Applied anatomy of the paranasal sinuses

This is a very difficult concept to understand and requires a very systematic approach.

The nasal cavity extends from the anterior skull base superiorly to the floor of the nose inferiorly and it is divided by the nasal septum.

The anterior skull base is made up anteriorly to posteriorly of the frontal bone, ethmoid bone, and sphenoid bone. The floor consists of the palatine process of the maxilla, anteriorly, and the horizontal plate of the palatine bone, posteriorly.

Each lateral nasal wall has an inferior, middle, and superior turbinate. There may be a fourth turbinate called the supreme turbinate. This is located superior to the superior turbinate. Choncha strictly refers to the bone, that is the turbinate without mucosa (*plural, chonchae*).

Between the turbinates and the lateral nasal wall are the meati (*singular, meatus*), each named according to the corresponding turbinate.

The inferior turbinate is a separate bone that articulates with the maxillary, palatine and ethmoid bones. It has a robust scroll-like structure that increases the surface area for air contact. The inferior turbinate receives its blood supply primarily from the posterior lateral nasal artery (a branch of the sphenopalatine artery (SPA)). The anterior portion is perfused by an anastomosis between the anterior lateral nasal artery (facial artery (FA) branch) and the anterior ethmoid artery (AEA).

The posterior aspect of the turbinate is particularly vascular and surgical procedures in that area can be associated with significant bleeding.

The middle and superior turbinates are part of the ethmoid bone. View the anatomy of the septum on the image roll.

It is important at this stage to examine the blood supply of the septum and lateral nasal wall. The lateral nasal wall is supplied by both the external (ECA) and internal carotid artery (ICA) system. Both the septum and the lateral nasal wall receive their blood supply from the same four arteries. The sensory (nerve) supply will be addressed later.

ECA Branches	ICA Branches
Facial artery (FA)	Anterior ethmoidal artery (AEA)
Sphenopalatine artery (SPA)	Posterior ethmoidal artery (PEA)

Anterior ethmoidal artery (AEA)

The anterior ethmoidal artery is a branch of the ophthalmic artery, which is a branch of the ICA. In the orbit it passes between the medial

rectus and superior oblique muscles to exit via the anterior ethmoidal foramen where it sometimes forms a "beak" as it crosses the lamina papyracea, then it travels obliquely across the ethmoidal roof from posterolateral to anteromedial where it enters the anterior cranial fossa through the lateral lamella (of the CP). It then turns anteriorly in the anterior ethmoidal sulcus to re-enter the nose to supply the superior septum and middle turbinate. The anterior ethmoidal sulcus is the thinnest part of the skull base and is a common site of a CSF leak, both spontaneous and acquired.

The AEA may be covered by bone of the skull base, or it may be suspended in a mesentery up to 5mm below skull base which puts it at increased risk of injury intraoperatively, especially during anterior ethmoidectomy or surgery in the frontal recess. Its position may vary on each side. An injured artery can retract into the orbit resulting in a rapidly expanding orbital haematoma, resulting in traction on the optic nerve and blindness. This is known as acute orbital compartment syndrome. A lateral canthotomy and cantholysis, and orbital decompression (medial and /or lateral) in the event of injury to the artery may prevent visual impairment.

The septal branch of anterior ethmoidal artery is a common site of epistaxis and should be carefully looked for in patients presenting with intractable epistaxis. Nasal packing often does not compress this branch of the anterior ethmoidal artery, which lies about 1cm below the level of the cribriform plate and just posterior to the anterior aspect of the middle turbinate, on the superior septum and posterior to the nasal swell body (Stamm's s-point).

AEA-related epistaxis is less common than SPA-related epistaxis (described below) and is typically associated with midface trauma or iatrogenic injury during endoscopic sinus surgery. Addressing an AEA injury is frequently addressed via an external approach, but as anterior skull base surgical skills advance in the field, may also be approached endonasally or transcurancular.

Posterior ethmoidal artery

The posterior ethmoidal artery (PEA, also a branch of the ophthalmic artery) exits the orbit via the posterior ethmoidal canal.

The distances between anterior lacrimal crest, the anterior ethmoidal foramen, and the posterior ethmoidal foramen, and the optic canal are approximately 24mm, 12mm and 6mm.

The posterior ethmoidal artery crosses the anterior skull base anterior to sphenoid face and is usually covered by bone, making it less vulnerable to surgical injury. The artery can often be seen at the junction between skull base (fovea ethmoidalis) and the sphenoid face. Rarely, a middle ethmoidal artery is present between the anterior and posterior ethmoidal arteries.

Sphenopalatine artery

The SPA is a terminal branch of the internal maxillary artery (IMA). It accounts for up to 90% of the blood supply to the nasal cavity (lateral nasal wall, turbinates and septum). The IMA runs behind the posterior wall of the maxillary sinus in the pterygopalatine fossa and exits as the sphenopalatine artery via the sphenopalatine foramen, which is formed by the body of the sphenoid posteriorly and the orbital process of palatine bone anteriorly. The sphenopalatine artery may have as many as 10 branches, and these may divide before (40%) or after the sphenopalatine foramen.

The posterior septal branch of the sphenopalatine artery runs across the face of the sphenoid below the sphenoid ostium to supply the posterior septum. The Hadad-Bassagasteguy vascularised nasoseptal pedicled flap is based on this artery (used to repair skull base defects and CSF leaks). Intranasally, a projection of palatine bone, called the ethmoidal crest, is the most reliable landmark to find the sphenopalatine artery; the artery runs immediately behind this crest.

<u>Septum</u>

The confluence of arteries in the anterior part of the septum is called Kisselbach's plexus (also known as Little's area) and it consists of the AEA, and branches of the FA, and SPA. The superior labial artery is a branch of the FA, the greater palatine artery are branches of the SPA (a terminal branch of the maxillary artery).

This site is responsible for a large proportion of epistaxis. Much of the nasal cavity is supplied by the SPA and in situations where epistaxis is intractable to first aid measures, or cauterisation of Kisselbach's plexus, SPA ligation may be performed as a surgical procedure.

Woodruff's plexus is a vascular network located on the posterior lateral wall of the inferior meatus and it has been associated with posterior epistaxis. It was originally described as a venous plexus, which has been supported by anatomical studies. Although there are a multitude of reports that the plexus may be arterial in nature, there is an absence of anatomical studies to support this idea.²

Nasal cavity

There are 4 groups of paranasal sinuses and at birth the sinuses, from largest to smallest are: the ethmoid, maxillary, sphenoid, and frontal. Pneumatisation (development and enlargement) of the maxillary sinuses begins in the 3–5-year-old age range, which is also when the frontal sinus begins to develop. The order of development generally progresses from ethmoid to sphenoid and maxillary, and then frontal sinuses.

This has clinical significance in children who present with complicated sinusitis and require maxillary antrum washout, or an uncinectomy and middle meatal antrostomy to address the source of the sepsis. Without reviewing the CT scan, the surgeon may injure a tooth bud. Similarly, with frontal sinus trephination, it is important to consider the anatomical markers to prevent an intracranial breech.

Ethmoid bone

The ethmoid bone consists of 3 parts: the cribriform plate, perpendicular plate and labyrinth/lateral masses.

The cribriform plate is paper-thin and forms part of the roof of the nasal cavity. It articulates with the ethmoidal notch of the frontal bone anteriorly. The crista galli extends superiorly from the cribriform plate in the midline and is attached to the falx cerebri on its posterior border. Two laterally projecting alae help complete the foramen caecum which contains the emissary vein that drains to the superior sagittal sinus.

The ethmoidal roof is a high-risk surgical area. In the anterior cribriform plate is a fissure to either side of the crista galli that occupies a process of dura mater. Lateral to this fissure, a foramen transmits the nasociliary nerve and AEA.

Medially, the cribriform plate is narrow and deeply grooved on either side of the crista galli where it contains the olfactory bulbs. Olfactory fibres pass through multiple foramina in the cribriform plate to the superior turbinate, upper nasal septum, and middle turbinate.

Laterally the ethmoidal roof is formed by a thicker, horizontal portion and, medially by a thinner, vertical portion of the bone. (Known as the fovea ethmoidalis and lateral lamella(ae), respectively).

The superior/vertical attachment of the middle turbinate divides the anterior skull base into the cribriform plate (medially) and the fovea ethmoidalis (laterally).

The lateral lamella of the cribriform plate is only 0.05 - 0.2 mm thick and is at high risk of injury during surgery. The Keros classification describes the depth of the olfactory fossae. It is a measurement of the height of the lateral lamella at its highest point and is measured from the fovea ethmoidalis to the cribriform plate. This measurement is asymmetrical in up to 15% of patients. A higher value is associated with increased risk of cribriform plate injury, CSF leaks and injury to the anterior ethmoidal artery.

The perpendicular plate of the ethmoid is an inferior vertical projection below cribriform plate of the crista galli and forms the upper part of the posterior bony septum. Anterosuperiorly it articulates with the spines of the frontal and nasal bones, posteriorly with the sphenoidal crest and vomer, and anteroinferiorly with the quadrangular cartilage of the nasal septum. The labyrinths (lateral masses) contain the ethmoid cells that are exenterated during ethmoidectomy. They consist of numerous thinwalled cavities known as ethmoidal cells or ethmoid sinuses and lie between two vertical bony plates (the orbital plate (lamina papyracea) laterally and the basal or vertical lamella of the middle turbinate medially).

The anatomy of the ethmoidal labyrinth is variable between patients and careful consideration of CT scans is essential to prevent confusion during surgery.

Recognised groups of ethmoid cells are:

- 1. Anterior ethmoidal cells
- 2. Agger nasi
- 3. Haller cells
- 4. Frontal / frontoethmoidal cells
- 5. Suprabullar cells
- 6. Frontal bullar cell
- 7. Supraorbital ethmoidal cell
- 8. Posterior ethmoidal cells
- 9. Onodi cell

Middle turbinate

The middle turbinate is a key anatomical landmark during sinus surgery, and it should always be preserved. It is part of the ethmoid bone. It comprises vascular, erectile glandular tissue on spongy bone and is lined by pseudostratified columnar ciliated respiratory epithelium. Anteriorly it fuses with the agger nasi to form the axilla. Superiorly it attaches to the lateral lamella of the cribriform plate in a sagittal plane. Posteriorly it rotates to lie in a coronal plane (basal lamella) and attaches to the lamina papyracea, thereby separating the anterior from the posterior ethmoid cells. Posterior to the sphenopalatine foramen it attaches to the perpendicular plate of the palate in a horizontal plane.

The olfactory area of the nose is located between the turbinate and the septum and adhesions (post-surgical scarring) occurring medial to the turbinate can cause anosmia.

The anatomy of the middle turbinate is confusing. The best description of its complicated structure is from Kamel, R., 2018. Understanding the complex anatomy of the middle turbinate via educational origami.³

The lateral extension of the middle turbinate (the basal/ground lamella) divides the anterior from the posterior ethmoid air cells and should be identified at surgery as an anatomical landmark. It attaches to the lamina papyracea.

The free edge of the middle turbinate typically faces laterally towards the middle meatus but may also paradoxically face medially.

A concha bullosa is a pneumatised middle turbinate and is present in up to 50% of people. Even though it may obstruct the osteomeatal complex (discussed later) and predispose to acute or chronic rhinosinusitis, most people with concha bullosae are asymptomatic. A concha may impede access to the middle meatus and need to be reduced prior to uncinectomy or ethmoidectomy.

Caution should be exercised when handling the MT because of its attachment to the paper-thin cribriform plate above. Excessive manipulation of the turbinate can fracture the cribriform plate and cause a CSF leak. The cribriform plate is very thin medial to the turbinate and should be avoided, if possible, during surgery.

Uncinate process

The uncinate process is a thin, sickle-shaped projection of ethmoid bone that is encountered anteriorly in the lateral nasal wall. Removing the uncinate provides access to the hiatus semilunaris and the ethmoidal bulla.

It has a free posterior edge which lies anterior to the ethmoidal bulla.

The uncinate attaches to the posterior edge of the lacrimal bone anteriorly and to the superior edge of the inferior turbinate inferiorly, and has a free edge posteriorly covered by mucosa.

Superiorly it has a variable attachment to the lamina papyricea, fovea ethmoidalis or middle turbinate. This superior attachment influences the frontal sinus drainage pathway (either medial to, or directly into superior ethmoid infundibulum).

It is in close proximity to the orbital wall, which may be injured should a surgeon use poor surgical technique when removing it.

The uncinate process may be pneumatised and cause obstruction to the infundibulum or have more than one attachment superiorly.

The anterior ethmoidal cells (AECs)

The AECs are separated from the posterior ethmoidal cells by the basal/ground lamella (lateral extension of the middle turbinate at its posterior end). The AECs drain into the middle meatus. The PECs are situated posterior to the basal lamella of the middle turbinate. They drain into the superior meatus.

These will be discussed according to the following list:

- 1. Anterior ethmoidal cells
- 2. Agger nasi
- 3. Haller cells
- 4. Frontal / frontoethmoidal cells
- 5. Suprabullar cells
- 6. Frontal bullar cell

- 7. Supraorbital ethmoidal cell
- 8. Posterior ethmoidal cells
- 9. Onodi cell

The **ethmoidal bulla** (bulla ethmoidalis) is a constant landmark during ethmoid surgery and is the largest anterior ethmoid air cell. It lies posterior to the uncinate process.

The **agger nasi** is the most anterior ethmoid air cell. It is located in the lacrimal bone anterior and superior to the axilla (attachment to the lateral nasal wall of the middle turbinate). The agger nasi is present in 90% of CT scans and is the 1st anterior ethmoidal cell to become pneumatised. It is seen just superior to the lacrimal sac on coronal CT scan. The posterior wall of the agger nasi forms the anterior boundary of frontal recess, and its medial wall is closely related to the vertical lamella of middle turbinate. The superior part of the uncinate process forms the medial wall of the agger nasi. Laterally it is bounded by the lamina papyracea.

Haller cells are anterior ethmoid air cells extending into the maxillary sinus. They can obstruct the outflow tract of the maxillary sinus and must be removed when there is pathology within the maxillary sinus. These cells are important to identify preoperatively on CT scan.

Frontal cells (also known as frontoethmoidal cells) are anterior ethmoid cells that pneumatise the frontal recess/sinus above the agger nasi. Bent & Kuhn classified these frontal cells into 4 types:

- Type I: Single cell above agger nasi not extending into frontal sinus (25%)
- Type II: Group of cells (≥2) above agger nasi cell but below orbital roof (5%)
- Type III: Single cell extending from agger nasi into frontal sinus (3%)
- Type IV: Isolated cell within frontal sinus, not contiguous with agger nasi (<1%)

Excessive pneumatisation of these cells (especially Types III and IV) may obstruct the frontal recess and predispose to frontal sinus disease.

Suprabullar cells are anterior ethmoidal air cells located above the bulla ethmoidalis and extend towards the frontal recess, but not into the frontal sinus.

A frontal bullar cell is a suprabullar cell that pneumatises from the posterior frontal recess and pneumatises along the skull base into the frontal sinus.

A supraorbital ethmoidal cell is a suprabullar anterior ethmoidal air cell that arises behind the frontal recess and extends over the orbit by pneumatising the orbital plate of the frontal bone. When it is large, it may be mistaken for the frontal sinus and it may obstruct the frontal recess.

An Onodi cell is a posterior ethmoid (sphenoethmoidal) cell that extends superior and often lateral to the sphenoid sinus.

Horizontal septations within the sphenoid sinus seen on CT represent an **Onodi cell,** with the Onodi cell being the posterolateral cell at the level where the horizontal septation is seen. It is found in up to 25% of patients and is important to identify on a preoperative CT scan because the middle cranial fossa is immediately behind the Onodi cell (and the sphenoid sinus is below the Onodi cell).

It is often closely related to the optic nerve and the nerve is therefore at great risk during posterior ethmoid surgery. There is an increased risk of optic nerve injury (15% dehiscent in Onodi cell), carotid artery injury (20% dehiscent in Onodi cell) or brain injury.

Messerklinger described 5 lamellae (bony structures) that traverse the ethmoids and extend from the lamina papyracea laterally to the cribriform plate superiorly (in the region of the fovea ethmoidalis) The frontal bone is their anterior limit.

1st Lamella: Uncinate process (incompletely developed lamella)

2nd Lamella: Bulla lamella (pneumatisation of this lamella forms the ethmoidal bulla)

3rd Lamella: Ground / basal lamella of the middle turbinate (most constant and completely formed lamella)

4th Lamella: Superior turbinate

5th Lamella: Supreme turbinate (only occasionally present)

Lamina papyracea

The lateral wall of the labyrinth is formed by the orbital plate of the ethmoid (lamina papyracea). It articulates with the orbital plate of the frontal bone superiorly, the maxillary and orbital processes of the palatine inferiorly, the lacrimal bone anteriorly and the sphenoid posteriorly.

Maxillary sinus

The maxillary sinus ostium is located on the supermedial aspect of the maxillary sinus. It opens into the ethmoidal infundibulum. The natural ostium is typically oval shaped and orientated obliquely. It is not visible during endoscopic examination unless the uncinate process has been removed.

The anterior and posterior fontanelles are bony defects in the medial wall of the maxillary sinus above the inferior turbinate. The fontanelles are covered only by mucosa and connective tissue. Defects in the fontanelles are called accessory ostia. They are more commonly located posteriorly and are spherical with the long axis in a horizontal plane.

The osteomeatal complex

The osteomeatal unit is a functional unit which is the common drainage pathway for the frontal, maxillary and ethmoid sinuses. It includes the ethmoidal infundibulum, middle turbinate, ethmoidal bulla, uncinate process, hiatus semilunaris and frontal recess.

The middle meatus is the curved anteroposterior passage above the superior border of the inferior turbinate, between the middle turbinate and lateral nasal wall.

The hiatus semilunaris is the 'entrance' to the ethmoidal infundibulum. It is a 2-dimensional opening between the free posterior edge of the uncinate process and the anterior face of the bulla ethmoidalis.

The ethmoidal infundibulum is a 3-dimensional space bound by the uncinate process medially, maxillary sinus ostium inferiorly, lamina papyracea and frontal process of maxilla (+/- lacrimal bone) laterally and the ethmoidal bulla posteriorly. Anteriorly it ends blindly in an acute angle where the uncinate process attaches to the lateral nasal wall and has a variable superior configuration depending on the attachment of the uncinate process (either ending blindly in the recessus terminalis if the attachment is to lamina papyracea, or into the frontal recess if attached to the skull base or middle turbinate)

The retrobullar recess is a space that may be present between the posterior surface of the bulla ethmoidalis and the basal lamella.

The suprabullar recess may be present between the superior surface of the bulla and the fovea ethmoidalis.

Sphenoid sinus

The sphenoethmoidal recess lies anterior to the sphenoid face (anterior wall of sphenoid) and medial to the superior turbinate. The sphenoid ostium is located medial to the superior turbinate (85%) at a level horizontal to the superior border of the natural maxillary ostium.

The nasolacrimal system

Both the upper eyelid and the lower eyelid have a small opening (puntum, *pl. puncta*) on the surface of the eyelid margin near the medial canthus. Each punctum extends to a canal that flows into the lacrimal sac and then the nasal cavity. The drainage canal connecting the ocular surface to the nasal cavity consists of multiple parts.

Within the lower eyelid, the punctum leads to a 2 mm long ampulla, which runs perpendicular to the eyelid margin. The ampulla turns 90

degrees medially, becoming the inferior canaliculus and travels 8 to 10 mm before reaching the common canaliculus. The upper canaliculus travels 2 mm superiorly in the eyelid before turning 90 degrees medially and moving 8 to 10 mm before connecting to the common canaliculus. The common canaliculus drains into the lacrimal sac. At the junction of the common canaliculus and the lacrimal sac is the valve of Rosenmüller. It is a one-way valve that prevents reflux from the lacrimal sac to the puncta.

The lacrimal sac drains inferiorly to the nasolacrimal duct, which is bordered medially by palatine bone and the inferior turbinate in the nose and laterally by maxillary bone. The nasolacrimal duct opens at the inferior meatus located underneath the inferior nasal turbinate. The lacrimal sac is approximately 10 to 15 mm in axial length and 13 to 20 mm in coronal length, and the nasolacrimal duct is 12 to 18 mm long. The inferior nasal meatus is partially covered by a mucosal fold known as the Hasner's valve.