THE PARANASAL SINUSES:

There are four paired sinuses: maxillary, frontal, ethmoid, and sphenoid sinuses. Their functions are to lighten the skull, humidify/heat inhaled air, provide resonance for the voice, serve as crump zones to the facial skeleton and play a role in mucociliary clearance.

**Mucociliary clearance:** It consists of ciliated cells (75%), goblet cells (20%), and basal cells (5%) and has an acellular basement membrane. This epithelial lining protects the upper airway from inhaled pathogens and debris by a process referred to as MCC. It creates and moves a mucus blanket is cleared toward the nasopharynx every 10-15 minutes. Humans clear 20-40 cc of mucus daily. The mucus layer as a sol layer – invests the cilia and a gel layer – more viscous, working layer of the mucus blanket. Functionally, the MCC can be assessed with a saccharin test. The MCC in the paranasal sinuses has an ORGANIZED, directed, NON-gravity dependent direction of flow.

**Embryology:** During the fourth week of gestation the frontonasal processes and nasal placode (gives rise to medial and lateral processes) develop. During the fifth to seventh week of gestation, the nasal pits/sacs/nares and oronasal membrane (gives rise to choanae) form. By the eighth week, the lateral nasal wall structures (sinus structures and turbinates) begin to develop. There 6-7 ridges in the lateral nasal wall at 8 weeks gestation. These ridges give rise to up to five ethmoturbinals and one maxilloturbinal.

- 1st ethmoturbinal = agger nasi, uncinate
- 2nd ethmoturbinal = middle turbinate
- 3rd ethmoturbinal = superior turbinate
- 4th/5th ethmoturbinal = supreme turbinate
- One maxilloturbinal = inferior turbinate

During week nine to ten of gestation the cartilaginous nasal capsule develops. This may be the true driver of nasosinus development. For example, resorption of the nasal capsule is
responsible for allowing the maxillary sinus to enter to maxilla. Secondary evaginations and invaginations give further rise to sinus structures. Through a fusion of these turbinals, varies 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. 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.

**Neurovascular supply:** The vasculature to the paranasal sinuses are plentiful. Rule of thumb: any sinus with V1 innervation receives it vasculature from internal carotid (ophthalmic) arteries. Any sinus with V1 innervation receives it vasculature from external carotid (internal maxillary) derived arteries. The sphenoid sinus is the only sinus to have both.

**MAXILLARY SINUS (ANTRUM OF HIGHMORE)**

**Structure:** It is the first and largest sinus. It is fluid filled at birth and has a biphasic growth pattern (Growth pattern: 0 (60 days) -3 years then 6-12 years). During the early phase, growth is directed in the horizontal and posterior directions. During the later phase, growth proceeds inferiorly toward the maxillary teeth. It has a pyramid shaped - apex points laterally. Its nervous supply: V2 and greater palatine nerve. Its vascular supply: branches of the internal maxillary artery. It is 15cc in volume at adult size.

**Antrum and Surgical considerations:**
Its antrum is located in the superior medial wall of the maxillary sinus. Multiple cadaveric studies have shown it generally lies in mid-relation to the infundibulum.

**Antrum size:** In general, for mild disease a minimal antrostomy size is recommended as a wide antrostomy may inhibit function. In fact, a study in rabbits showed a wide antrostomy lead to decreased or absent MCC and decreased nitric oxide concentrations in maxillary sinus (bacteriostatic). For, chronic Inflammatory disease or osteitis a wider antrostomy size is recommended.

**Nasolacrimal duct:** 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. This can be prone to injury with performing a maxillary antrostomy. Care should be taken when performing an antrostomy with a “back-biting” forceps. 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.

**Recirculation:**

The natural os should be connected with surgical antrostomy to avoid recirculation (drainage outflow through the natural os only to re-enter the sinus through the non-connected antrostomy).
This can lead to continued symptomatic disease (recurrent maxillary sinusitis) and must be surgically corrected. Fontanelles or accessory ostium can also lead to recirculation and connection to the natural os should be considered.

**Silent Sinus Syndrome:**

Evidenced by enophthalmos (can have diplopia) and a hypoplastic maxillary sinus. Has been also described as “Imploding Antrum Syndrome” and as “a spontaneous and progressive enophthalmos and hypoglobus with hypoplasia of the maxillary sinus and resorption of the orbital floor”. It is thought to be originally idiopathic but can be due to trauma or iatrogenic causes. It is caused by congestion of the osteomeatal complex resulting in negative pressure within the maxillary sinus and a gradual implosion of the antral cavity. The treatment is to reestablish maxillary aeration with sinus surgery.

**ETHMOID SINUS**

**Structure:**

Well defined, fluid filled at birth. Grows until 12 years of age. The anterior ethmoidal air cells are formed first during fetal development followed by the posterior ethmoidal air cells. 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 (infraorbital or “Haller” cell, 10%), even above the orbit (supraorbital, 15%), or lateral to the sphenoid (Onodi, 10%). The ethmoidal air cells are bounded by:

- middle turbinate = 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 fovea ethmoidalis (roof of the ethmoidal labyrinth) laterally.

**Neurovascular supply:** Vascular supply is the anterior ethmoid (AEA) and posterior ethmoid artery (PEA); the neurologic supply is CN V1 (nasociliary to AEA and PEA nerves).

**Ethmoids and Lateral nasal wall structures:** Ethmoidal surgery necessitates knowledge of the lateral nasal wall structures and the various ethmoidal air cells.

- 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
**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.
- Multi-plane structure:
  - Anterior 1/3 – oriented in sagittal plane
  - Middle 1/3 – oriented in coronal plane (basal lamella)
  - Posterior 1/3 – oriented in axial plane.

  Posterior attachment of the middle turbinate is adjacent to the sphenopalatine foramen where the sphenopalatine artery emerges.

**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:
  - Lamina papyracea: 70% → drainage medial to uncinate
  - Middle turbinate: 19% → lateral
  - Fovea ethmoidalis: 11% → lateral

**Bulla Ethmoidalis:**
- Another important and constant landmark of sinus surgery that is posterior to the uncinate.
- Largest ethmoidal air cell
- Makes the 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) – space superior to the bulla, separating it from the skull base
  - Retrobullar recess (RBR) aka posterior semilunar hiatus – space posterior to the bulla separating it from the ground lamella.

**Hiatus Semilunaris/Ethmoid infundibulum & Osteomeatal complex:**

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 anterolaterally, the lamina papyracea medially, and the ethmoid bulla posteriorly. The frontal sinus, anterior ethmoids, and maxillary sinus drain into the infundibulum.

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 – Effective Ethmoid Surgery:**

Understanding the anatomy of the variants of the ethmoid complex can lead to effective 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:** 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.

**Haller cell:** 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.

**Onodi cell:** It 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 infractured 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).

**Preventing complications – Posterior Ethmoidectomy:** The posterior ethmoids should be entered by infracturing the basal lamella at its inferomedial aspect.

**Surgical Anatomy - Fovea Ethmoidalis:**
• Also known as the ethmoidal roof. It slopes inferiorly from anterior to posterior and lateral to medial; it is synonymous with the slope of the skull base.
• The bone transitions from thick to thin – lateral to medial
• Two parts:
  o thick, horizontal part → the orbital plate of the frontal bone
  o thin, near vertical part → the lateral cribriform 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 – greatest risk of injury to the skull base; has more surface area in the surgical field to compromise.

  "Heparin Hands" - Where the blood vessels are:
The AEA sits on the roof of the ethmoidal cavity and is essentially at the posterior most extent of your frontal recess. Care should be taken in this area to avoid injury to this artery. The PEA sits just anterior to the rostrum (face of the sphenoid) or the posterior most aspect of the posterior ethmoids. Care should be taken in this area to avoid injury to the artery.

FRONTAL SINUS

Structure:
The frontal sinus starts to develop at 2 years after birth.
• Borders:
  o Posterior: sloping skull base
  o Anterior: frontal process (or agger nasi)
  o Medial: LCPL
  o Lateral: lamina papyracea
  o Inferior: Bulla, suprabullar cell
• Frontal recess: The frontal recess is bound by the agger nasi anteriorly, the ethmoidal bulla posteriorly, the lamina laterally and the middle turbinate medially. It can be complicated by a number of anterior ethmoidal air cells that can pneumatize in its vicinity.
  o the agger nasi air cell
  o interfrontal sinus septal cell
  o supraorbital cell
  o frontal bulla cell
  o Suprabullar cell
o four types of frontal cells

<table>
<thead>
<tr>
<th>Types of Frontal Cells</th>
<th>Type I</th>
<th>Type II</th>
<th>Type III</th>
<th>Type IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single frontal recess cell</td>
<td>• above agger cell</td>
<td>&gt;1 cell in frontal recess</td>
<td>Large single cell pneumatizing cephalad into the frontal recess</td>
<td>Single isolated cell within the frontal sinus</td>
</tr>
<tr>
<td></td>
<td>• below frontal sinus</td>
<td>• above agger cell</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• below frontal sinus</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Frontal Recess Complication:

AEA injury: To reiterate and as per Kennedy, 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.

SPHENOID SINUS

Structure:
- Develop separately from ethmo/maxilloturbinals
- Starts to develop at age 3 and reaches adult size by age 18
- Single vertical intersinus septation:
  - Rarely midline
  - Can insert onto carotid canal
- Drains into the sphenoehtmoidal recess
- The anterosuperior wall of the sphenoid is thick anteriorly but thin superiorly and its pneumatization pattern varies.
- The landmark for the sphenoehtmoidal recess is the superior turbinate
- Varying considerations:
  - Conchal sphenod sinus – 3% prevalent
  - Pre-Sellar sphenoid sinus – 11% prevalent
  - Post-sellar – 86% prevalent; 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

Neurovascula anatomy:
- Vascular: PEA, sphenopalatine
- Neuro: V1 and V2

Surgical considerations - Sphenoid Sinus Natural Os:
- Medial to the superior turbinate
- 10mm above the sinus floor
- 30 degree angle from anterior nasal floor
**Increased complications**: The common causes for increased complications in this area include: dehisced or minimal bony coverings over vessels or skull base such as with an Onodi cell and poor technique.

**Sphenoidotomy with Ethmoidectomy**: The superior meatus and the superior turbinate are identified. The inferior 1/3 of the superior turbinate is resected. The ostium is identified and 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. Remember, posterolaterally the carotid artery is located and can be dehisced in 22% of the population. Care should be taken to enlarge the os superolaterally where the optic nerve is close.

**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 in a child with frontal disease, anterior ethmoidectomy/maxillary antrostomy are attempted first; if needed then limited frontal recess work (agger nasi) may be attempted. 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.

**Ethmoid surgery and Skull base**:  
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. This leads to increased risk of skull base injury.

**Cystic Fibrosis**:  
CF patients have less well-developed sinuses.  

Studies show CF patients have a higher rate of bilateral aplasia of the frontal sinuses and low ethmoidal roof (Eggesbo et al). This features should be assessed when considering safe surgery in this population.
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
- Disease of the sinuses – Kennedy Chapter 1 and 2 16A