Pathological consequences of anatomical variations in the sino-nasal region: how can radiologists help clinicians?

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Learning objectives

In this exhibit we will discuss the role of multidetector computed tomography (MDCT) in the evaluation of anatomical variations of the paranasal sinuses, focusing on the main findings radiologists should bring to the attention of clinicians for their potential correlation with pathological conditions.
**Background**

The nasal cavity and paranasal sinuses constitute an anatomical and functional unit covered by the same mucosa. They communicate via small openings and narrow ducts that allow both aeration and sinus drainage.

Paranasal sinuses develop in a certain sense as "diverticula of the nose".

Pneumatization is preceded by the formation of "yellow bone marrow" and then by fluid-like content.

The lack of pneumatization is normal before 1 year.

At birth, maxillary and ethmoid sinuses may contain a little amount of air; the sphenoid sinus pneumatizes after 3 years and the frontal sinus after 6.

The regional anatomy of the paranasal sinuses is complex and includes normal anatomical variations, which are not necessarily pathological, but may contribute to the occurrence or persistence of chronic inflammatory diseases or be the source of difficulty during surgery.

For these reasons, appropriate radiologic imaging interpretation plays an important role in the management of these conditions.

Computed tomography (CT) is the imaging modality of choice in the definition of the paranasal sinuses anatomy and gives precious information about bone structures, sinus pneumatization and soft tissues. Particularly, coronal CT sections can delineate the disease as well as the anatomic variations.

However, also magnetic resonance imaging (MRI) provide excellent soft tissue discrimination and spatial resolution necessary for the diagnosis of sino-nasal disorders.
Findings and procedure details

PROCEDURE DETAILS

CT has replaced conventional radiographs in recent years for the high-resolution sectional images less than 1 mm thick obtained out within a few seconds. Additionally, the primary scans provide data sets for the computer generation of reconstructed image planes called multiplanar reconstructions (MPRs), without subjecting the patient to additional radiation exposure and with the advantage of the elimination of metallic artifacts.

Axial slices can thus be supplemented by coronal and sagittal image planes for a better understanding of regional anatomy. This is particularly helpful in the evaluation of the frontal recess and the frontal sinus where the anatomy is complex and variable.

The raw image data are also available for manipulation into any tissue algorithm (bone, intermediate and soft tissue) or field of view (target) as well as for three-dimensional renderings (3D-postprocessing).

Another rising imaging technique for the evaluation of sinus anatomy is Cone Beam CT (CBCT). In fact, it provides high-contrast resolution images (even if resolution is inferior in comparison to those obtained with the multi detector CT) combined with a relatively low dose and compact design of the equipments.

Even if it doesn't represent the imaging modality of choice, MRI can supply the CT data, providing a study carried out the normal anatomy and standard deviation of the numerous variants, single or in combination.

FINDINGS

NASAL SEPTUM

The most important morphological variations of the nasal septum consist on septal deviation, chondro-vomeral junction deformity, vomer pneumatisation and nasal bone spur.

Septal deviation represents a divergence of the septum from the midline, with associated deformities or significant asymmetry of any or all of the adjacent conchae and nasal wall structures.
The antero-superior margin of the vomer is normally in the form of a variable grove that hosts the adjacent edge of the quadrangular cartilage. **Deformity of the Chondro-vomeral Junction** (Fig. 1) occurs when this relationship is disrupted, thus the inferior edge of the quadrangular cartilage is displaced from the midline and projects into one of the nasal fossas.

The vomer forms the postero-inferior part of the bony nasal septum and it can be occasionally **pneumatised** by the sphenoid sinus (Fig. 2).

Nasal septal **spur** is generally asymptomatic, but can be an obstacle for the nasal air flow. It may be associated with septal deviation (Fig 3).

**MIDDLE TURBINATE**

**Paradoxical curvature**

It results from the alteration of the convexity of the middle turbinate, which is directed laterally toward the nasal septum in the paradoxical middle turbinate while it's normally directed medially (Fig. 4). Paradoxical turbinate can narrow the ethmoid infundibulum and also cause lateral deviation of the uncinate process.

**Concha bullosa**

Concha bullosa (incidence 4% - 80%) is one of the most common variation of sino-nasal anatomy (Fig. 5). It consists on the pneumatization of the middle turbinate and, less commonly, of the inferior and superior turbinate (middle, superior and inferior concha bullosa). Various degrees of pneumatization of the concha may be observed. An extensive pneumatization with accompanying mucosal contact can cause headache and marked nasal obstruction even in the absence of sino-nasal inflammation.

**Secondary middle turbinate**

Secondary middle turbinate (SMT) is a bony projection arising from the lateral wall of the middle meatus, covered by soft tissue. It's a rare anatomical condition which can be mistaken for a polyp, an osteoma or for the "accessory middle turbinate" at nasal endoscopic examination. It may predispose to inflammatory sinus disease, by narrowing the ostio-meatal complex. It's easily detected by Coronal CT scans.

**ETHMOIDAL CELLS**
Onodi (spheno-ethmoid) cell

The Onodi cell (incidence of 8-14%) is a posterior ethmoid cell which pneumatizes laterally and superiorly to the sphenoid sinus (Fig. 6 a-b). For the anatomical contiguity to the optic nerve (ON), which often runs within its small cavity, it could bring to retro-bulbar optic neuropathy for mechanical compression. It's also correlated to an increased surgical risk of injury to the ICA and the ON. Onodi cell inflammation can be suspected in patients with searing retro-orbital headache, impaired visual acuity, blurred vision in the eye and "black-dots" in the central visual field. It is best depicted on the axial images in CT scans, where the course of the ON can also be followed.

Agger nasi cell

Agger nasi air cells (incidence 10%-89%) are the most anterior ethmoidal air cells located close to the lacrimal bone, antero-lateral and inferior to the fronto-ethmoidal recess and anterior and above the attachment of the middle turbinate (Fig. 7 a-b).

They have as lateral relations the orbit, the lacrimal sac and the nasolacrimal duct. The close relationship of this cell to the lacrimal bone readily explains the findings of epiphora in select patients with sinus disease. The Agger nasi cell can be involved in some cases of frontal sinusitis. Coronal CT scans demonstrate the anatomic relationship of the Agger nasi with the frontal sinus and frontal recess.

Haller's cells (infraorbital ethmoid cell)

Haller's cells (incidence 2%-45%) are extramural ethmoidal cells that extend into the infero-medial orbital floor, adjacent to and above the maxillary sinus ostium (Fig. 8). It is controversial that the Haller’s cells originate from the anterior or posterior ethmoid cells. However, if enlarged, they can constrict the ostium of the maxillary sinus and the posterior aspect of the ethmoidal infundibulum, causing recurrent maxillary sinusitis. Diagnosis can be easily made with coronal CT images.

The ethmoid bulla

It's the largest air cell of the ethmoid complex which can tighten/obstruct the middle nasal meatus and the infundibulum when it reaches sufficient size (Fig. 9).

Bulla frontalis

They appear as ethmoid air cells located above the ethmoid bulla bulging frontal bone's floor, without any connection with this sinus. Depending on their dimensions, they may affect the frontal sinus drainage and represent a cause of inflammatory diseases as well as a difficulty for a surgical management of such a sinus.
**Frontal Cells**

Frontal cells (incidence 20-33%), along with the Agger nasi cell, constitute the anterior group of frontal recess cells.

The anterior wall of the frontal recess or the frontal sinus represents the anterior boundaries of these cells, which do not extend posteriorly to abut the skull base.

There are four types of frontal cells described in the *Kuhn classification*:

<table>
<thead>
<tr>
<th>Type</th>
<th>Incidence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>About 37% of cases</td>
<td><em>Single</em> anterior ethmoid cells within the frontal recess sitting above the Agger nasi cell with no extension into the frontal sinus</td>
</tr>
<tr>
<td>Type 2</td>
<td>About 19% of cases</td>
<td><em>Two or more</em> ethmoid cells sitting above the Agger nasi cell located anteriorly to the frontal recess</td>
</tr>
<tr>
<td>Type 3</td>
<td>About 6-8% of cases</td>
<td><em>Single voluminous cell</em> detected above the Agger nasi cell which <em>pneumatizes into the frontal sinus</em></td>
</tr>
<tr>
<td>Type 4</td>
<td>About 2-4% of cases</td>
<td>An ethmoid cell within the frontal sinus with no connection with the Agger nasi cell</td>
</tr>
</tbody>
</table>

**Aerated Crista Galli**

When aerated, the crista galli may communicate with the frontal recess with consequent obstruction of the ostium. It is important to identify this anatomical variation since it can cause chronic sinusitis and mucocele formation. It's also crucial to differentiate the aerated crista galli from an ethmoid air cell before surgery in order to avoid inadvertent entry into the anterior cranial fossa.

**MAXILLARY SINUS**

**Maxillary Sinuses Septa**
Maxillary sinus septa are thin walls of cortical bone arising from the inferior and lateral walls of the maxillary sinus which divide the sinus into two or more cavities (Fig. 10).

**Accessory Maxillary Ostia**

Generally solitary, but occasionally multiple, accessory maxillary ostia can be congenital or secondary to sinusal diseases (Fig. 11). Even if it’s not clear their developmental process, they could result from main ostium obstruction, maxillary sinusitis or rupture of membranous areas derived from anatomical/pathological factors in the middle meatus.

**Maxillary sinus hypoplasia**

Maxillary sinus hypoplasia (MSH) (incidence about 10%) is an uncommon condition that may be misdiagnosed as chronic sinusitis and might be related to the aberrant anatomy of the ipsilateral uncinate process, with impediment of the mucociliary clearance of the sinuses. If not recognized, it could lead to inadvertent intraoperative damage to the adjacent medial orbital wall. Additionally, there may be difficulty in finding the ostium of the maxillary sinus.

**Sphenomaxillary plate**

The sphenomaxillary plate (incidence about 15%) divides the ethmoid and maxillary sinus. It is triangular shaped, with horizontal axis when remarkable pneumatization occurs. Its detection is since during the transantral ethmoidectomy the sphenoid sinus is mistaken for posterior ethmoidal cells.

**UNCINATE PROCESS**

**Medialization/lateralization**

Variations such as hypertrophy, deviation and pneumatization may affect the drainage, generating abnormalities in the ostio-meatal complex and predisposing to obstruction. Medialization occurs with giant bulla ethmoidalis. Lateralization of the uncinate process may obstruct the infundibulum (Fig. 12).

**Uncinate bulla**

It consists on the pneumatization of the uncinate process, which can bring to the narrowing of the infundibulum, functional blockage of the ostio-meatal complex and can impair sinus ventilation (Fig. 13). It’s a rare condition, but the prevalence of this anatomic variation is not well provided.
PARANASAL SINUSES VARIATION OF PNEUMATIZATION EXTENT

The pneumatization extent of the sphenoid sinuses is variable. Pneumatised recesses are related to the greater sphenoid wing, although lateral extensions may also be observed in the smaller sphenoid wing, inferolateral and septal recesses.

It's crucial to remark also that, on the bases of the location of the air, sphenoid pneumatization can be classified in four types (Fig. 14):

a. conchal
b. presellar
c. sellar
d. postsellar

Increased sinusal aeration may be also found into the frontal sinus beyond the normal margin of the frontal bone, predominantly in male individuals between 20 and 40 years.

There are also four recesses described in literature as concerns the maxillary sinus:

- *palatine recess*, that extends infero-medially to the hard palate towards the midline;
- *alveolar recess*, close to the molar and premolar teeth roots
- *infraorbital recess*, extending anteriorly along the roof of the maxillary sinus;
- *zygomatic recess*, projecting over the malar bone.

**Pneumatisation of Anterior Clinoid Process**

Anterior clinoid process pneumatization is associated with type II and type III optic nerve (following Delano’s classification) and predisposes this nerve to injury during endoscopic surgery.

**CRIBRIFORM PLATE**

The cribriform plate may present at variable levels according to Keros’ criteria (Fig. 15), which are based on the height of the olfactory fossa in relation to the roof of the ethmoid sinus as compared with the length of the lateral lamella of cribriform plate.

Particularly, Keros categories are:

- **type 1**: depth of 1-3 mm (26.3% of population)
- **type 2**: depth of 4-7mm (73.3% of population)
- **type 3**: depth of 8-16mm (0.5% of population)

The possibility of surgical injury of the cribriform plate and olfactory fossa is greater when the Keros grade is higher, with consequential risk for iatrogenic cerebrospinal fluid fistula and olfactory impairment.

**PANASAL SINUSES: INTERNAL CAROTID ARTERY AND OPTIC NERVE RELATIONSHIPS**

Before endoscopic surgery it is very important to clarify the relationship between internal carotid artery (ICA) and the optic nerve (ON) with the paranasal sinuses (in particular with the sphenoid and ethmoid sinus), in order to avoid very dangerous, sometimes fatal, consequences.

The **ICA** traverses postero-laterally to the sphenoid sinus area and may occasionally protrude into it, especially when there is an over-pneumatization in the sphenoid base. A **dehiscence** in the bone covering the artery may lead to direct contact of the artery with sinus mucosa and this condition is easily detected by axial images.

It is hardly possible to control the bleeding from a ruptured ICA within the sphenoid sinuses, and this is why the surgeon must be aware of such a variation.

The sphenoid septum may also be adjacent to the ICA. Carotid avulsion can occur also when the septum is grasped and twisted anteriorly at the entrance to the sphenoid, with resulting forced transmission to the posterior attachment at the level of the carotid.

Another devastating potential complication of endoscopic surgery is the injury of the ON, which is at risk when the posterior ethmoid anatomical variation exists (i.e. Onodi cell).

Moreover, the ON traverses supero-laterally to sphenoid sinus, but occasionally it may traverse the sphenoid sinus, especially when the anterior clinoid process is pneumatised.

In this case, the ON may be covered by thin bone measuring 0.5 mm or less, or lack its bony covering as it courses within the sphenoid sinus. In literature, a dehiscence in the bone covering the ON was reported in 4% of cases. This is why the ON can be injured through direct inflammatory invasion of the sinus disease.

Finally, visual deficits may result from a mucocele compressing the ON in the canal.
Fig. 1: Axial CT image shows deformity of the Chondro-vomeral Junction

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**Fig. 2:** Coronal reformatted CT image shows pneumatized vomer containing an air-fluid level

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**Fig. 3:** Coronal CT image shows nasal septal spur

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Fig. 4: Coronal reformatted CT image shows paradoxical turbinate associated with nasal septal deviation

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Fig. 5: Coronal reformatted CT image shows bilateral Concha bullosa

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Fig. 6: Coronal (a) and Sagittal (b) reformatted CT images show Onodi cells
Fig. 7: Coronal (a) and Sagittal (b) reformatted CT images show Agger nasi cell
**Fig. 8:** Coronal reformatted CT image shows obliterated Haller’s cell

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**Fig. 9:** Coronal reformatted CT image shows Bulla ethmoidalis
Fig. 10: Sagittal reformatted CT image shows maxillary sinus septum

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Fig. 11: Axial CT image shows bilateral accessory maxillary ostia

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Fig. 12: Landsberg & Friedman classification of superior uncinate process insertion. A: Type 1, insertion into the lamina papyracea. B: Type 2, insertion into the posterior wall of agger nasi cell. C: Type 3, insertion into the lamina papyracea and junction of the middle turbinate with the cribiform plate. D: Type 4, insertion into junction of the middle turbinate with the cribiform plate. E: Type 5, insertion into the skull base. F: Type 6, insertion into the middle turbinate.
Fig. 13: Coronal reformatted CT image shows Uncinate bulla

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**Fig. 14:** Sphenoid pneumatization: A. conchal, B. presellar, C. sellar, D. postsellar

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**Fig. 15:** Fig 15. Keros classification. A: Type 1, B: Type 2, C: Type 3

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Conclusion

There is a wide variability of the MDCT appearance of the paranasal sinuses anatomy. In this setting, radiologists should get familiar with MDCT imaging findings to give clinicians the right advice in order to avoid therapeutic failure and/or iatrogenic complications.
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References


