constitutes the hiatus semilunaris (curved arrow).*

It is important to realise that the ethmoid infundibulum is a three-dimensional structure and not two-dimensional as depicted on CT. As the maxillary sinus ostium opens into the floor of the ethmoid infundibulum, it is not possible to see the ostium endoscopically without removing the uncinate process. If an ostium is seen endoscopically, it is most likely to represent an accessory ostium or fontanelle.

The hiatus semilunaris gains its name from the arched appearance in the sagittal plane. It runs obliquely in a posteroinferior direction between the uncinate process and the ethmoid bulla. It

is best identified on parasagittal sections. On CT, it is bounded superiorly by the ethmoid bulla, laterally by the medial bony orbit, inferiorly by the uncinate process and medially the middle meatus. The hiatus semilunaris, the final segment of the drainage pathway from the maxillary sinus and ethmoid infundibulum, communicates medially with the middle meatus.

### Uncinate process

The relations of the uncinate process is again different from the three-dimensional view through an endoscope and the two-dimensional view portrayed on CT. Anteriorly, it is attached to the nasolacrimal apparatus; inferiorly to the inferior turbinate; posteriorly it has a free margin; and superiorly, its attachment is variable.

On CT, the uncinate process can be seen attached inferiorly to the inferior turbinate with the free edge representing the posterior free margin. Anteriorly, the uncinate process may be attached to the lamina papyracea, the skull base or the middle turbinate. This variable superior attachment results in different clinical implications.



*Fig. 3. Coronal CT shows inflammation involving the left ostiomeatal unit which consists of the frontal recess (solid star), anterior ethmoid cells (black arrow), ethmoid infundibulum (white arrow) and maxillary sinus (asterisk). Note the infundibular pattern on the right involving the right maxillary sinus ostium (curve arrow) and the antrum (hollow star).*

If the uncinate process inserts into the lamina papyracea, the ethmoid infundibulum would be effectively closed superiorly by a blind-ending pouch known as the recessus terminalis. In this instance, the frontal recess and the ethmoid infundibulum are separated and this explains why ethmoid infundibular inflammation does not result in concomitant frontal sinusitis. However, if the uncinate process is attached superiorly to the skull base or the middle turbinate, the frontal sinus opens into the ethmoid infundibulum and infection in the infundibulum may affect the frontal sinus, resulting in the involvement of the frontal, ethmoid and maxillary sinuses.

### The ethmoid bulla

The ethmoid bulla is a prominent anterior ethmoid cell, constituting a reliable anatomical landmark (Figure 2). The degree of pneumatization varies considerably (Figure 4) ranging from failure of pneumatization (torus ethmoidalis) to a giant ethmoid bulla insinuating between the

middle turbinate and uncinate process, displacing the uncinate process medially (Figure 5). The ethmoid bulla is bordered inferomedially by the infundibulum and hiatus semilunaris; laterally by the lamina papyracea and superoposteriorly by the sinus lateralis and basal lamina.

### The Middle Turbinate

The middle turbinate has a complex bony attachment. Anteriorly, it is attached superiorly to the cribriform plate (Figure 6). Posteriorly, it swings laterally into the coronal plane and attaches itself to the lamina papyracea (Figure 2). This coronal portion of the middle turbinate is called the basal lamella or ground lamella. The lamella basalis divides the ethmoid cells into the anterior and posterior ethmoid cells. The surgical relevance is that the anterior ethmoid cells drain into the middle meatus while the posterior ethmoid cells drain into the superior meatus. The classical anatomy of dividing the ethmoid sinus into anterior, middle, and posterior group of cells is no longer surgically relevant.

The middle turbinate continues posteriorly in an axial plane, forming the roof for the posterior portion of the middle meatus. This three-dimensional orientation gives the middle turbinate exceptional stability. Resection of the posterior portion may thus lead to anterior instability.



Fig. 4. Coronal CT shows a small right ethmoid bulla (arrow) and bilateral concha bullosa (asterisks).

### Sinus lateralis

The gap between the ethmoid bulla and the basal lamina is known as the sinus lateralis and it opens into the middle meatus (Figure 2). The relationships of the sinus lateralis are as follows: the ethmoid bulla anteriorly, the skull base superiorly, the basal lamina posteriorly, and the lamina papyracea laterally. Disease affecting the sinus lateralis is usually obvious radiologically but is often difficult to identify endoscopically.

### Sphenoid sinus

The sphenoid sinus is housed in the body of the sphenoid bone and is related to the sella turcica superiorly. Its ostium is located medially in the anterosuperior portion of the anterior sinus wall and communicates with the sphenothmoidal recess and the posterior portion of the superior meatus. The sphenothmoidal recess is located lateral to the nasal septum and although best demonstrated in the sagittal and axial planes, may also be seen on coronal images. Important surgical relations of the sphenoid sinus include the carotid artery in its lateral walls (Figure 7), the optic nerve superolaterally, and the Vidian canal in its floor. The carotid artery may bulge into the sinus in 65% to 72% of patients and in 4% to 8% of cases, the thin sinus wall separating the two may be absent (Figure 7).° The intersphenoid septum is often deflected to one side, and may be

attached to the bony wall covering the carotid artery. Hence, the artery may be injured when the septum is avulsed during surgery (Figure 8). Due to its relations with the maxillary nerve, sphenoid sinusitis can produce trigeminal neuralgia (Figure 9).



*Fig. 5. Coronal CT shows bilateral well-pneumatized ethmoid bullae (stars). Note the associated flattening of the uncinete processes (white arrow) medially which may potentially narrow the middle meatus.*

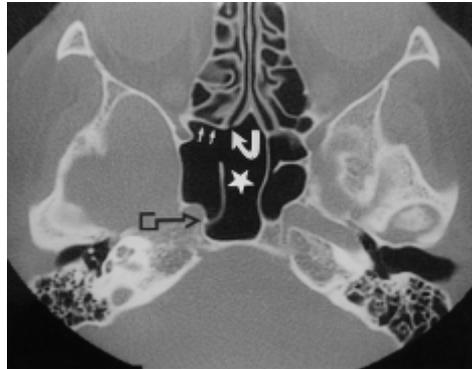


*Fig. 6. Coronal CT shows the delicate attachment of the left middle turbinate (arrow) to the cribriform plate. Note the inflammatory changes in the right frontal recess and anterior middle meatus (star).*

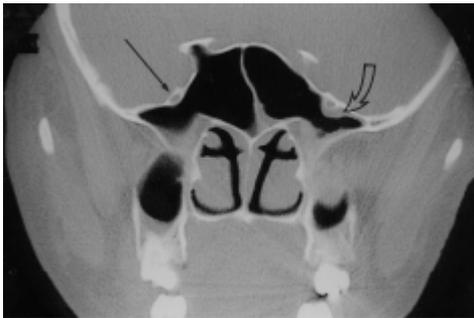
The posterior ethmoid has a variable relationship with the sphenoid sinus and is intimately related to the optic nerve. The surgeon cannot assume that the sphenoid sinus is directly posterior to the posterior ethmoid sinus (Figure 10). In some cases, the posterior ethmoid cell may extend laterally or superiorly beyond the anterior wall of the sphenoid sinus. This relationship, if not appreciated, may lead to the potential injury to the optic nerve by an unsuspecting endoscopist. It was reported that the anterior opening of the optic canal may be located adjacent to the most posterior ethmoid cell (50%), at the junction of the posterior ethmoid and anterior sphenoid (25%) or adjacent to the sphenoid sinus (25%).<sup>8</sup> However, a recent study based on coronal CT showed that the optic nerve is mostly related to the sphenoid sinus rather than the posterior ethmoid sinus.<sup>1</sup> Complete bony dehiscence of the optic canal exposing the nerve to injury may be present in 4% - 24 % of patients."



*Fig. 7. Axial CT shows a dehiscent right carotid artery wall and associated bulging of the artery into the sphenoid sinus (arrow). Note the inflammatory changes involving the left sphenoid sinus (star).*



*Fig. 8. Axial CT shows the common wall between the right anterior sphenoid sinus wall and the posterior wall of the posterior ethmoid cell (arrows). The ostium (curved arrow) of right sphenoid sinus (star) opens into the sphenothmoidal recess. Note the attachment of the sphenoid septum to the thin wall of the right carotid canal (black arrow).*



*Fig. 9. Coronal CT shows the relationship of the right maxillary nerve (straight arrow) with the sphenoid sinus. Note the inflammatory changes in the left sphenoid sinus (curved arrow) adjacent to the left maxillary nerve which may result in trigeminal neuralgia.*



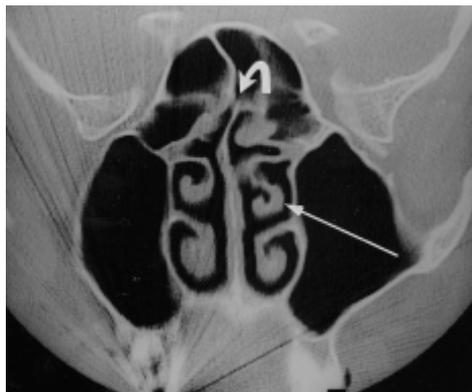
*Fig. 10. Axial CT shows the relationship between the right optic nerve (asterisks), posterior ethmoid sinus (small star) and sphenoid sinus (large star).*

### **Anatomical variants**

The nasal anatomy shows much individual variation. These variations may predispose the patients to inflammatory disease because they may obstruct the infundibulum or any part of the OMU resulting in the interference of airflow or mucociliary clearance.

### **Middle turbinate variants**

A concha bullosa is a pneumatised middle turbinate and has a reported prevalence of 34%." The presence of a concha bullosa does not necessarily imply an abnormality. Indeed, concha bullosa is often noted in asymptomatic individuals. However, a concha bullosa may be large enough to cause obstruction in the middle meatus or the infundibulum (Figure 4). The middle turbinate usually curves medially toward the nasal septum. However, in 26% of patients, the convexity is directed laterally resulting in a paradoxical middle turbinate (Figure II).



*Fig. 11. Coronal CT shows paradoxical left middle turbinate (arrow). Note the ostium of the right sphenoid sinus (curve arrow) which is usually better demonstrated on axial images.*

### **Uncinate process variants**

The free edge of the uncinate process may be deviated medially (Figure 5), laterally, pneumatised or bent. Lateral deviation may obstruct the infundibulum while medial deviation may narrow the middle meatus. Pneumatisation may be seen in 4% of patients but this uncinate process variant rarely compromises the infundibulum." A bent uncinate process may simulate a double middle turbinate on endoscopy. The term "atelectatic uncinate process" refers to the situation where the edge of the uncinate process approximates the orbital floor or the inferior aspect of the lamina papyracea. This phenomenon is usually associated with a hypoplastic ethmoid bulla or maxillary sinus. Uncinectomy may therefore result in injury to the orbital contents.

### **Haller cells**

Haller cells are ethmoid cells that extend along the floor of the orbit. They vary in size and when large can narrow the ostium of the maxillary sinus or the ethmoid infundibulum. Rarely, isolated inflammatory disease may be noted within the Haller cells.' Inflammatory disease involving the Haller cells is usually diagnosed on CT. Endoscopic evaluation is often unremarkable in these patients.

### **Onodi cells**

An Onodi cell is a posterior ethmoid cell that extends lateral and superior to the sphenoid sinus and abuts the optic nerve. Kainz and Stammberger defined an Onodi cell as a posterior ethmoid cell with an endoscopically visible bulge of the optic canal. The vulnerability of the optic nerve with or without the presence of an Onodi cell is further compounded by the thin lamina papyracea in the posterior ethmoid area (Figure 10).

### **Ethmoid roof**

Asymmetry in the height of the ethmoid exposes the lower side to inadvertent intracranial penetration during endoscopy. The ethmoid roof is of critical importance for two reasons: Firstly, the bone is thin rendering this area vulnerable to cerebrospinal fluid leaks when breached (Figure 6). Secondly, the anterior ethmoidal artery is vulnerable to injury which may cause catastrophic bleeding into the orbit. The anterior ethmoidal artery is a branch of the ophthalmic artery. From the orbit, it passes through a canal into the anterior ethmoid sinus just posterior to the frontal recess. It then crosses the sinus and enters the anterior cranial fossa before exiting and re-entering the nasal cavity via the cribriform plate. This is the site where the artery is most liable to injury.

The roof of the ethmoid is formed by the fovea ethmoidalis of the frontal bone laterally and the cribriform plate of the ethmoid bone medially. Due to the delicate attachment of the

middle turbinate to the cribriform plate anteriorly, surgery in this area should be performed with care as detachment of the middle turbinate may damage the dura, resulting in cerebrospinal fluid leak (Figure 6).<sup>5</sup>

### Paranasal sinusitis

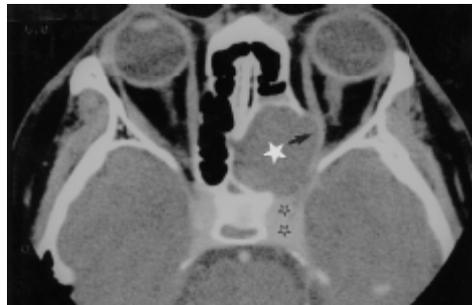
Obstruction and impaired mucociliary drainage of the paranasal sinuses results in sinusitis. Inflammatory changes in the paranasal sinuses can be radiologically grouped into several patterns of involvement. Isolated involvement of the maxillary sinus is often referred to as "infundibular pattern" (Figure 3). Involvement of the maxillary sinus with inflammatory changes in the ipsilateral frontal and anterior ethmoid sinuses is classified as the "OMU pattern" (Figure 3). Obstruction at the sphenothmoidal recess results in sphenoid and posterior ethmoid sinusitis giving rise to the "sphenothmoidal pattern" (Figure 12). However, in up to a third of patients with paranasal sinusitis, the pattern of inflammation does not fit neatly into one of the above three groups. Patients who conform to one of the above-described patterns of obstruction fare better following endoscopic surgery compared to the group of patients with a random pattern of involvement.

### Paranasal sinus mucocoeles

Paranasal sinus mucocoeles are mostly found in the frontal sinus followed by the ethmoid sinus (Figure 13). The maxillary and sphenoid sinuses (Figure 14) are rarely affected. On CT, mucocoeles typically produce smooth expansion of the involved sinus (Figure 13). Large mucocoeles may breach bone and extend into nasal cavity, orbit or intracranial cavity. Mucocoeles may become infected and these pyocoeles are now frequently decompressed using endoscopic techniques. A delay in the treatment of pyocoeles often leads to orbital abscess, meningitis, subdural empyema or cavernous sinus thrombosis.



*Fig. 12. Axial CT shows sphenothmoidal recess mucosal thickening (curve arrow) resulting in left posterior ethmoid (asterisk) and sphenoid sinusitis (star).*



*Fig. 13. Axial contrast-enhanced CT shows a left posterior ethmoid mucocoele (solid star). The lesion has extended into the apex with displacement of the medial rectus muscle. Note the relationship with cavernous sinus (hollow stars) posteriorly.*

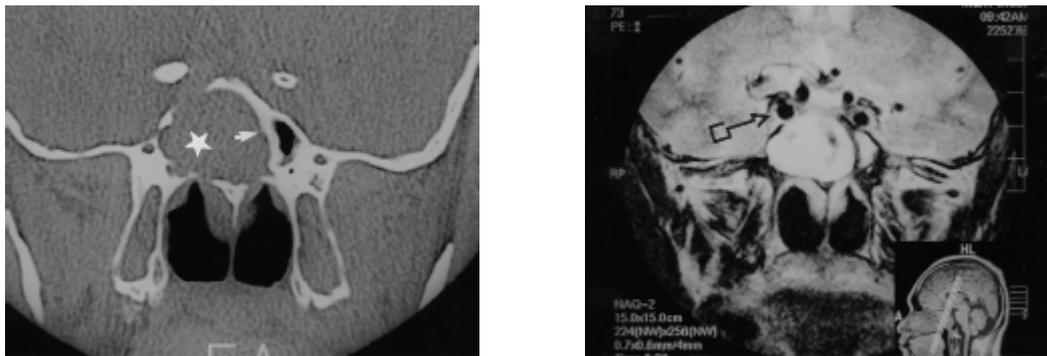


Fig. 14. a). Coronal CT shows expansion of the right sphenoid sinus (star) with multiple areas of erosion. Note the thickened sinus septum (arrow) indicating a long-standing lesion. b). Coronal T2-weighted MRI shows a high signal intensity mucocoele which was found to be infected at surgery. Note the slight superolateral displacement of the internal carotid artery (arrow).

### 3. Conclusion

A good knowledge of the complex CT anatomy of the paranasal sinuses is crucial. This knowledge will provide an accurate assessment of the normal variants and pathological changes required for successful FESS.

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