Functional Endoscopic Sinus Surgery: Anatomy and Complications

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Paranasal Sinuses

- Four paired sinuses
- Functions:
  - Lighten
  - Humidify/Heat
  - Resonance
  - Crump zones
  - Mucociliary Clearance (MCC)

http://www.aboutcancer.com/paranasal_sinus_cancer.htm
Mucociliary Clearance

- ciliated cells (~75%)
- goblet cells (~20%)
- basal cells (~5%)
- acellular basement membrane
- This epithelial lining protects the upper airway from inhaled pathogens and debris by a process referred to as MCC

Protective and hygienic function to the nose and paranasal sinuses

Marcelo B. Antunes, MD, David A. Gudis, MD, Noam A. Cohen, MD, PhD. Epithelium, cilia, and mucus: their importance in chronic rhinosinusitis. Immunology and Allergy Clinics of North America - Volume 29, Issue 4 (November 2009) DOI: 10.1016/j.iac.2009.07.004

Mucus blanket is cleared toward the nasopharynx every 10-15 minutes

We clear 20-40cc of mucus daily
Sol layer – invests the cilia
Gel layer – more viscous, working layer of the mucus blanket
Saccharin test
NOTE: the MCC in the paranasal sinuses has an ORGANIZED, directed, NON-gravity dependent direction of flow – this is important for surgery
1. inferior meatal punctures – don’t work
2. make sure maxillary antrostomy is connected with natural os
Paranasal Sinuses - Embryology

- FOURTH WEEK OF GESTATION –
  - Frontonasal processes
  - Nasal placode – medial and lateral processes
- FIFTH – SEVENTH WEEK OF GESTATION –
  - Nasal pits/sacs/nares
  - Oronasal membrane
- EIGHTH WEEK + OF GESTATION –
  - Lateral nasal wall structures

Fries PD, Katowitz JA: Congenital craniofacial anomalies of ophthalmic importance. Surv Ophthalmol 35:87, 1990,
Embryology – Lateral Nasal Wall

• 6-7 ridges in the lateral nasal wall at 8 weeks gestation
• Up to 5 ethmoturbinals
  • 1\textsuperscript{st} = agger nasi, uncinate
  • 2\textsuperscript{nd} = middle turbinate
  • 3\textsuperscript{rd} = superior turbinate
  • 4\textsuperscript{th}/5\textsuperscript{th} = supreme turbinate
• One maxilloturbinal = inferior turbinate

Coronal section of a human embryo at approximately 56 days development. The primordial middle turbinate (arrow) and inferior turbinate can be seen emerging from the lateral nasal wall.
Source: Kennedy Chapt - 1
Embryology: Cartilaginous Nasal Capsule

- 9-10 weeks gestation
- May be true driver of nasosinus development

Coronal section of a human fetus at approximately 60 days' development. The primordial superior turbinate (st); middle turbinate (mt); and inferior turbinate (it) can be seen developing directly from the cartilaginous (arrows).

Source: Kennedy Chpat 1

Resorption of the nasal capsule is responsible for allowing the maxillary sinus to enter to maxilla.
Embryology Con’t

- Secondary evaginations and invaginations give further rise to sinus structures.

Through a fusion of these turbinals, various recess and spaces are formed including the ethmoidal infundibulum, hiatus semilunaris, middle meatus, frontal recess, superior meatus, and the supreme meatus. Of note, the maxillary sinus develops from the inferior aspect of the ethmoidal infundibulum.

Coronal section of a human fetus at approximately 63 days’ development. The primordial uncinate process can be seen as an evagination from the lateral wall with early ossification (arrow). Lateral to the primordial uncinate, a corresponding invagination forms the primordial infundibulum.

Source: Kennedy chatp 1
Embryology – Origin of the Sinuses

- Maxillary sinus → ethmoidal infundibulum
- Ethmoids → 2° invaginations and evaginations
- Frontal sinus → ??? Frontal recess OR ethmoid air cell OR infundibulum
- Sphenoid → cupolar recess

Sphenoid sinuses: during the third month of gestation the nasal mucosa invaginates into the nasal capsule and this expands into a pouch-like cavity called the cupolar recess. The wall around the cartilage ossifies and the cartilage resorbs and it will eventually form the sphenoid cavity.
Quick Word on Neurovascular Supply

How to remember neurovascular supply to the sinuses?

• V1 innervation = Internal carotid derived (ophthalmic)
• V2 innervation = External carotid derived (int. maxillary)

• The ONLY sinus with both is the sphenoid
Maxillary Sinus (Antrum of Highmore)

- First and largest
- Fluid filled at birth
- Biphasic growth pattern
- Pyramid shaped - apex points laterally
- Nervous supply: V2 and greater palatine nerve
- Vascular supply: branches of the internal maxillary artery

http://imaging.birjournals.org/cgi/content/full/19/1/39/F1
Surgical Anatomy: Natural Maxillary Ostium

• Superiorly in the medial wall of maxillary sinus.
• Relation in ethmoid infundibulum/hiatus semilunaris
  • Ünlü et al (1997): - In 92.4% maxillary ostium related to the anterior surface of the bulla ethmoidalis was on the second and third quarters.

  • Rice (1995) empties into the infundibulum, generally in the second, third and fourth quarter of this groove (hiatus semilunaris)

  • (Lang and Sakals, 1982; Lang, 1989) the ostium of the maxillary sinus is situated in the posterior quarter in 2%, in the third quarter in 48%, in the second quarter 28%, and in the anterior quarter in 22% of the cases.

  • Van Alyea (1936) posteriorly in the infundibulum in 2/3 of cases, in the middle in 1/4 of cases, and in the anterior part of the infundibulum in 10% of anatomical specimens.

  • Myerson’s material (1932) the ostium of the maxillary sinus is situated at the posterior end of the semilunar hiatus in 23% of cases.
2 mm posterior to the anterior most insertion of the uncinate process
Surgical Anatomy: Nasolacrimal Duct
Surgical Considerations: Nasolacrimal Duct

- NLD to maxillary os distance
  - Ünlü et al (1997): A total of 15 adult cadaver skulls; distance 5.5 mm. (Anterior margin)
  - Rice (1994) - 4 mm posterior to the NLD
  - Calhoun et al. (1990) - average distance to be 9±3 mm

The nasolacrimal sac lies between the anterior and posterior crus of the medial canthal tendon within the lacrimal fossa. Medial to the sac is the middle meatus of the nasal cavity, separated by the thin lacrimal bone and frontal process of the maxillary bone.

http://www.wrighteyecare.com/Nasolacrimal_Duct_Obstruction.html
Prior to the use of nasal endoscopes, ventilation of the maxillary sinus was usually accomplished by making an opening from the inferior meatus into the maxillary sinus; in that procedure, the NLD was usually not at risk since it opens high in the inferior meatus.

- Occurs within 2 weeks post op, epiphora, dacrocytorhinostomy
Complication: Recirculation

- Should be connected with surgical antrostomy to avoid recirculation
Surgical Considerations: Fontanelles

- Anterior and Posterior Fontanelles → Accessory Ostium
  - Rice (1994). These ostia exist in 15-40% of patients
  - Ünlü et al (1997) - 50% of specimen; statistically significant differences were found between the L and R (p=0.047).

http://rhinitis.hawkelibrary.com/album05/48_G
Surgical Disease of the Maxillary Sinus

Maxillary Sinusitis  Antrochoanal Polyp  Mucoceles


Case Report – K.C

- 35 YOM
- CC: nasal congestion
- HPI: chronic right sided nasal obstruction, right sided nasal congestion, and R>L facial pressure. Hx of allergies worse in winter. History of recurrent sinusitis. No nasal/facial trauma. No visual complaints
- PE: enopthalmos
- Nasoendoscopy: congested, septum contacting inferior turbinate on the right, on the left the septum appears to be dislocated from the nasal spine, BITH
Case Report – K.C

Note the hypoplastic sinus and the proximity of the uncinate to the lamina.
Silent Sinus Syndrome

• “a spontaneous and progressive enophthalmos and hypoglobus with hypoplasia of the maxillary sinus and resorption of the orbital floor”

• Imploding Antrum Syndrome

• Idiopathic (original) but term now applied to iatrogenic or trauma related causes.

• Pathophysiology: SSS arises from congestion of the ostiomeatal complex resulting in negative pressure within the maxillary sinus and a gradual implosion of the antral cavity.

• Treatment: ESS to restablish maxillary aeration.

• Numa et al. 2005
Ethmoid Sinuses

- Well defined, fluid filled at birth.
- Grow until 12 years of age.
- The anterior ethmoidal air cells are formed first during fetal development followed by the posterior ethmoidal air cells.
- Variable pneumatization pattern.
- The ethmoidal air cells are bounded by:
  - middle turbinates = medial
  - lamina papyracea = laterally
  - Anterior skull base = superior border of the ethmoid cavity. The vertical lamella of the middle turbinate divides the skull base into two regions: the cruciate membranous bone medially (contains crista galli, cribriform plate, and perpendicular plate) and the tovea ethmoidalis (roof of the ethmoidal labyrinth) laterally.

The ethmoid air cells can be variable in their growth and pneumatization pattern as they can be found in front of the frontal sinus (agger nasi), headed into the roof maxillary sinus (infraobital or “Haller” cell, 10%), even above the orbit (supraorbital, 15%), or lateral to the sphenoid (Onodi, 10%).
Neurovascular Supply

- Vascular: Anterior ethmoid (AEA) and posterior ethmoid artery (PEA)
- Nerves: CN V1 (nasociliary to AEA and PEA nerves)
Surgical Considerations Of the Ethmoids

- Lateral nasal wall structures:
  - Middle turbinate
  - Uncinate
  - Ethmoid Bulla (bulla ethmoidalis)
  - Hiatus Semilunaris/Ethmoid infundibulum & Osteomeatal complex
- Cells:
  - Concha bullosa
  - Haller cells
  - Onodi cells
  - Agger nasi cell
- Safe ethmoidectomy

As mentioned the following are ethmoid in origin: agger nasi cell, uncinate, middle turbinate, superior turbinate (as supreme if present), ethmoidal infundibulum, hiatus semilunaris, middle meatus, frontal recess, superior meatus, and the supreme
Lateral nasal wall

- sphenoidoethmoid recess (arrow above 1)
- superior concha (1)
- superior meatus (tip of arrow)
- middle concha (2)
- middle meatus (tip of arrow)
- inferior concha (3)
- inferior meatus (tip of arrow)

BOTTOM PICTURE:
Post removal of the middle and inferior conchae reveals other items to be identified:

- cut edges of middle and inferior conchae (1 and 2)
- hiatus semilunaris (3)
- ethmoid bulla (bulge formed by ethmoid air cells (4)
- small bulge formed by the nasolacrimal duct (5) (not always apparent)

Source: http://home.comcast.net/~wnor/lesson9.htm
Middle turbinate

- Important anatomic landmark for ESS.
- Body, anterior buttress, and posterior buttress, vertical and horizontal lamella → Preservation of these structures prevents lateralization of the turbinate secondary to destabilization.
- Anterior 1/3 – sagittal plane
- Middle 1/3 – coronal plane (basal lamella)
- Posterior 1/3 axial plane.
- Posterior attachment of the middle turbinate is adjacent to the sphenopalatine foramen where the sphenopalatine artery emerges.
Middle turbinate

Basal lamella separates anterior from posterior ethmoid cavities
Uncinate

- Lateral to the middle turbinate; crescent shaped bone.
- Anterior attached edge and posterior free edge
- Anteromedial wall of the ethmoid infundibulum.
- Free edge is anterior border of the hiatus semilunaris
- Attachment pattern:
  - (A) Lamina papyracea: 70% → drainage medial to uncinate
  - (B) Middle turbinate: 19% → lateral
  - (C) Fovea ethmoidalis: 11% → lateral

![Diagram of the uncinate process and its attachments](image)
Bulla ethmoidalis

• Another important and constant landmark of sinus surgery that is posterior to the uncinate.
• Largest ethmoidal air cell
• Posterior margin of the hiatus semilunaris and the posterosuperior boundary of the ethmoidal infundibulum.
• Usually extends to the skull base but not always:
  • suprabullar recess (SBR)
  • retrobullar recess (RBR) aka posterior semilunar hiatus.

Sinus lateralis - misnomer
The hiatus semilunaris is a two dimensional space bound by the uncinate anteriorly and the ethmoid bulla posteriorly. This space leads straight into the ethmoid infundibulum (CONTIGUOUS) inferiorly. The ethmoid infundibulum is formed by the uncinate anteriorlaterally, the lamina papyracea medially, and the ethmoid bulla posteriorly. The frontal sinus, anterior ethmoids, and maxillary sinus drain into the infundibulum.
Ostiomeatal complex:

The osteomeatal complex (OMC) is a functional space rather than a physical one that signifies a common pathway of mucociliary clearance (MCC) from the frontal recess, maxillary sinus, anterior ethmoids, and the infundibulum. Obstruction in this area can cause a retrograde disruption in mucus clearance and infection.
Avoiding complications – Effect Ethmoid Surgery

• Understanding the anatomy of the variants of the ethmoid complex can lead to effect sinus surgery in this area.

• If these structures are not properly addressed intraoperatively, the post-surgical complication recurrent/persistent sinus disease can result:
  • Concha bullosa
  • Haller cell
  • Agger nasi
  • Onodi cell*
**Concha bullosa**

Concha bullosa: Pneumatization of the middle turbinate. This is a normal anatomic variant but it can lead to obstruction of the sinus outflow tracts in this area. Thus, concha bullosa resection is considered to restore outflow.
As described previously, this is an anterior ethmoidal air cell that can pneumatize infraorbitally leading to obstruction of maxillary sinus outflow and the ethmoidal infundibulum. It should be identified and resected to restore outflow and alleviate maxillary obstruction.
Agger Nasi cell: It is found in the part of the lateral nasal wall anterior to the anterior attachment of middle turbinate. It is often pneumatized and its posterior edge forms the anterior aspect of the frontal recess. If it is over-sized, it can lead to obstruction of frontal sinus outflow and will need to be resected to restore this.
Agger Nasi Con’t
Onodi Cell

• **Onodi cell**: As described previously, this is a posterior ethmoidal air cell (sphenoethmoidal air cell) that pneumatizes lateral to the sphenoids. It can perilously contain the optic nerve or carotid in its lateral wall as opposed to their usual location lateral to the sphenoid proper. Failure to identify this can lead to injury of these structures.
• It is positioned superior to the sphenoid sinus
Preventing complications: Anterior Ethmoidectomy

Per Kennedy, the ethmoid bulla is infrastructed at its medial aspect and once it is entered it can be removed. This can be done with microdebrider or surgical instruments. Another safe technique is to enter the bulla from the retrobullar recess. An instrument such as a curette can be placed in this space and used to fracture the bulla anteriorly. As soon as the bulla is removed, the lateral most extent should be palpated i.e.: palpate the lamina papyracea to determine the safest extent of lateral operating. Continuing to work medially can cause skull the thin bone of the skull base where as working laterally this area of skull base is ten times thicker. Further, if the posterior ethmoids are to be entered, entering inferomedially is safest (just superior to the horizontal part).
Figure 16B-6  The basal lamella may be infractured with either forceps or a microdebrider, just above its inferior horizontal portion.
Surgical Anatomy: Fovea Ethmoidalis

- Slopes inferiorly from anterior to posterior and lateral to medial; is synonymous with the slope of the skull base.
- Thick to thin – L → M
- Two parts:
  - thick, horizontal part → the orbital plate of the frontal bone
  - a thin, near vertical part → the lateral cribiform plate lamella (LCPL) - determines the depth of the olfactory cleft.
    - Keros type I: 1-3mm
    - Keros type II: 4-7mm
    - Keros type III: 8-16mm

Keros type III – greatest risk of injury to the skull base – more surface area in the surgical field to compromise
Keros Type and Skull base Injury

Greater Risk of Skull Base Injury
Surgical Anatomy: AEA, PEA, and Optic Nerve

Source: http://t0.gstatic.com/images?q=tbn:ANd9GcRoBKPRPY733HPeWclqir10ON1_VUoo89nyYAngCrqDFb3LHYeJNg
“Heparin Hands”

- **AEA** – frontal recess
- **PEA** - rostrum

- **AEA** – sits on the roof of the ethmoidal cavity and is essentially at the posterior most extent of your frontal recess

- **PEA** – just anterior to the rostrum (face of the sphenoid)

http://1.bp.blogspot.com/_NDcTbOyfDBE/StjBzsVocjl/AAAAAAAAAhg/8ixh-IfUJvY/s400/bloody-nose.jpg
Frontal Sinuses

- Starts to develop at 2 years after birth.
- Borders:
  - Posterior: sloping skull base
  - Anterior: frontal process (or agger nasi)
  - Medial: LCPL
  - Lateral: lamina papyracea
  - Inferior: Bulla, suprabullar cell?
- Frontal recess:
  - the agger nasi air cell
  - interfrontal sinus septal cell
  - supraorbital cell
  - frontal bulla cell
  - Suprabullar cell
  - four types of frontal cells

The frontal recess can be complicated by a number of anterior ethmoidal air cells that can pneumatize in its vicinity, including the agger nasi air cell, the interfrontal sinus septal cell, supraorbital cell, frontal bulla cell, suprabullar, and four types of frontal cells.

Frontal recess is bound by the agger nasi anteriorly, the ethmoidal bulla posteriorly, the lamina laterally and the middle turbinate medially.

Radiographically evident by age 7
Frontal Sinus Anatomy

Hiatus semilunaris/ethmoid infundibulum
CT images showing frontal bullar cell (A), supraorbital ethmoidal cell (B), suprabullar cell (C), and intersinus septal cell (D). Each cell is shown as asterisk (*) marker.

http://openi.nlm.nih.gov/detailedresult.php?img=2896737_ceo-3-76-g005&query=the&fields=all&favor=none&it=none&sub=none&uniq=0&sp=none&req=4&simCollection=2954374_ATM-5-201-g052&npos=50&prt=3
Types of Frontal Cells

Type 1  Single frontal recess cell
       - above agger cell
       - below frontal sinus

Type II >1 cell in frontal recess
       - above agger cell
       - below frontal sinus

Type III Large single cell pneumatizing cephalad into the frontal recess

Type IV Single isolated cell within the frontal sinus

Am J Rhinol 8: 185, 1994
The frontal sinus (FS) is identified by removing the anterior ethmoid cells off the fovea ethmoidalis (FE). In addition, the medial orbit (MO) wall and anterior ethmoid artery (AEA) are preserved during dissection.
Frontal Recess Complication: Stenosis

Figure 16B-12. Endoscopic view of the frontal sinuses at the time of surgery (A) and 4 months later (B) in a patient who underwent an endoscopic Lothrop procedure with significant bone and mucosal trauma in the presence of infection. There is a marked narrowing of the previously widely patent frontal os at 4 months postoperatively.
**Sphenoid Sinus**

- Develop separately from ethmo/maxilloturbinals
- Start to develop 3 – adult size by 18
- Single vertical intersinus septation:
  - Rarely midline
  - Can insert onto carotid canal
- Drains into the sphenoeothmoidal recess
- Vascular: PEA, sphenopalatine
- Neuro: V1 and V2

1. Anterosuperior wall thick anteriorly but thin superiorly
2. Various pneumatization
3. The landmark for the sphenoeothmoidal recess is the superior turbinate
Varying configurations of the sphenoid sinus – base on the degree of pneumatization.
(A) Conchal – 3%, (B) Pre-sellar – 11% and (C) Sellar – 86%

- Sellar/post sellar carries a greater risk of injury as this most posterior position places the sinus just adjacent to vital sutures such as the carotid arteries, optic nerves, maxillary branch of CN 5, Vidian nerve, the pons, sella turcica, and cavernous sinus
- 3% A, 11% B, 86% C
Sphenoid Sinus Natural Os

- Medial to the superior turbinate
- 10mm above the sinus floor
- 30 degree angle from anterior nasal floor
Sphenoid Sinus: Neighboring Structures

“You could die! You could lose your eye! We could poke a hole in your brain!!!!”
Increased complications

- Dehisced or minimal bony coverings over vessels or skull base
  - Onodi cell
- Poor technique

http://uwmsk.org/sinusanatomy2/Sphenoid-Normal.html
Sphenoidotomy with Ethmoidectomy

- ID the superior meatus and the superior turbinate
- Resect most inferior part of the superior turbinate
- The ostium is enlarged where the bone is not too thick.
- Care should be taken to enlarge the os superolaterally where the optic nerve is close
- Posterolateral = carotid artery
  - 22% dehisced

Per Kennedy, the safest method for entering the sphenoid from within the ethmoid sinus is to identify the superior meatus and the superior turbinate by palpation medially between the superior and middle turbinate. The most inferior part of the superior turbinate is often resected then the sphenoid can be palpated and entered medially. The ostium is inlarged where the bone is not too thick. Care should be taken to enlarge the os superolaterally where the optic nerve is close.
1. Does not involve resection of the superior turbinate thus preserving any olfactory neuroepithelium in this area.
Pediatric Considerations

- Frontal Sinuses:
  - In children less than 5 years old, approximately 3% of the children have frontal sinuses
  - Between ages 5 and 10 years, approximately 50% have frontal sinuses
  - At the age of 11 years and older, 65%–75% have frontal sinuses

Surgically – anterior ethmoidectomy/maxillary antrostomy are attempted first; if needed the limited frontal recess work (agger nasi)

In most children, the back wall of the agger nasi is an extremely fragile bone. Gentle anterior pressure will easily displace it, enlarging the drainage pathway.
Pediatric Considerations

- Ethmoid Sinuses
  - Rapid descent of ethmoidal roof

- Sphenoid Sinus
  - Starts development at age 3 – 18

Increased risk of skull base injury.

In younger children, the posterior ethmoid is poorly pneumatized and may be quite small. Often, the roof of the ethmoid descends rapidly, and injury to the skull base in children can happen easily.
Pediatric Considerations: Cystic Fibrosis

- CF patients have less well-developed sinuses.
- Bilateral aplasia of the frontal sinuses. (Eggesbo et al.)
- Low ethmoidal roof

CF patients have less well-developed sinuses. In the excellent study by Eggesbo et al. in which they analyzed 116 CF patients against controls, they found that 44% of the CF patients studied had bilateral aplasia of the frontal sinuses [3]

30% of those CF patients studied had a low ethmoid roof, which must alert the surgeon to this anatomical feature when considering surgery, as it may potentially lead to intracranial complications.
Greed: Biggest Complication of All

Dr. Mark Weinberger – “Nose No Bounds”

2003 - Weinberger has a gross income of almost $14 million
Convicted in 2004 – given 7 years
Sources

- Marcelo B. Antunes, MD, David A. Gudis, MD, Noam A. Cohen, MD, PhD. Epithelium, cilia, and mucus: their importance in chronic rhinosinusitis. Immunology and Allergy Clinics of North America - Volume 29, Issue 4 (November 2009) DOI: 10.1016/j.iac.2009.07.004
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