Chapter

1

Surgical Anatomy—Nose and Paranasal Sinuses

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The surgical anatomy of the nasal cavity and paranasal sinuses are complex and variable. The anatomical variations in the lateral wall may lead to impairment of drainage leading to chronic sinusitis. Nasal endoscopy and advent of multidetector computed tomography (MDCT) have paved the way in understanding this complex anatomy. A precise understanding of the three-dimensional anatomy of lateral nasal wall, sphenoethmofrontal sinuses and their vital relations to adjacent structures including skull base and cadaveric dissections is mandatory. Moreover, with expansion in indications for endoscopic surgeries in this region and beyond, a detail knowledge and understanding of this complex anatomy and associated landmarks are the key to become a successful endoscopic sinus and skull base surgeon. Vital structures like the orbit, cranial cavity, optic nerve, internal carotid artery, etc. lie in close relation to the sphenoethmofrontal sinuses, usually separated by a thin bone; making them vulnerable to injury during an endoscopic sinus surgery.

The exact orientation of various intranasal and extranasal structures with respect to their location, attitude and interrelation can be studied only by repeated cadaveric dissections. Strong knowledge of anatomy and its variation plays a pivotal role in diagnosis and endoscopic approaches to surgeries like septoplasty, septorhinoplasty, adenoidectomy, hypophysectomy, excision of benign tumour like glioma, medial maxillectomy, etc.

The introduction of nasal and sinus endoscopy, better imaging techniques and study of whole organ mounted sections has helped us to understand better the microarchitectural anatomy of sphenoethmoids and their vital relations.

SKELETAL FRAMEWORK OF EXTERNAL NOSE (Figs 1.1 and 1.2)

It consists of bony and cartilaginous supportive framework.

Bony part consists of the following (Fig. 1.1).

1. Paired nasal bone
2. Paired frontal process of the maxilla
3. Nasal process of the frontal bone.

Nasal bone articulates with the nasal process of the frontal bone superiorly, frontal

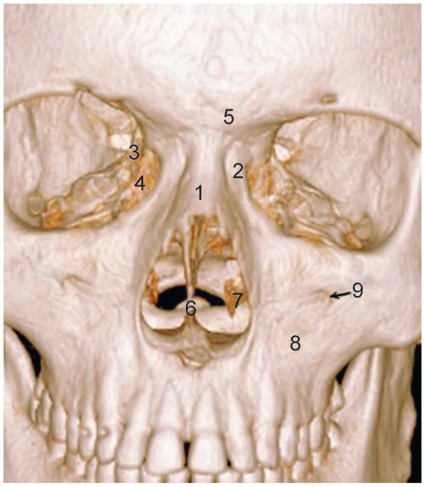


Fig. 1.1: Bony skeletal framework of external nose and orbit: (1) Nasal bone, (2) Frontal process of maxilla, (3) Lamina papyracea, (4) Lacrimal bone, (5) Nasal process of frontal bone, (6) Nasal septum, (7) Concha, (8) Canine fossa, (9) Infraorbital foramen

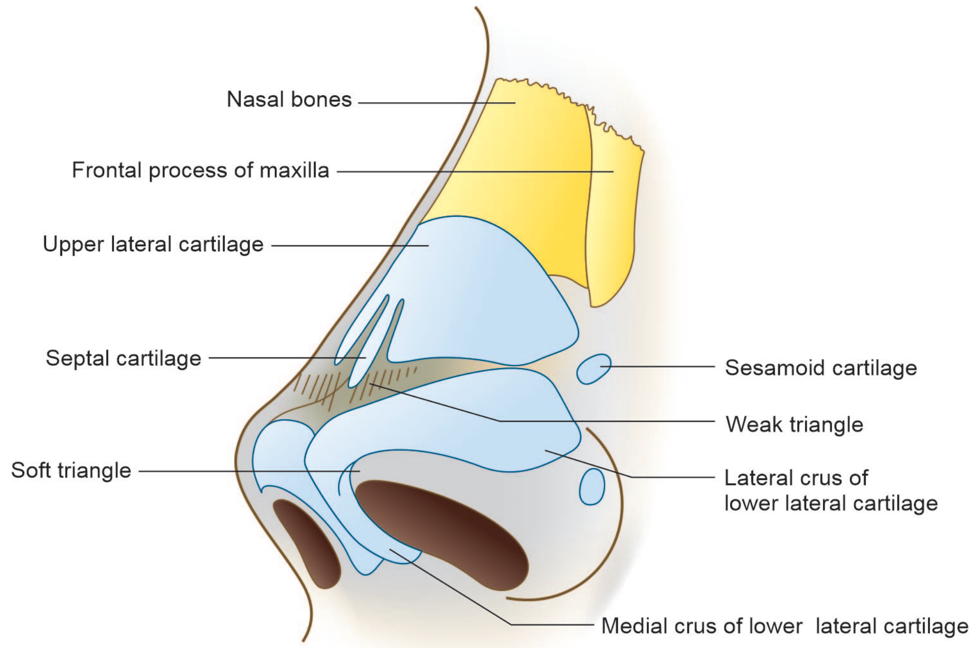


Fig. 1.2: Skeletal framework of external nose

process of the maxilla laterally, inferiorly with the upper lateral cartilage and medially with nasal bone of the other side. The junction between the two nasal bones forms the bridge of the nose (Oneal and Beil 2010).

Cartilaginous part is made up of the following cartilages (Coverse 1955).

1. Paired upper lateral cartilage.
2. Paired lower lateral cartilage (alar cartilages)
3. Sesamoid cartilage
4. Anterior part of the septal cartilage.

The upper lateral cartilage is triangular in shape and is attached above with the frontal process of maxilla and inferior margin of nasal bone. Medially it is continuous with the septal cartilage and in fact is a triangular flat expansion of the septal cartilage forming the middle third of the nose.

The lower lateral cartilage or the alar cartilage forms the lower third of the nose and is responsible for maintaining the projection and shape of the tip. It consists of slender medial crus and wider lateral crus. The two medial crurae support the columella. Each lateral crus forms the ala of the nose. The projection between the medial and lateral crurae of the cartilage supports the tip of the nose, which forms the dome.

The minor sesamoid cartilages are present between the upper and lower nasal cartilages.

The nasal cartilages are made up of hyaline cartilage. Nasal bones and cartilages are connected to each other by periosteum and perichondrium, which is continuous. The upper and lower lateral cartilages prevent the collapse of the vestibule during inspiration.

The skin covers the skeletal framework of the external nose, which is continuous with the skin of the columella and vestibule of the nose.

NASAL CAVITY

Knowledge of the interior of nasal cavity to human being dates back to ancient civilization when the nose was predominantly associated with the sense of smell. The earliest record of an anatomical observation is in the papyrus of Ebers and Egyptian tomb inscriptions, dated well before 1500 BC, where the nose was used as a route for extracting the contents of the cranial vault as part of the mummification process, thereby avoiding any facial disfigurement. This implies an intimate knowledge of the intricate relationship between the roof of the ethmoids and the brain (Kaluskar 1997). The nasal cavity is divided into right and left nasal cavities by the nasal septum. Each nasal cavity has a medial and a lateral wall, a roof and a floor cottle. The anterior most part of the nasal cavities lined by the skin is called the vestibule of the nose. Rest of the nasal cavities is lined by the respiratory epithelium below and olfactory epithelium above (dangerous area of nose). Each nasal cavity is approximately 5–7 cm in length and 5 cm in height. It is narrow transversely, measuring approximately 1.5 cm at the floor and 1–2 mm at the roof.

VESTIBULE

It is the entrance of the nasal cavity from the nostrils and is lined by skin containing hair follicles. It forms the part of the dangerous area of face because of the presence of the retrograde venous drainage through ophthalmic veins (without valves), which can lead to complications like cavernous sinus thrombosis. The vestibule is demarcated from the nasal mucosa by the limen nasi, which corresponds to the superior margin of the lower lateral cartilage (Oneal, et al 1999).

COLUMELLA

It is the part between the two nasal vestibules and forms the caudal end of the nasal septum. It is formed by the medial crurae of the two lower lateral cartilages. The lower lateral cartilages and the caudal end of the septum supports the tip of the nose. Injury of any form to either caudal septum or lower lateral cartilages will change the shape of the tip.

Framework of the Nasal Cavity

In an articulated skull, the following bones/ cartilages bind each nasal cavity.

1. **The floor is formed by:**
   a. Palatine process of the maxilla.
   b. Horizontal process of the palatine bone.
2. **The roof consists of:**
   a. Cribriform plate of the ethmoid.
   b. Nasal process of the frontal bone.
   c. Body of the sphenoid.
3. **The medial wall is formed by:**
   a. Cartilaginous nasal septum
   b. Bony nasal septum
   c. Membranous columella.
4. **Lateral wall consists of:**
   a. Medial wall of the maxilla
   b. Inferior concha
   c. Middle and superior concha of the ethmoid bone.

MEDIAL WALL (NASAL SEPTUM)

This is formed by bony and cartilaginous framework and is lined by the mucoperiosteum and the mucoperichondrium, respectively. This forms the bulk of the nasal septum. The small caudal part is membranous (columella) and is lined by skin. The superior part of nasal septum located above the inferior turbinates and extending up to the anterior part of the middle turbinates is termed as septal swell body. Histologically, it contains glandular structures with lesser vascularity than inferior turbinate (Wexler, et al 2006).

Following structures form the bony nasal septum (Figs 1.3 and 1.4).

Major contribution from:

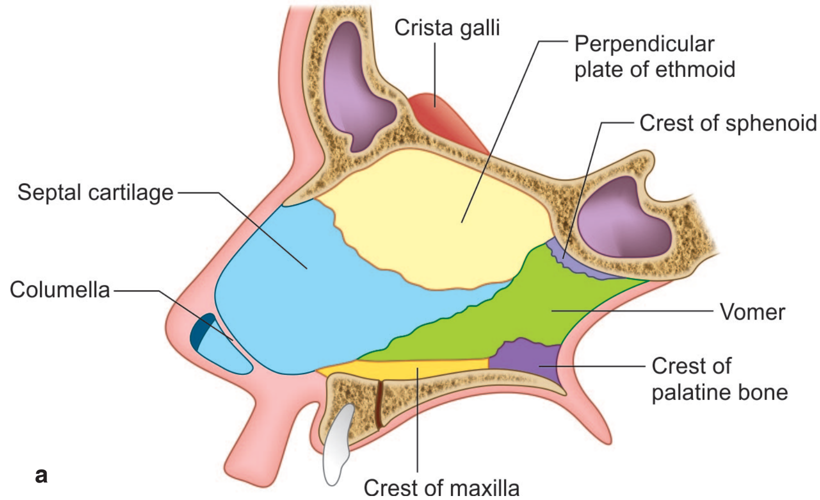
- Perpendicular plate of ethmoid
- Vomer
- Palatine crest
- Maxillary crest

Small contribution from:

- Nasal spine of the frontal bone
- Rostrum of the sphenoid
- Anterior nasal spine of the maxilla

The cartilaginous part of the nasal septum is formed by quadrangular cartilage with contributions from upper and lower lateral cartilages (Converse 1955).

Membranous columella: It is the membranous part of the septum between the medial crus of the lower lateral cartilage and the quadrangular cartilage. It is lined by skin. It



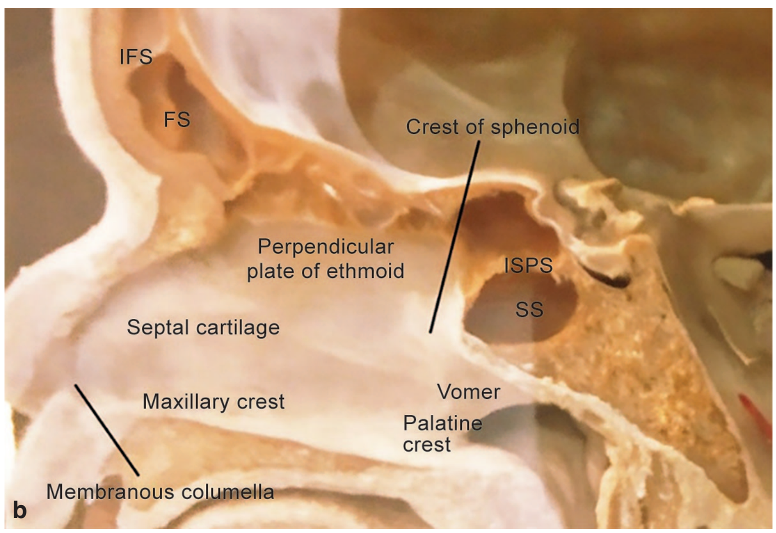


Fig. 1.3: **a.** Bony and cartilaginous part of the nasal septum; **b.** Various parts of nasal septum and frontal sinus (FS), interfrontal septum (IFS), intersphenoidal septum (ISPS), sphenoid sinus (SS)

does not have much relevance with respect to endoscopic sinus surgery, except that a deviated septum can be associated with caudal dislocation of the septum. Injury to caudal septum and medial crus can change the shape of the nasal tip.

Roof: The roof of nasal cavity is curved with concave surface downwards. The middle part is formed by the cribriform plate of ethmoid and is nearly horizontal. The anterior and posterior parts are sloping. The anterior part is formed by the nasal part of frontal bone, the nasal bone.

The posterior part consists of the anterior and inferior surfaces of the body of the sphenoid and the bones in contact with these surfaces (Oneal, et al 1999).

Lateral Wall of the Nasal Cavity

Compared to the simple medial wall, the lateral wall is complicated in its anatomy. It bounds most of the paranasal sinuses and receives the openings from these sinuses (Figs 1.4 and 1.5).

The external nares lead to the skin lined part of the lateral nasal wall, the vestibule. This

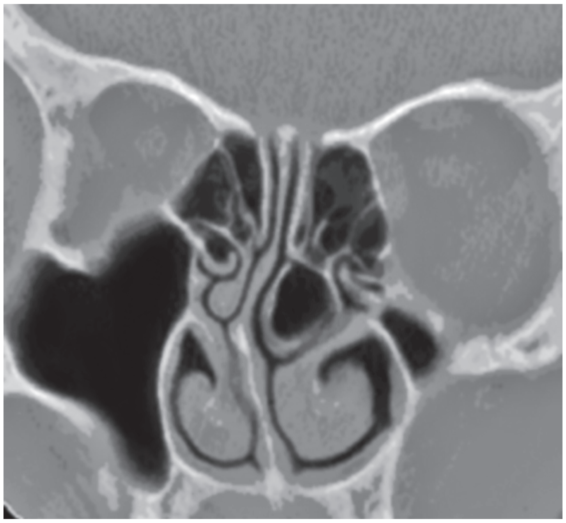


Fig. 1.4a: CT scan of the nose and paranasal sinus

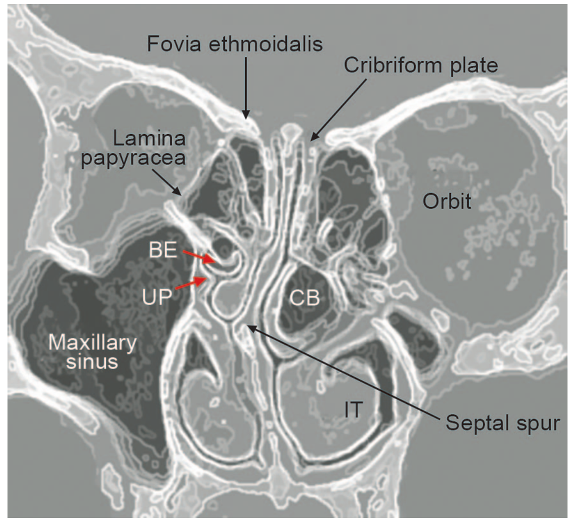


Fig. 1.4b: Same CT restructured showing the details—uncinate process (UP), bulla ethmoidalis (BE), pneumatized middle turbinate or concha bullosa (CB), inferior turbinate (IT)

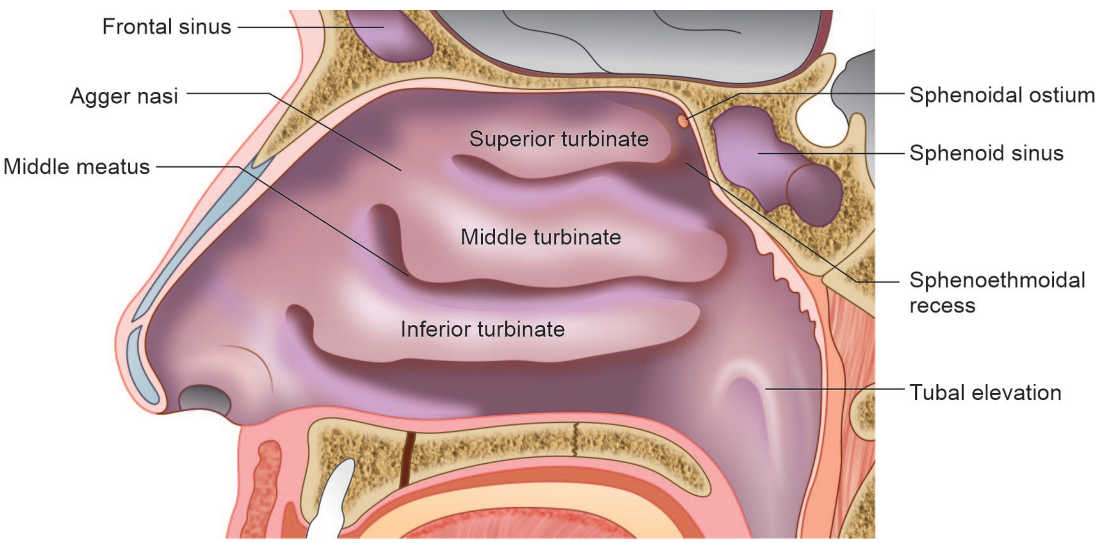


Fig. 1.5a: Anatomy of the lateral nasal wall

corresponds to the ala of the nose and is separated from the rest of the lateral wall (lateral wall proper) by a ridge, limen nasi or limen vestibuli which is formed by the lower end of upper lateral cartilage.

The lateral wall proper, lined by mucosa, bears 3 or 4 nasal conchae or turbinates, which are delicate projecting scrolls of bone covered by mucous membrane (Fig. 1.5a and b).

These are named from below to upwards—inferior, middle and superior conchae. The fourth one, the supreme concha, is present unilaterally or bilaterally in 60% of cases. This is the smallest of all and is usually a mere ridge. The air spaces beneath and lateral to the conchae are termed meati which are named according to turbinates to which they are related, viz. inferior, middle and superior meati. The supreme meatus when present is

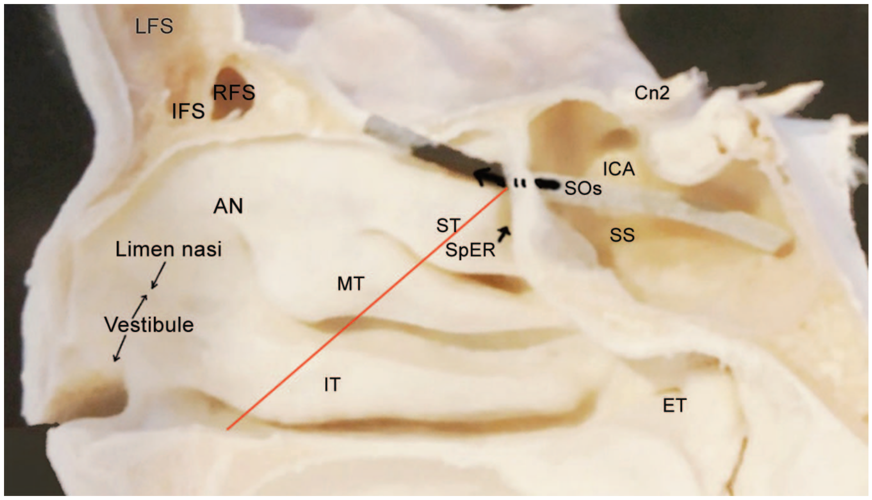


Fig. 1.5b: The vestibule, limen nasi, agger nasi (AN), inferior turbinate (IT), middle turbinate (MT), superior turbinate (ST), arrow leading to opening of sphenoid sinus (SOs), sphenoethmoidal recess (SpER), left frontal sinus (LFS) connected through interfrontal septum (IFS) with right frontal sinus (RFS), interior of sphenoid sinus (SS), bulging of internal carotid artery (ICA) and optic nerve (Cn2) and optic carotid recess appearing as a depression between the two, eustachian tube (ET), the red line denotes the distance between anterior nasal spine to sphenoid ostium to be 7 cm

usually a barely perceptible furrow below supreme concha. The part of the nasal cavity above the uppermost concha and below the body of sphenoid bone is the sphenoethmoidal recess. The sphenoid ostium is about 7 cm from anterior nasal spine (Fig. 1.5b).

All the anterior group of sinuses, viz. the frontal, anterior and middle ethmoid and maxillary sinuses drain into the middle meatus. The posterior group of sinuses, i.e. the posterior ethmoid and sphenoid drain above the middle turbinate. The sphenoid sinus drains into the sphenoethmoidal recess and the posterior ethmoids into the superior or supreme meatus (Figs 1.5 and 1.6).

Both inferior and middle conchae begin anteriorly approximately at the level of the vertical plane of the forehead and extend one below the other almost to the choana.

Anterior to these two conchae, the lateral wall of nose above the limen nasi is more delicately marked, i.e.

1. About halfway between the anterior end of the middle concha and the dorsum of the nose is a slight projection, the agger nasi (Fig. 1.5b). It is derived from the Latin word *agger* meaning mound (Wormald 2005). It is said to be the remnant of additional concha found in lower animals, but is more important in man as it marks the location of anterior most of the anterior ethmoid cells called agger nasi cells. It is situated in the lacrimal bone and is present anterior and superior to the anterior buttress of the middle turbinate. It is the most prominent and constant ethmoidal cell, which is characterized as a bulge in the lateral nasal wall in over 90% of CT scans studied (Womald 2005). The uncinate process and the agger nasi cell are derived from 1st ethmoturbinal. During the process of development, the descending part of the first ethmoturbinal persists as the uncinate process, while the ascending portion regressed as the agger nasi cell (Daniel, et al 2003).
2. The passageway above the agger nasi, the olfactory sulcus, leads to the olfactory area (dangerous area of nose).
3. Below and posterior to the agger nasi, it leads to the middle meatus proper through a shallow depression known as atrium of the middle meatus. This is situated above and anterior to the attached end of inferior turbinate.

The superior concha, about half the length of the other two, begins at about the middle of these. The three conchae converge somewhat towards each other posteriorly and the remaining part of the nasal cavity behind their posterior ends is the nasopharyngeal meatus. This opens into the nasopharynx through the choana. Sphenopalatine foramen is situated in the nasopharyngeal meatus, just midway between posterior ends of middle and superior turbinates. The vessels and nerves here can be traced towards the foramen and their vanishing point helps to locate the foramen.

Inferior Nasal Concha (Fig. 1.6) and Inferior Meatus

Inferior nasal concha is an independent bone covered with thick mucous membrane which contains a vascular, cavernous plexus.

It is so arched that the inferior meatus is narrow anteriorly and posteriorly, but is both wider and higher at the junction of anterior and middle one-third of inferior turbinate. Here the attachment of inferior turbinate curves sharply, called the genu of inferior turbinate.

The nasolacrimal duct opens into the inferior meatus, in its most cephalic part, under the genu of inferior turbinate and is about 15–20 mm from limen nasi and 30–40 mm from the anterior nares. Nasolacrimal duct dysfunction rarely results from surgery of inferior meatus, just under the genu.

The nasolacrimal duct rarely opens lower in the inferior meatus and in such cases the orifice is slit-like, as the duct runs obliquely through the mucous membrane. Here it is usually protected by a fold of mucous membrane, the plica lacrimalis or the valve of Hasner.

Middle Nasal Concha (Fig. 1.6) and Middle Meatus

The lateral wall of nasal cavity above the inferior turbinate is basically formed by the ethmoid labyrinth. Middle nasal concha is a part of the ethmoid labyrinth.

The attachment of middle turbinate to the lateral wall has 2 slopes, the ascending and the descending rami which meet at an angle, the genu of middle turbinate. The genu is situated anteriorly. The highest part of the middle meatus lies below the genu and is known as the frontal recess (Holinshead).

The insertion of the middle turbinate into the lateral wall is called axilla. Creating a flap

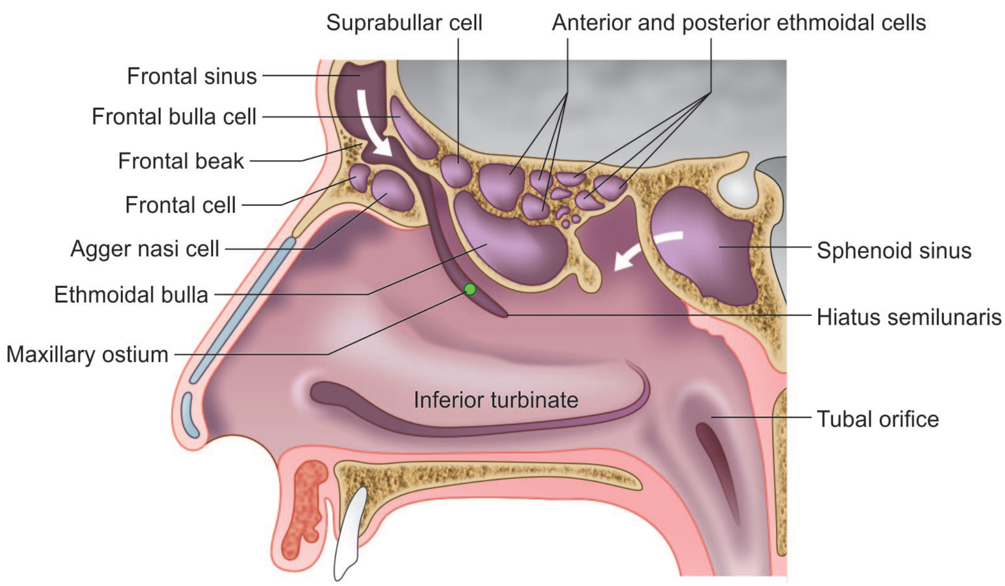


Fig. 1.6a: Endoscopic anatomy of the lateral nasal wall and middle meatus

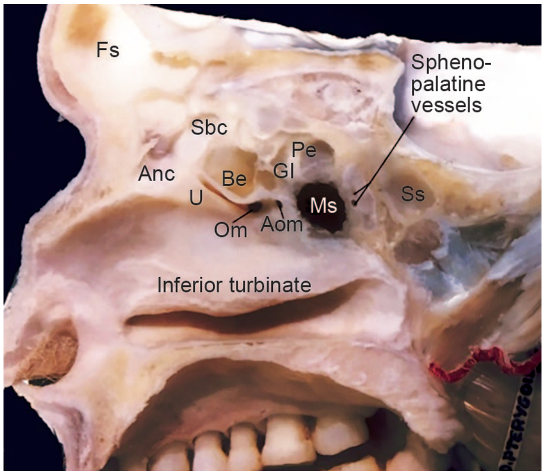


Fig. 1.6b: Structures in the lateral wall parasagittal cut through middle meatus in cadaveric specimen: Frontal sinus (Fs), agger nasi cell (Anc), uncinate process (U), opened bulla ethmoidalis (Be), suprabullar cell (Sbc), posterior ethmoid (Pe), ground lamella (Gl), maxillary ostium (Om), accessory maxillary ostium (Aom), maxillary sinus cavity (Ms) after removal of posterior medial wall

in this region (axillary flap) can overcome the problem in accessing the frontal recess and the frontal sinus (Wormald, 2002). The middle turbinate has three attachments: 1. Junction of cribriform plate and the fovea ethmoidalis, 2. Lamina papyracea, 3. Posterior ethmoid.

The prominent structures in the middle meatus from the anterior to posterior are the uncinate process, the hiatus semilunaris and the bulla ethmoidalis.

The uncinate process is a crescent-shaped ledge of bone, part of the ethmoid, and its posterior free and sharp margin form the anterior margin of a semilunar opening, the hiatus semilunaris. The bulla ethmoidalis, a term introduced by Zukerkandl in 1893, is a rounded projection of the middle meatus, contains one or more ethmoid cells with their delicate walls. These cells are known variously as middle ethmoid or bullar cells. Some consider it as a part of anterior ethmoid. About 30% of ethmoidal bulla poorly pneumatizes and are termed as Torus ethmoidalis (Lang 1988).

The recess above the bulla is called suprabullar recess. This is found when the the ethmoidal bulla does not reach the skull base and when the dorsal border of bulla does not reach the middle turbinate it is called the retrobullar recess. Part of middle meatus posterosuperior to bulla and anterior to the posterior part of middle turbinate is called sinus lateralis.

The hiatus semilunaris leads to a groove between the uncinate process and bulla and presents as a sagittally oriented cleft (Figs 1.6b and 1.7b). It acts as an entrance to a curved channel known as ethmoidal infundibulum, a term used by Boyer in 1805, which is an upstream of maxillary sinus like a narrow funnel (Messerklinger, 1979). The ethmoidal infundibulum from the hiatus semilunaris extends downwards and forwards and varies in depth from 0.5 to 10 mm (average 5 mm) and therefore the upwardly projecting uncinate process varies in its height. Removal of uncinate process during endoscopic sinus surgery (ESS) exposes the infundibulum (infundibulotomy).

Boundaries of ethmoidal infundibulum (Fig. 1.8): It is a three-dimensional space and is bounded as follows:

- ***Anteriorly and superiorly:*** Frontal process of maxilla.
- ***Anteromedially and anteroinferiorly:*** Uncinate process, and the mucosa lining over it.
- ***Posteriorly:*** Bulla ethmoidalis.
- ***Medially:*** Communicates with middle meatus through the hiatus semilunaris, which forms the super medial boundary.
- ***Laterally:*** Lamina papyracea and the lacrimal bone superiorly and the maxillary fontanelle inferiorly.

The relationship of infundibulum to frontal recess is determined by the attachment of the uncinate process. Based on the attachment superiorly with different situations, the uncinate process can be divided as (Fig. 1.7a) depending on the drainage of the frontal sinus (Bolger and Stamburger 1995) although five types have been described by some authors due to combination of primary types. Type-1 comprises 33%, type-2 (10%) and Type-3 attachment or with combinations comprises 57% (Zhang, et al 2016):

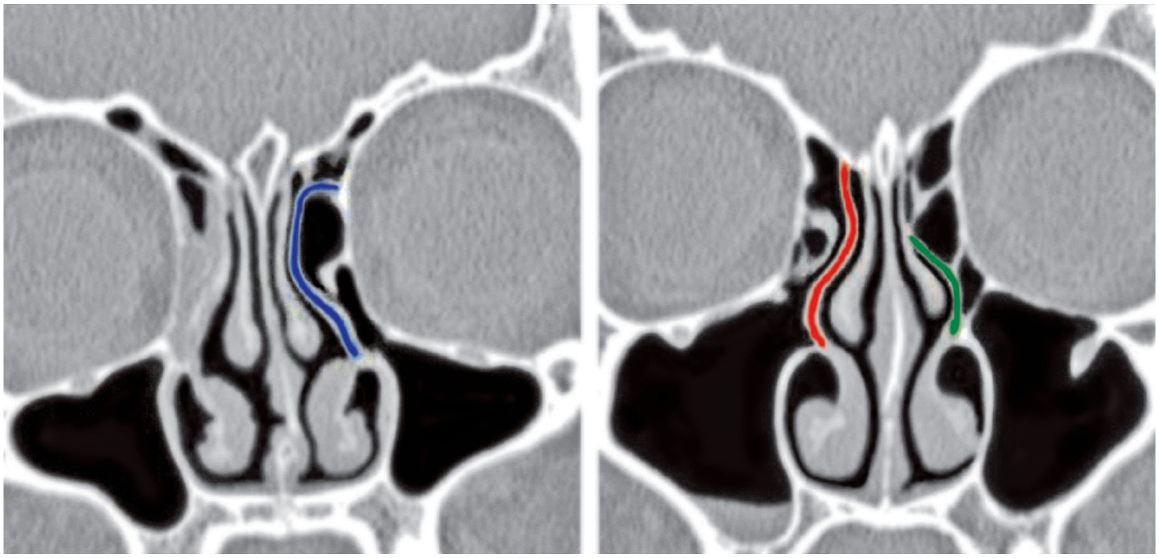


Fig. 1.7a: CT scans showing different types of uncinate process: Type-1 (•), Type-2 (•), Type-3 (•)

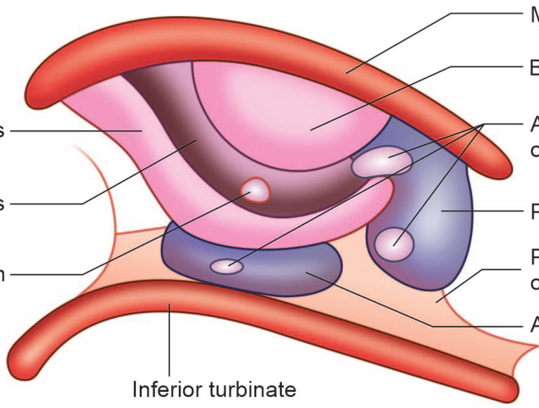


Fig. 1.7b: Anatomy of the middle meatus

- Type-1: If inserts at the lamina papyracea
- Type-2: If inserts at the skull base
- Type-3: If inserts at the middle turbinate.

The posteroinferior one-third of the infundibulum receives the natural ostium of the maxillary sinus which is formed by part of the maxillary fontanelle (Fig. 1.7b).

The term **frontal recess** was first used by Killian in 1898. A true frontonasal duct does not exist. Mosher described connection between frontal sinus and anterior ethmoid as a recess. The frontal recess is bounded laterally by the lamina papyracea, medially by the vertical lamella of middle turbinate, anteriorly the agger nasi cell and posteriorly the ethmoidal bulla cells. Van Alyea found the relationship of anterior ethmoidal cells to frontal recess besides agger nasi and termed these cells frontal cells. Agger nasi cell can vary in size and thus can affect the drainage pathway within the frontal recess. Zhang, et al (2006) observed by using spiral CT of skulls and cadaver sectioning, and confirmed that the agger nasi cell was medially, superiorly

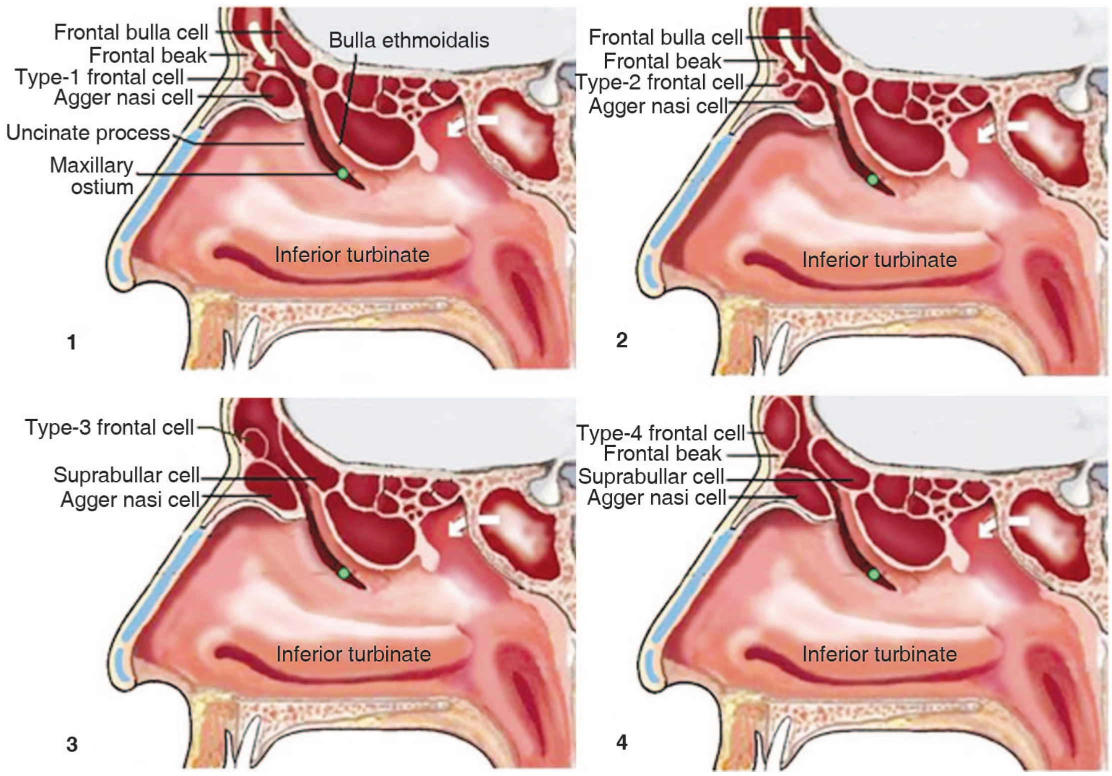


Fig. 1.7c: Four types of frontal cells: **1.** Type-1, **2.** Type-2, **3.** Type-3, **4.** Type-4, classified by Kuhn in1996

and inferiorly bounded by the uncinate process. Nearly 90% of the uncinate processes attached to the lamina papyracea. Kuhn (1996) classified frontal cells into four different types, the modification of this includes (Fig. 1.7c):

- **Type-1:** Single cell above the agger nasi
- **Type-2:** Tier of cells above the agger nasi
- **Type-3:** Cells extending cephalad into the frontal sinus through the ostium but not extending 50% beyond the vertical height.
- **Type-4:** Frontal cell that extends more than 50% beyond the vertical height.

Frontal bulla cell: Cell that extends from the suprabullar area and extends into the frontal sinus along the posterior wall. Wormald, et al (2016) call it as **suprabullar frontal cell**.

Because of the variation in the development of the agger nasi and the frontal cell, the frontal recess surgery is quite challenging and the surgeon needs to have a thorough knowledge and prior radiological evaluation should be done before carefully uncapping these cells to clear the disease from the frontal recess and the frontal sinus.

Anatomy of drainage pathway anterior group of sinuses: The medial wall of maxillary sinus is partially membranous in the posterior part of middle meatus between the uncinate process, inferior concha and palatine bone, where the bone is dehiscent. This is divided into anterior and posterior fontanelles by the ethmoidal process of the inferior turbinate (Fig. 1.7b). The maxillary sinus opens at the junction of anterior and posterior fontanelles. At the fontanelle, the maxillary sinus mucosa and nasal mucosa are coated with no intervening bone. Any dehiscence in the fontanelle presents as an accessory ostium, thus creating an additional opening into the infundibulum.

Posteriorly and inferiorly, the infundibulum becomes continuous with the middle meatus. Myerson demonstrated that the constant guide to cannulation of maxillary ostium is the angle formed by divergence of the uncinate process and bulla from one another in the posterior part of infundibulum.

The frontal sinus drains either directly or indirectly through the anterior ethmoidal cells into the infundibulum through frontal recess into the middle meatus medial to the infundibulum through the anterior ethmoid cells (Figs 1.7a and d). The frontal ostium is situated between frontal beak anteriorly and skull base posteriorly and is the narrowest area between frontal sinus and frontal recess. The drainage of frontal sinus into the infundibulum is dependent on the three types of superior attachement of the uncinate process. In type 1, it drains medial to the infundibulum and thus directly to the middle meatus, while in type 2 and 3, frontal sinus drains into the infundibulum. Thus frontal sinusitis in type 2 and 3 can cause secondary maxillary sinusitis (Stammberger and Bolger 1995).

The anterior ethmoid cells drain either into the infundibulum (at the frontoethmoidal recess) or anterior to it through the uncinate process (frontal recess of middle meatus).

The middle ethmoid cells open upon or above the bulla (suprabullar recess).

The opinion regarding the location and configuration of maxillary sinus ostium varies with different pioneers.

Myerson (1932) imagined a three-dimensional relationship of maxillary ostium. He opined that the internal ostium leads into a tubular intranasal channel of varying configuration depending on the development of uncinate process and bulla. He recognized that the ostium is located immediately below the orbital floor and the lamina papyracea, and penetrating the lateral wall of infundibulum superior to ostium during surgery can violate the orbit.

Van Alyea (1936) found maxillary ostium situated posteriorly in the infundibulum in two-thirds of cases, in the middle in one-fourth of cases and in the anterior in 70% of cases. He found that the ostium was easily accessible for cannulation in only 40% of specimens.

When viewed from inside the antrum, the internal ostium is situated just 2–3 mm below the junction of medial wall and roof of the sinus, roughly half distance between anterior and posterior walls and about 4 cm from the floor of the antrum. When peered through the ostium towards the nasal cavity, uncinate process is seen anterosuperiorly and bulla posterosuperiorly.

The accessory sinus ostium when present is usually situated posterior to the natural ostium, even though endoscopically due to illusory effect, it appears inferior to natural ostium. Van Alyea found accessory ostium in 23%, Myerson in 31%, Schaeffer in 43%, and Neivert in 25% of specimens.

Thus from the functional standpoint, the infundibular space represents the confluence of drainage from frontal, anterior and middle ethmoidal and maxillary sinuses. The infundibulum like the stem of a funnel collects the drainage from the anterior group of sinuses and opens into the middle meatus through the hiatus semilunaris. All these microchannels are situated in the anterior and middle ethmoid sinuses and hence any anatomical and pathological variation here causes diseases in dependent sinuses (Fig. 1.8).

Noting this clinical significance, Naumann in 1965 described the anterior ethmoid-middle meatus complex as ostiomeatal unit (Fig. 1.8).

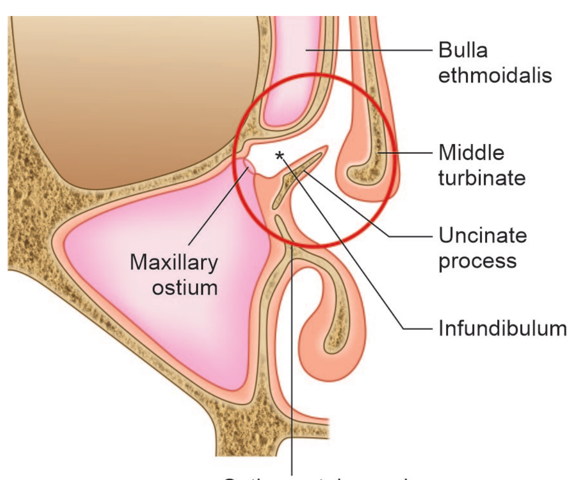


Fig. 1.8: The cross-sectional anatomy of ostiomeatal complex

Osteology of Lateral Nasal Wall

Mainly formed by two bones:

1. Ethmoid labyrinth
2. Inferior nasal concha

Other bones participating:

1. Medial wall of maxillary antrum
2. The lacrimal bone
3. Nasal bone
4. Frontal process of maxilla
5. Palatine bone (vertical lamina)

PARANASAL SINUSES

Berenger del Carpi, an anatomist in 16th century, gave clear indication about the existence of the paranasal sinuses (Lund, et al 2002). They are air-filled spaces in the skull bones and are lined by mucosa, which drains into the nasal cavity by the mucociliary drainage. They are 8 in number, 4 on each side, namely the frontal, ethmoidal, maxillary and sphenoidal sinuses. The 4 pairs of paranasal sinuses are lined by ciliated, pseudostratified columnar epithelium. Goblet cells are interspersed among the columnar cells. The mucosa is attached directly to the bone. Involvement of the surrounding bone and further extension

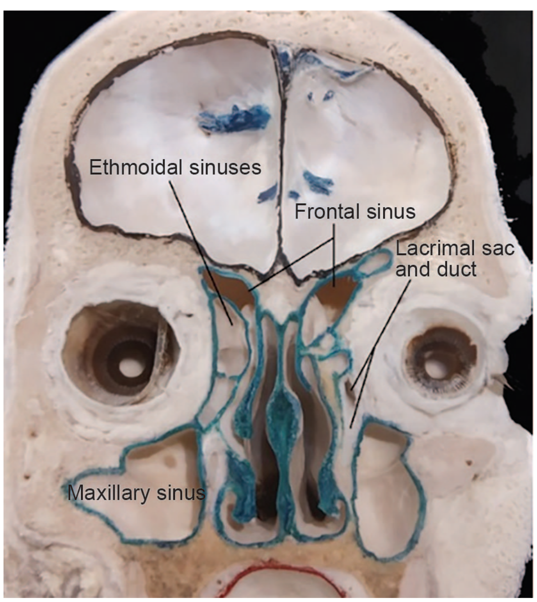


Fig. 1.9: Position of the anterior group of sinuses in the skull

of the infection into the orbital and intracranial compartments occur in inadequately treated patients and in specific types of sinusitis such as fungal sinusitis (Fig. 1.9).

Functionally there are two groups:

1. ***Anterior group:*** These drain into the middle meatus.
   a. Frontal sinus
   b. Maxillary sinus
   c. Anterior ethmoidal sinus
2. ***Posterior group:*** These drain into the superior meatus/sphenoethmoidal recess.
   a. Posterior ethmoidal sinus
   b. Sphenoid sinus.

MAXILLARY SINUS (ANTRUM OF HIGHMORE)

Nathaniel Highmore (1651) was first to recognize and describe precisely the maxillary antrum. This is a three-sided pyramidal in shape. In an adult, its capacity is approximately 15 ml (Fig. 1.10).

Base (medial wall) corresponds to the lateral wall of nasal cavity in relation to the middle and inferior turbinates. The ostium of the maxillary sinus opens in the medial wall into the middle meatus between the uncinate process and the bulla ethmoidalis as described under lateral wall of the nasal cavity.

Apex is directed towards zygomatic process.

The three walls of this pyramid are:

a. ***Anterolateral wall*** covered by the periosteum, soft tissue and skin of the cheek. It is relatively thinner in the canine fossa and is present lateral to the canine eminence. This site is used for approaching the maxillary sinus in Caldwell-Luc operation. This wall has an opening called infraorbital foramen, which is situated about 1 cm below the infraorbital margin. Infraorbital nerve and vessels emerge through this foramen.

b. ***Superior wall (roof of antrum)*** is formed by orbital plate. This is covered by the orbital periosteum. At its midpoint in its inferior aspect is a groove, through which the infraorbital nerve and vessels pass before emerging out of the infraorbital foramen.

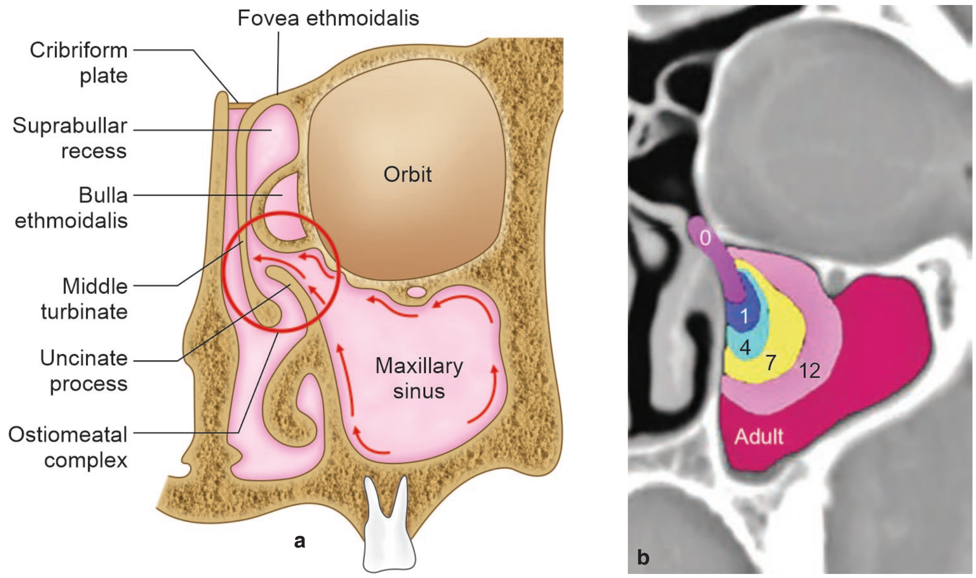


Fig. 1.10: **a.** Relations of maxillary sinus with respect to orbit, ethmoids and ostiomeatal complex; **b.** Development of maxillary sinus in relation to age—from birth (0) to 12 years of age

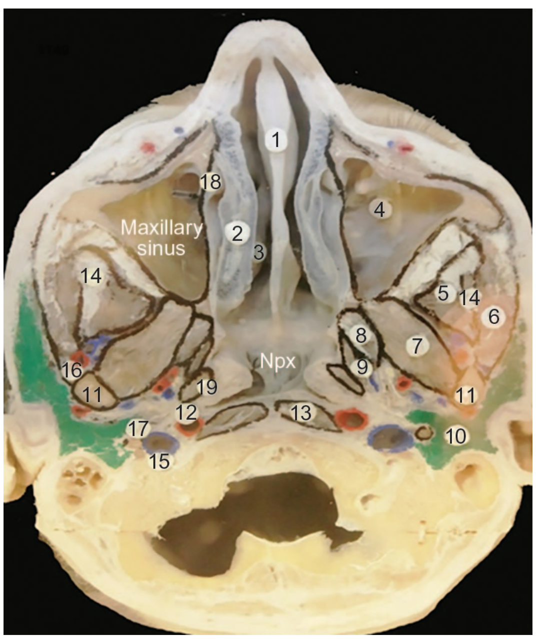


Fig 1.10c: Relationship of the maxillary sinus: (1) Nasal septum, (2) inferior turbinate, (3) middle turbinate, (4) infraorbital nerve and vessels, (5) temporalis muscle, (6) messeter, (7) lateral pterygoid, (8) tensor veli palatini, (9) eustachian tube, (10) parotid gland, (11) mandibular condyle, (12) internal carotid artery, (13) prevertebral muscles, (14) coronoid process, (15) internal jugular vein, (16) external carotid artery, (17) CN IX, X, XI, (18) nasolacrimal duct, (19) levator veli palatini

c. ***Posterior wall*** is formed by a thin plate of bone and is related to pterygopalatine fossa, which consists of third part of internal maxillary artery, vidian nerve and the sphenopalatine ganglion. Posteromedially the bone is attached to pterygoid plates with a dehiscence called the sphenopalatine foramen. This opens into the lateral wall of the nose just behind the posterior end of the middle turbinate. This foramen transmits the sphenopalatine vessels and the nerves. Knowing various relations to this wall is extremely important for endoscopic surgical approaches to pterygopalatine fossa, pterygoid recess, sphenoid, nasopharynx and middle cranial fossa.

Floor is formed by alveolar and palatine process of the maxilla and is variable with age. It lies at or above the floor of the nasal cavity in a child while it lies at a lower level in an adult (Fig. 1.10b).

FRONTAL SINUS

It is pyramidal in shape and its volume, size and shape is variable and can often be rudimentary. The two frontal sinuses are often asymmetrical in shape. Bony septa may partially subdivide it into one or more compartments. Its average capacity is about

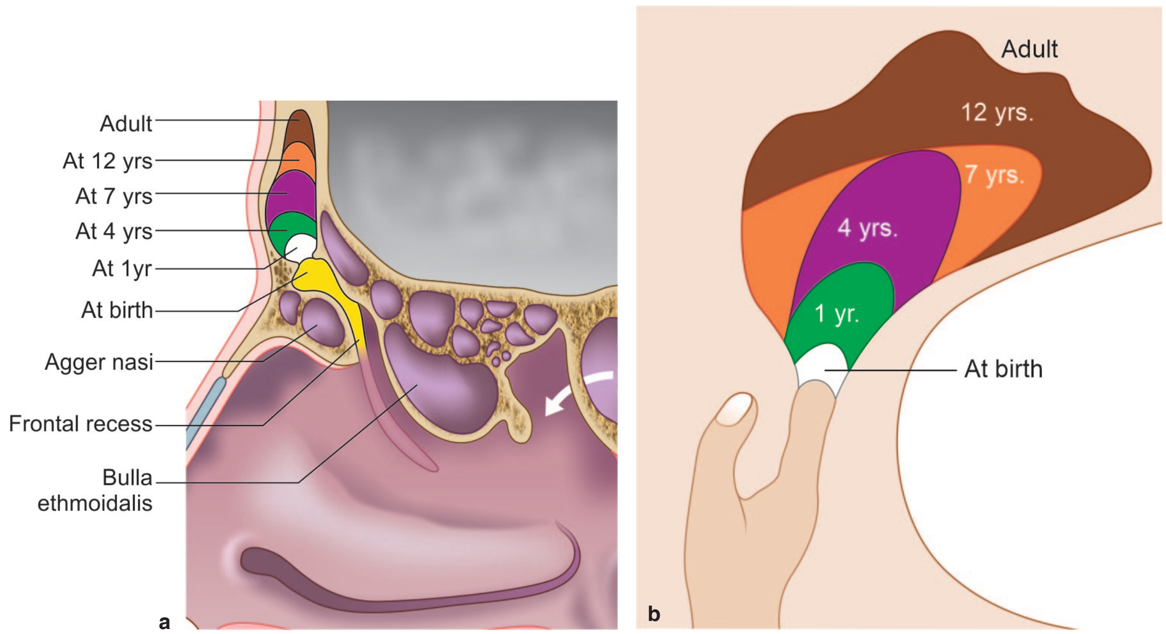


Fig. 1.11: Size and extent of the frontal sinus at various age

7 ml in adults. It is not present at birth and it usually develops after the age of about 5 years as an extension of the anterior ethmoidal air cell. The age-wise expansion of frontal sinus is depicted in Fig. 1.11.

Development of this sinus varies markedly. It develops as one of the several outgrowths from the region of the frontal recess similar to the anterior ethmoidal cells. In fact some regard it as an anterior ethmoid cell that has invaded the frontal bone.

Several sinuses may occur on one or both sides, lying one lateral to other or one behind the other. These sinuses may either drain one into the other or drain separately.

Frontal bulla is cells that pneumatize from the anterior ethmoid into the frontal sinus. Two features distinguish a frontal bulla from a Kuhn type-3 cell:

- It is pneumatized from the region above the ethmoid bulla and along the skull base into the frontal sinus.
- Its posterior wall is formed by the skull base. Its anterior wall directly faces the interior of the frontal sinus.

Frontal bullae may narrow the frontal recess from the posterior side. When combined with agger nasi and Kuhn cells, they may contribute to the obstruction of ventilation and drainage (Leunig, 2008).

Important relations of frontal sinus are the anterior cranial fossa and the orbit. The bone separating the sinus from the above is usually thin and thus an operative perforation can easily occur.

Frontonasal Connections (Frontal Recess)

It is a space posterior to nasal process of frontal bone (frontal beak) to which frontal sinus drains (Wormald, et al. 2016). The drainage of frontal sinus is highly variable and depends on its development, i.e. whether it originates in frontal recess directly or from one or more anterior ethmoid cells (frontal cells) arising in frontal pits (discussed in detail under **ethmoidal sinuses**).

According to Kasper's investigations, the frontal sinus drained into the frontoethmoidal recess directly in 4% of cases and indirectly through the infundibular anterior ethmoidal cells in 34% of cases. In 62%, it drained via the anterior ethmoidal cell into the area below the genu of middle turbinate either anterior, posterior or superior to the frontoethmoidal recess also known as frontal recess, the term first used by Killian in 1903, which is now considered as a key area for surgical approach to frontal sinus (Lee, et al 2004).

Van Alyea opined that anatomical variations such as frontal bulla and blockage of middle meatus caused by impingement of middle turbinate head against lateral wall were the commonest causes of chronic frontal sinusitis. Zhang, et al (2006) found in their study, the interaction between the upper portion of the uncinate process and the agger nasi cells to be important for understanding the anatomy of the frontal recess drainage pathway. Frontal recess is a highly complex space with variable anatomy depending on pneumatization of various cells surrounding this space including agger nasi, frontal cells, suprabullar cells, frontal bullar cells, supraorbital cells and interfrontal cells (Walter, et al 2004). The anatomy of frontal sinus and the recess is like an hourglass with the narrowest part being the ostium. It is bounded mainly by agger nasi cell anteriorly, middle turbinate medially, orbit laterally while posterior boundary depends on the upper attachment of bulla (Daniel, et al 2003).

Position and Relations of Frontal Sinus

- It is situated between the inner and outer table of the frontal bone. It occupies variable amount of frontal bone.
- Floor is formed by orbital roof. As it is relatively thin, it is used as a surgical approach.
- Medially it is separated from the other frontal sinus by a thin interfrontal septum.
- Posterior wall is related to anterior cranial fossa.
- Anterior wall is covered by periosteum and skin of the forehead (Fig. 1.12).

ETHMOIDAL SINUSES

It is well developed in children and it occupies the medial wall of the orbit and upper third of the lateral wall of the nose. It consists of 7 to 15 cells on each side and is divided into two groups based on their drainage. The ethmoidal air cells are small and do not have regular disposition, symmetry or fixed number.

These are situated within the ethmoid labyrinth and separates the nasal cavity from orbit. The ethmoid labyrinth is roughly pyramid shaped with the base posteriorly in relation to sphenoid and apex anteriorly limited by the frontal process of maxilla and nasal process of frontal bone.

It is about 4–5 cm long (anteroposterior), 2.5–3 cm high and about 0.5 cm wide anteriorly and 1.5 cm posteriorly. Thus as a whole, the ethmoid labyrinth forms a thin plate broader posteriorly and thinner anteriorly.

Superiorly, the labyrinthine roof is thicker and is called fovea ethmoidalis. This is limited anteriorly by the inferior wall of frontal sinus and posteriorly by the sphenoidal bone. Superior wall of ethmoid labyrinth/the ethmoidal roof is formed by fovea ethmoidalis and is related to the anterior cranial fossa (ACF). The fovea slopes medially and downward. Its medial part is thinner and may be easily injured. The fovea is at a higher level than the cribriform plate, especially in its lateral part.

Laterally, it is related to the orbit and the lacrimal sac and is separated by a papery thin bone called lamina papyracea.

Posterolaterally, it is related to the sphenoid sinus. The posterior ethmoid cells may extend lateral to the sphenoid sinus where it is related to the optic nerve. These cells are called Onodi's cells.

Medially, the ethmoid labyrinth is related to nasal cavity.

The lateral wall of the ethmoidal labyrinth is attached to several bones that are related to the optic nerve, orbit and the lacrimal sac. They are extremely important to the surgeon as they can be injured or can be surgically approached through this wall. They include frontal bone lying anteriorly and above, lacrimal bone (OS unguis) anteriorly and below. Immediately posterior to these two structures is the lamina papyracea (OS planum) above that separates the orbit and the medial wall of maxilla and the vertical lamina of the palatine bone below.

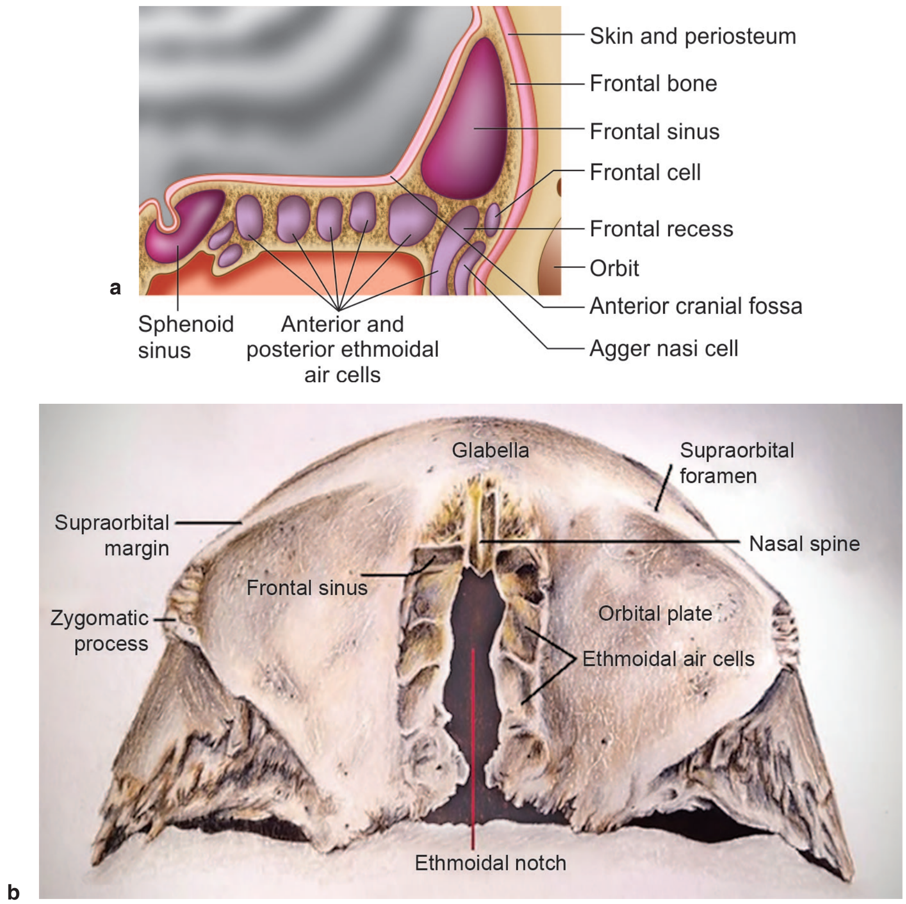


Fig. 1.12: **a.** Relation of the frontal sinus and ethmoids; **b.** Relations of ethmoid and orbit shown in a cadaveric specimen (coronal section)

Inferiorly ethmoid has no wall. Its lower limits are marked by the opening of middle meatus and can, therefore, be considered the horizontal plane passing along the lower margin of middle turbinate.

The medial wall of ethmoid labyrinth consists above of a continuous lamina called turbinate lamina and below of ridges called turbinates (middle, superior and supreme) and corresponding meat.

The medial wall has five principal lamellae which penetrate into the labyrinth towards the lateral wall. They are: 1. Uncinate process, 2. bulla, 3. middle turbinate, 4. superior turbinate and 5. supreme turbinate (Fig. 1.13b).

The more delicate secondary lamellae are placed irregularly between the primary ones, giving rise to multiple ethmoid cells.

1. ***Uncinate process lamella*** is crescent shaped, curves downwards and backwards with the concave free sharp margin facing upwards. It is inserted obliquely into the external wall forming a part of the infundibular canal. The lower free edge is secured from front to back to the frontal process of maxilla, lacrimal bone and maxillary sinus medial wall immediately above the attachment of inferior turbinate.

   The uncinate process lamella posteriorly terminates in a partially membranous wall of maxilla (fontanelle) where it splits onto several slender extensions which reinforce the membranous wall.
2. ***Bullar lamella:*** Few millimeters behind and above the uncinate process is a second arched lamella which forms a dome-shaped

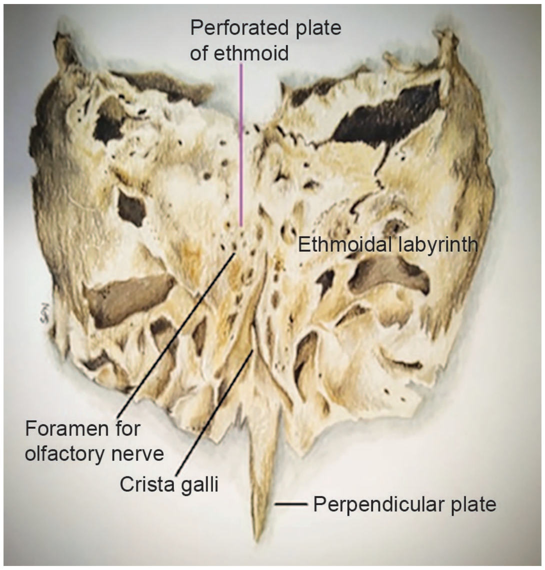


Fig. 1.13a: Ethmoid bone

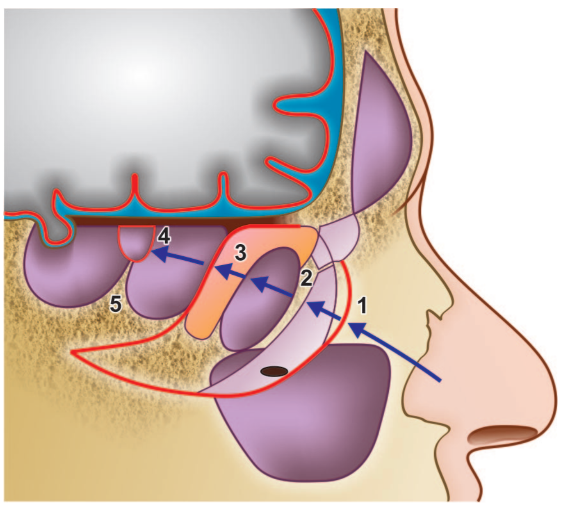


Fig. 1.13b: Five principal lamellae of the medial wall of ethmoid

protuberance called the bulla ethmoidalis. This lamella is applied laterally on the papyraceous lamina. Posteriorly, it is attached to the front of the middle turbinate lamella, forming a sulcus, the suprabullar sulcus.

3. ***Middle turbinate lamella*** is the least variable. It consists of two parts: One lateral (lamina basilaris) and another medial (lamina recurvata), perpendicular to each other. The lamina basilaris (ground lamella) forming the posterior part of middle turbi-nate runs obliquely downwards and back-wards from the anterior ethmoid roof to a small crest of palatine bone (vertical branch) near sphenopalatine foramen, towards the lateral surface of the labyrinth (lamina papyracea). The lamina basilaris separates the middle and posterior ethmoidal cells.

   The lamina recurvata forming the anterior part of middle turbinate ascends upwards lining the ethamoid air cells medially and is attached to the roof of ethmoid at the junction of fovea with the cribriform plate.

   The lamina recurvata thus forms the anterior part of the turbinate lamina. The middle turbinate thus has two attachments:
   - To the lamina papyracea via basal lamina.
   - To the ethmoid roof (junction of fovea and cribriform plate) via lamina recurvata.
4. ***The superior turbinate lamella*** (present in 85% of cases). This divides the posterior ethmoidal cells into two groups—one above and one below the lamella.
5. ***Lamella of the sphenoid sinus:*** The ethmoids during their development have a tendency to grow steadily in all directions beyond the confines of ethmoid until deterred by hard compact bone. The cells which reside within the ethmoid bone are termed intramural cells and those outside are called extramural cells. Thus the ethmoid cells may invade the supraorbital plate of frontal bone, infraorbital plate of maxilla, the middle turbinate (concha bullosa), the sphenoid and lacrimal bone. The frontal sinus is considered by some as part of ethmoid which has invaded the frontal sinus.

The extent of pneumatization of ethmoid has definite implication in an endoscopic sinus surgery.

The ***anterior group of cells***, according to Bagatella and Guirado (1983), consists of 2–10 cells, their number being inversely proportional to their size. They are topographically divided into four subgroups from front to back as:

1. ***Preinfundibular cell*** (0–1) or agger nasi cell: Derived form the latin word '*nasal*

mound' is the remnant of 1st ethmoturbinal. The agger nasi cell is first to pneumatize in newborn, is bounded anteriorly by frontal process of maxilla, anterolaterally by nasal and lacrimal bones, laterally by lamina papyracea, superiorly by frontal sinus and inferiorly by uncinate process depending on pneumatization (Yanagisawa and Joe 1999).

2. ***Lateral infundibular cells*** (0–2) situated lateral to infundibulum, between the frontal process of maxilla, floor of frontal sinus and lacrimal bone. In over pneumatized state, these can invade the above bones. These cells are consistent with frontal and lacrimal cells. These cells are situated above the agger cell hence called **supra-agger frontal cell** (Wormald 2016).
3. ***Postinfundibular cells*** (0–2) situated posterior to infundibulum and anterior to bulla, between the papyraceous lamina and the floor of frontal sinus. These cells are suprabullar and frontal bulla cells. These cells are also called **suprabullar frontal cells** (Wormald, et al 2016).
4. ***The bullar cells*** (2–5): These are suprabullar cells a subset of variably present frontal recess cells and frontal bullar cells that extends into the frontal sinus along its posterior table.

The **posterior ethmoidal cells** are of two types:

1. ***Intramural cells***, which are located within the ethmoid bone.
2. ***Extramural cells***, which are located in the adjacent bones like maxilla and sphenoid bones, like Haller cells, Onodi cells.

The posterior ethmoidal cells are situated behind the level of the basal lamella and above the horizontal attachment of the middle turbinate to the lateral nasal wall. The posterior ethmoid cells are large and more rectangular in shape with their lateral wall in close contact with optic nerve. At a lower level, the sphenoid rostrum, protrudes into the posterior ethmoid cells at the midline like the nose cone of a rocket. Thus here the sphenoid ostium is surrounded by the posterior ethmoidal cells.

Here, the surgeon, who tries to enter the sphenoid through the posterior ethmoid, has to be cautious not to mistake the junction the sphenoid rostrum and roof of posterior ethmoid cells for the anterior sphenoidal wall. If mistaken, a craniotomy could be performed.

SPHENOIDAL SINUS

The sphenoid bone is situated in the posterior part of the nasal cavity and separates it from the anterior and middle cranial cavity. It has a body and two wings (greater and lesser) on either side giving the appearance of a bat. The sphenoid sinus is situated in the body of sphenoid. The sinuses of the two sides are divided by an asymmetrically placed median intersphenoidal septum. The sphenoid sinus drains into the sphenoethmoidal recess. It is related to a number of important structures because of its situation in the skull.

This sinus appears and begins to grow only after 3rd year and actually excavate the body of sphenoid. The degree of pneumatization of this sinus is highly variable. Its capacity is said to vary from 0.5 to 30 ml (average 7.5 ml).

The sinus either may be limited to the body of sphenoid, or it may extend to other parts of sphenoid, namely the greater and lesser wings, anterior clinoid process, pterygoid process, etc. and also to the basilar portion of the occipital bone. As the degree of pneumatization increases, the surrounding vital relations like optic nerve, ICA, maxillary nerve, etc. are brought more into the sinus cavity producing corresponding bulges into the cavity. ESS in such state is more dangerous.

The sphenoid sinus opens into the sphenoethmoidal recess (Fig. 1.6) usually through the posterior wall of the recess. Occasionally, it may open through the lateral wall of the recess. Anatomical variations can have an impact on approaching the pituitary through transphenoidal route. The type of sphenoid sinus can be classified into three groups in adults (Fig. 1.14a):

1. Conchal (area below the sella is solid block of bone without air cavity)
2. Presellar (moderate air cavity with no sellar indentation)

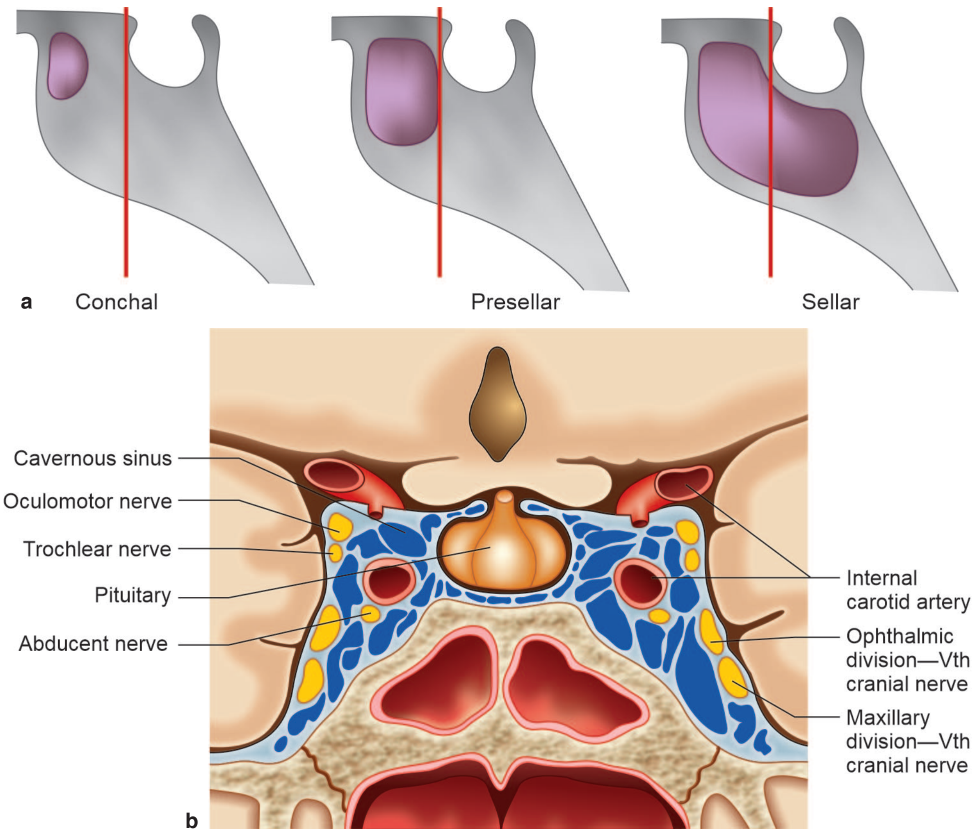


Fig. 1.14: a. Pneumatization of sphenoid sinus; **b.** Relations of the sphenoid sinus and contents of the cavernous sinus

3. Sellar (well-pneumatized sphenoid cavity with full indentation of sella)

Relations (Fig. 1.14b)

Superiorly

1. Pituitary gland bulges into the sphenoid sinus posterosuperiorly. This is often used as a surgical approach (transsphenoidal hypophysectomy).
2. Optic chiasma
3. Olfactory tract
4. Frontal lobe of the brain

Anteriorly

1. Sphenopalatine foramen
2. Sphenoidal crest
3. Nasal cavity

Inferiorly

1. Nasopharynx and choana
2. Vidian nerve is situated inferolaterally and its position helps in vidian neurectomy.

Posteriorly

1. Basilar artery
2. Brainstem

Laterally

1. Cavernous sinus and its contents (III, IV, V and VI cranial nerves).
2. Internal carotid artery

Vital Relations of Sphenoethmoidal Sinuses

Orbit

The ethmoid labyrinth is separated from the orbit by only a thin bone 'the lamina papyracea'. Apart from this, the lamina may have natural dehiscences especially in the two cranial quarters. This permits infection to spread from ethmoids to orbit (5.6% in Kozlov's series and 14/1188 skulls in Zuckerlandl's series had natural dehiscences).

The inferomedial aspect of lamina papyracea forms the lateral boundary of ethmoid infundibulum in close relation to the maxillary sinus ostium.

Thus an attempt to perform middle meatal antrostomy superior to the natural ostium violates the orbit.

A previous ethmoid surgery is likely to have distorted the nasal anatomy, and also could have caused dehiscence in the lamina, thus making prone to orbital injury during ESS (Fig. 1.15).

Injury to the lamina at the plane of anterior ethmoid artery could cause injury to medial and superior rectus causing diplopia.

Optic Nerve

This lies in close apposition to the lateral aspect of posterior ethmoid and sphenoid. The optic canal varying in length from 5.5 to 11.5 mm (av 9.22 mm) runs between the two roots of the lesser wing of sphenoid after coming in relation to posterior ethmoid.

Its distal opening termed the optic ring borders the most posterior ethmoid cells in about 50% of cases, on the sphenoid sinus in

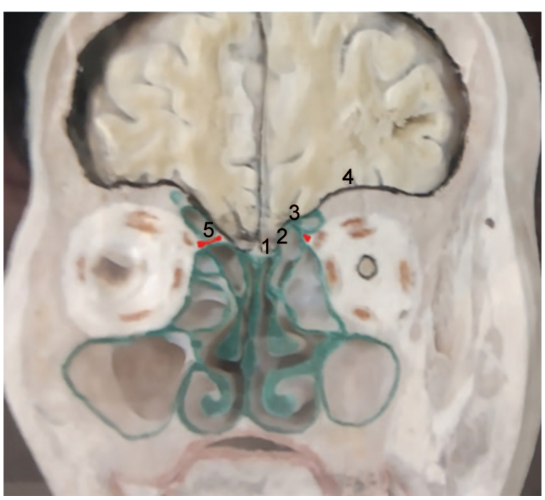


Fig. 1.15a: Relation of ethmoid and orbit in cadaveric specimen: 1—Cribriform plate, 2—lateral lamella, 3—fovea ethmoidalis, 4—orbital plate and 5—anterior ethmoidal artery

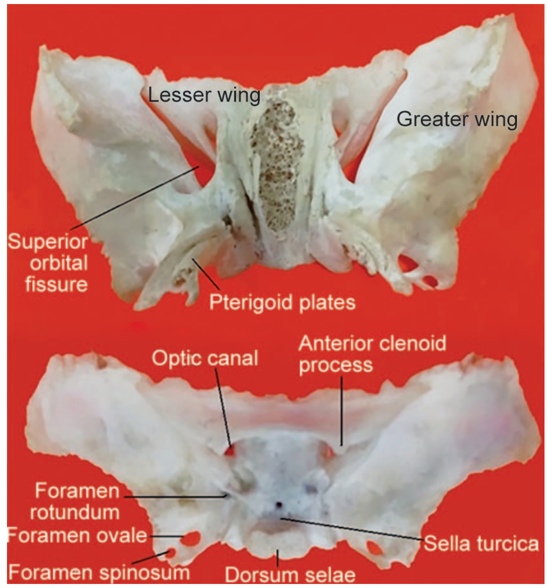


Fig. 1.15b: Sphenoid bone as seen from below: Sphenoid bone anterior wall with conchal type rudimentary sphenoid sinus open through anterior wall and posterior wall and above (cranial aspect)

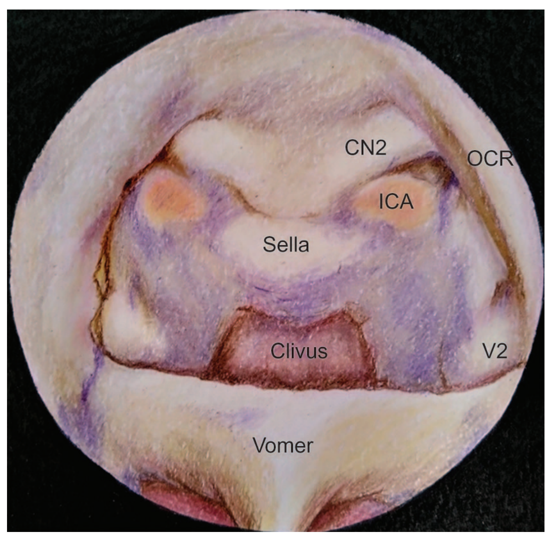


Fig. 1.15c: Interior of right sphenoid sinus endoscopic visualization through the ostium showing optic nerve (CN2), internal carotid artery (ICA), optic carotid recess (OCR) and maxillary nerve (V2)

25% and on the partition separating the two sinuses in other 25% of cases. Thus, in nearly 75% of cases, the optic nerve is not only in close relationship with sphenoid sinus, but also with the ethmoid sinus as well. In 25% of

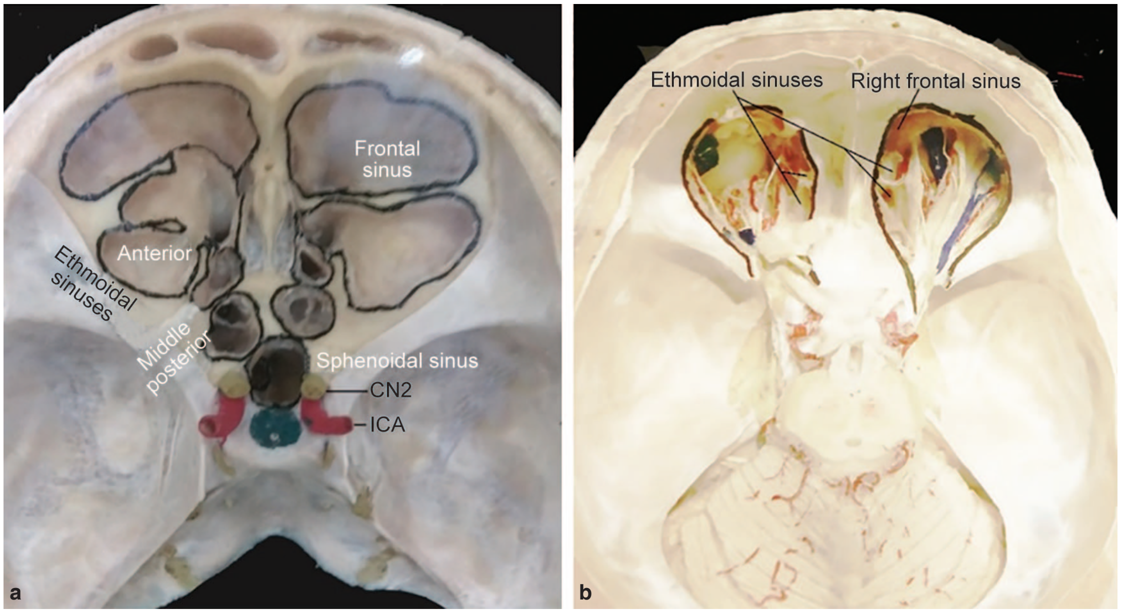


Fig. 1.16: a. Vital relations of sphenoid and ethmoids, orbital contents, optic nerve (CN2) and internal carotid artery (ICA) shown in cadaveric specimen with well-pneumatized frontal and ethmoid sinuses; **b.** Less pneumatized frontal and ethmoid sinuses. Note the orbital apex is directly related to middle cranial fossa

cases, the nerve is almost completely surrounded by an air space (Fig. 1.16).

During its course, the optic nerve produces against the superolateral wall of sphenoid, a bulge called optic bulge (Fig 1.5b) which is more pronounced in over pneumatized sphenoid cells. Such eminence was missing in only one of the 50% specimens investigated by Fuji, *et al*. They found that 78% of specimens had less than a 0.5 mm thickness of bone separating the nerve from sinus and dehiscence were present in 4%. Similar findings were observed by Maniscalco and Habal (1978), Meloni, *et* al. observed optic eminence with extremely thin bone in 70% patients by axial CT scans.

Internal Carotid Artery (ICA)

Similar to optic nerve, the internal carotid artery can also produce bulges into the sphenoid sinus between the bulging optic nerve and ICA, there is a recess called optic carotid recess (Fig. 1.5b).

Van Alyea found 65% of arteries bulging into the sinus. In 14% the whole serpentine course of vessel could be tracked along the lateral sinus wall. Renn and Rhoton (1975) reported carotid prominence in 71% of specimens. In 66%, the thickness of bone separating the artery from sinus was less than 1 mm and dehiscence was noticed in 4%. According to Fuji, *et al.*, the bony layer separating was thinner than 0.5 mm in 88% of specimens and dehiscence found in 8%. Teatani, *et al.* observed carotid prominence in 72% of axial CT scans.

Lacrimal Sac and Nasolacrimal Duct

The medial wall of lacrimal sac roughly corresponds to the atrium of the middle meatus. The anterior ethmoid cells may invade the lacrimal bone and in such conditions the lacrimal sac is vulnerable to injury by an ESS which is very rare.

The nasolacrimal duct runs from the lacrimal fossa downwards but slightly backwards and laterally and lies in a bony wall (nasolacrimal canal) between the maxillary sinus and nasal cavity. In the canal, the duct is closely fused to the periosteum.

Whitnall found close contact between anterior ethmoidal cells and upper half of lacrimal fossa in all 100 orbits he examined, and in more than half of these, the fossa was directly related to these cells. The lower half of the fossa was found, in every instance, directly related to the middle meatus.

The nasolacrimal duct may be injured during a middle meatal antrostomy when the ostium is enlarged anteriorly with a backbiting forceps. The duct lies 8–17 mm (av 10 mm) anterior to the ostium and approximately 5 mm from the anterior border of the membranous anterior fontanelle.

Anterior Ethmoidal Artery

The anterior and posterior ethmoidal arteries leave the orbit through their respective foramina in the frontoethmoid suture line, approximately 24 and 36 mm, respectively from anterior lacrimal crest. The arteries cross across the sinus having a brief intracranial course and enter the nose through their own foramina just below the cribriform plate.

During the intracranial course, at the skull base, the anterior ethmoidal artery runs in a partial or complete bony conduit at the junction of anterior and middle ethmoid cells, usually being attached to the ethmoidal roof by a bony septum.

This artery is a useful landmark during FESS as it indicates the level of fovea and thus the superior limit of ethmoidectomy. The artery is likely to be injured during ESS.

Anterior Cranial Fossa

The cribriform plate and the fovea separate the anterior cranial fossa from nasal cavity and ethmoids, respectively.

The cribriform plate is the most dependent portion of the anterior cranial fossa and forms the roof of the nasal cavity. It is perforated by nerve filaments of the olfactory nerve. Anteriorly the middle turbinate is attached to it by means of the planum recurvatum. This attachment is at the junction of fovea and cribriform plate.

The fovea ethmoidalis is the roof of the ethmoid labyrinth and lies at a higher level than cribriform plate. The former sharply dips down medially and gets attached to the latter. The medial aspect of fovea is very thin and can be easily damaged.

The surface of fovea is undulating and descends 15° from the horizontal as it passes posteriorly.

The level of cribriform plate is marked by the mid-pupillary line externally and by level of ethmoid foramina within the orbit.

The fovea ethmoidalis was found to be 4–7 mm higher than the level of cribriform plate in about 70%. Based on this depth, Keros (1962) described the olfactory fossa into three types: Type-I (0–3 mm), Type-II (4–7 mm), and Type-III (8–16 mm). Also the two cribriform plates could be found at different levels. During ethmoidectomy, staying lateral to the middle turbinate will prevent violation of cribriform plate. Traction to the mid-turbinate during nasal procedures may injure the cribriform plate.

Bone defects in the fovea have been reported. Kozlov observed them in 8.5% of 70 cadaver dissections. The dura is closely applied to the roof of the ethmoid and hence CSF leak easily occurs by injury to fovea. During ethmoidectomy, identify the fovea a yellowish bone. Anterior ethmoidal artery also suggests the level of fovea. Staying below this level helps in prevention of injury to fovea. At the region of anterior ethmoidal artery, the fovea was found to be 10 times thinner than the neighbouring roof (Stammberger).

Blood Supply of the Paranasal Sinuses

Infraorbital and superior dental arteries derived from the internal maxillary artery supply maxillary sinus.

Branches of the anterior and posterior ethmoidal artery supply ethmoidal and frontal sinuses.

Sphenoid sinus is supplied by pharyngeal branch of the internal maxillary artery.

Development of the Nose and Paranasal Sinuses

Nose develops from a number of mesenchymal processes surrounding the primitive stomodeum. The frontonasal process arises between the central aspect of the forebrain and the epithelial roof of the mouth. A highly specialized ectodermal tissue called olfactory placode develops during the 6th week of intrauterine life, on each side of ventral surface of the frontonasal elevation. This divides it into median and lateral nasal processes. The olfactory placode sinks in to form the olfactory pit (Fig. 1.17).

The extension of the mesenchyme from the median process gives rise to premaxillary process of the developing mouth. This subsequently also forms the upper lip and medial crus of the lower lateral cartilage. In the mean time, another mesenchymal process, the maxillary process, develops from the dorsal end of the mandibular arch and this fuses with the lateral nasal process, the two being separated by the nasomaxillary groove. Ectoderm along the boundaries of these two processes remains, giving rise to the nasolacrimal ridge from which the nasolacrimal duct arises later. The lateral nasal process forms the nasal bones, the upper lateral cartilages and the lateral crus of the lower lateral cartilages. The median maxillary process fuses with the median nasal elevation leading to the formation of the primitive external nares. From this, a deepening pit in the mesenchyme produces the nasal cavity. The primitive nose

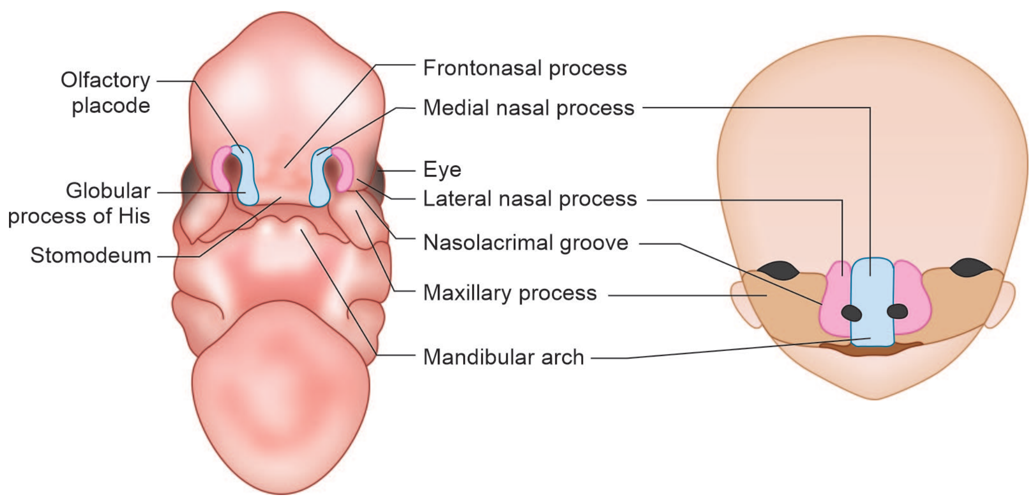


Fig. 1.17a: Embryo showing early stage (5 weeks) of development of nose, nasal and related structures and development at 10th week of gestation

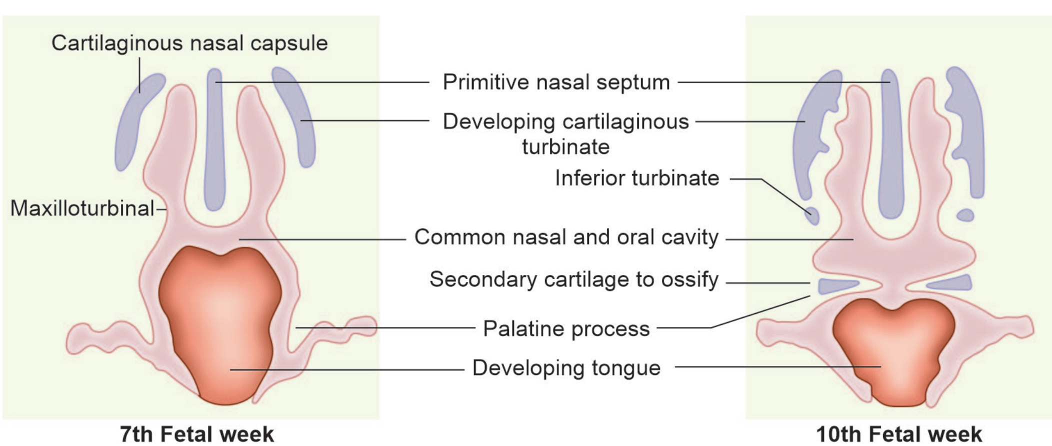


Fig. 1.17b: Development of nasal septum

and mouth are separated by the bucconasal membrane, which disappears later to facilitate communication posteriorly through a primitive choana. This is situated just behind the primitive palate. Failure to canalise leads to choanal atresia. Initially the external nares are widely separated but later come closer as the frontonasal process reduces gradually.

The precartilaginous nasal septum is formed from the frontonasal process. The cartlaginous extension to this nasal septum from the body of the sphenoid bone forms the primary cartilage of this primitive nasal septum. The primitive nasal septum is initially entirely cartilaginous. The superior portion undergoes ossification to form the perpendicular plate of the ethmoid. The premaxillary and the maxillary proceses establish the continuity with the primitive nasal septum, thus defining the two primitive nasal cavities. On each side of the anterior nasal septum, an invagination of the ectoderm represents the vomeronasal organ which is vestigial in human being. The vomer ossifies in the connective tissue covering the residual posterior inferior cartilage from two centres, which unites below the cartilage creating a deep grove in which the the developing septal cartilage (quadrilateral cartilage) lodges. As the growth continues, the bony lamellae fuse and the cartilage gets absorbed. At puberty, the lamellae are almost completely united with the everted alae. An anterior groove remains suggestive of the vomer's bilamellar origin. On the lateral wall of the nose, a series of elevations appears (three ethmoturbinals and maxilloturbinals) within the nasal cavity at 6th week of intrauterine life, which ultimately forms the turbinates. The ossification of the nose and nasal cavity starts during 5th month of fetal life, including the previous cartilaginous areas of the turbinates. Influenced by various transcriptional factors, including Sox, cells differentiate further into the various cell types including the respiratory mucosa (Park, et al 2006).

The development of the sinuses arise rather late during the prenatal period. The frontal sinus is the last to develop. In the first and second months of intrauterine life, the main features of the nasal cavities are defined. The paranasal sinuses arise as localized epithelial invaginations or recesses of the nasal mucosa, after the second month. These recesses become the ostia of the various sinuses. The maxillary sinus and sphenoidal sinus arise as mucosal recess during the 3rd prenatal month. The invagination developing from the hiatus semilunaris forms the future maxillary sinus. The maxillary sinus is present at birth and most of the growth occurs in first 8 years and the maximal size is reached by 16 years of age (Fig. 1.11). The age related size of the sinus can be best studied by CT scan (Lorkiewicz-MuszyMuszynskaska, et al 2015). In contrast to the paranasal sinuses, which develop into existence postnatally, the ethmoid exists before birth and is simply ventilated afterward. The cartilaginous forerunner of the ethmoid starts to develop from the beginning of the 8th week of embryonic life, in parallel with the olfactory region of the nasal cavity (Muller and O'Rahilly 2004). The ethmoidal cells originate during the 5th and 6th months of the IUL from the middle and superior meatus into anterior and posterior groups. They are divided into anterior and posterior groups respectively based on their origin. The frontal sinus (Fig. 1.11) develops after birth with a lot of variation due to different source of origin like either direct extension of the frontal recess into the frontal bone, in which case the frontal sinus drainage pathway is through a distinct ostium (primary frontal sinus ostium) or if it is from the ethmoidal infundibulum and takes origin from one or more anterior ethmoidal cells, the drainage pathway is restricted to the frontonasal duct. The growth of surrounding ethmoidal cells can encroach upon the proximal part of the frontal sinus to compress the nasofrontal duct. The growth of surrounding ethmoidal cells can encroach the proximal part of the frontal sinus and can affect the development of frontal sinus and may even exceed the growth of primary frontal sinus and sometime can present as a bullous presentation called frontal bulla {Fig 1.7c (2)}.

ORBITAL ANATOMY

The orbits divide the upper facial skeleton from the middle face. They are conical in shape and surround the organs of vision (Turvey and Golden 2012). The orbit is closely related to the paranasal sinuses. Each orbit is composed of **seven bones** including ethmoid, sphenoid, maxilla, zygomatic, frontal, lacrimal and palatine bone. The ethmoid sinus is separated from the orbit by a papery thin plate of bone called lamina papyracea. The lateral wall of the sphenoid sinus is closely related to the orbital apex and the optic nerve. Frontal sinus is related to the roof of the orbit and if over-pneumatized, the frontal sinus may even form the entire roof of the orbit. The roof of the maxillary sinus forms the floor of the orbit. Any inflammatory, traumatic or neoplastic lesion of the paranasal sinuses may complicate the orbit and similarly an orbital lesion may present in or could be surgically accessed through the sinuses. Moreover, the orbital anatomy is important for endoscopic sinus surgeon to perform endoscopic dacryocystorhinostomy. It is important to note that the lateral orbital wall and orbital apex are related to the middle cranial fossa (MCF) and the orbital roof is related to the anterior cranial fossa (Fig. 1.16b).

Orbit is a quadrilateral pyramid with its base facing forwards, laterally and slightly inferiorly. The average volume of orbit is 30 ml, of which 70% is occupied by retrobulbar structures. Orbit is made up of **seven bones**, namely sphenoid, lacrimal, palatal, maxillary, ethmoid, frontal, and zygomatic. It has also **seven important contents**, namely the globe (7 ml), extraocular muscles (EOM), optic nerve, cranial nerves III, IV, V and VI, blood vessels, lacrimal gland and sac, orbital fat. The intraorbital muscles are also seven in number except sphincter oculi muscles. There are also seven orbital nerve which passes through the superior orbital fissure except the optic nerve, that passes through optic canal (Rai and Rattan 2012).

The orbit consists of four walls (Fig. 1.18):
- Medial
- Lateral
- Superior (roof)
- Inferior (floor)

Medial Wall

- It is composed of
  - Frontal process of maxilla
  - Lacrimal bone
  - Lamina papyracea of ethmoid
  - Body of sphenoid
- At the frontoethmoid suture, where the medial wall meets the roof, foramina for anterior and posterior ethmoidal vessels and nerves are located.
- Ethmoid foramina are also indicators of level of cribriform plate.

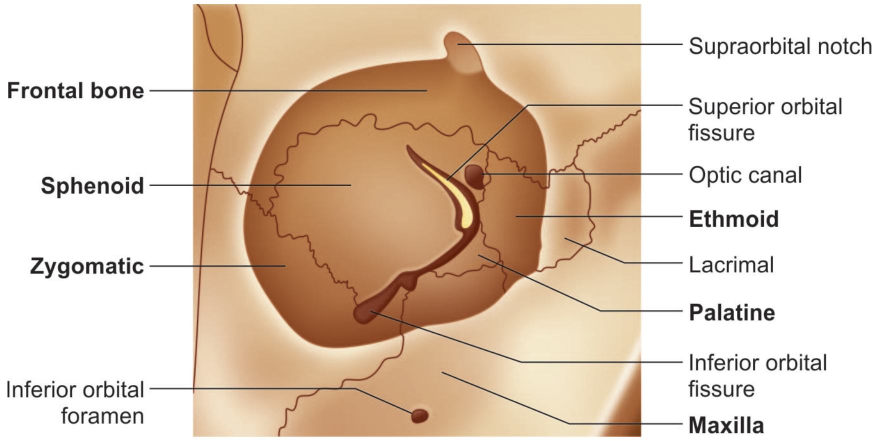


Fig. 1.18: Orbital anatomy

- Rule of 24-12-6 (Rontal, *et al.*)
  - Distance from anterior lacrimal crest to anterior ethmoid foramen—24 mm
  - Distance from anterior to posterior ethmoid foramen—12 mm
  - Distance from posterior ethmoid foramen to optic canal—6 mm
  - Lacrimal fossa for lacrimal sac lies between anterior and posterior lacrimal crests
- As the medial wall is thin in parts and could be dehiscent, there is risk for orbital cellulitis, from spread of paranasal sinus infection or mucocele.

Lateral Wall

- Greater wing of sphenoid
- Orbital surface of zygoma
- Zygomatic process of frontal bone:
  - Posterior boundaries of lateral wall could be taken as the superior and inferior orbital fissures.
  - **Superior orbital fissure** is about 28 mm from the frontozygomatic suture at the orbital rim.
  - Optic nerve lies 8 mm behind the medial edge of the superior orbital fissure (SOF).
  - SOF extends posteriorly to the cavernous sinus.
  - Lateral wall is encountered in:
    - Orbital decompression
    - Lateral craniotomy
    - Infratemporal fossa surgery
    - Lateral orbitotomy
    - Exploration of fractures

Superior Wall (Roof)

- Triangular in shape and consists of:
  - Orbital plate of frontal bone
  - Lesser wing of sphenoid
- In the superomedial area of roof, 5 mm posterior to the orbital rim is the trochlea—a connective tissue sling anchoring the tendinous part of the superior oblique muscle to the orbit. Avoid injury to trochlea during surgery to prevent vertical diplopia.
- Supraorbital notch/foramen in the superior orbital margin transmitting supraorbital vessels and nerves.
- Superior wall is encountered in:
  - Frontal sinus trephination
  - External frontoethmoidectomy
  - Orbital decompression
  - Orbital fracture repair
  - Orbital clearance/exenteration
  - Faciocranial resection

Inferior Wall (Floor)

- Composed of:
  - Orbital plate of maxilla (Fig. 1.19)
  - Zygomatic orbital plate (anterolaterally)
- The infraorbital canal which transmits infraorbital nerve and artery is the thinnest and hence weakest part of the floor. It leads to the infraorbital foramen.
- Anteromedially just behind the orbital rim is a shallow depression for the origin of the inferior oblique muscle. Disruption of IO causes vertical diplopia.
- Floor is separated from lateral wall by inferior orbital fissure. It transmits infraorbital nerve and artery, inferior ophthalmic vein and anterior/posterior superior alveolar nerves.
- It is encountered in:
  - Orbital decompression

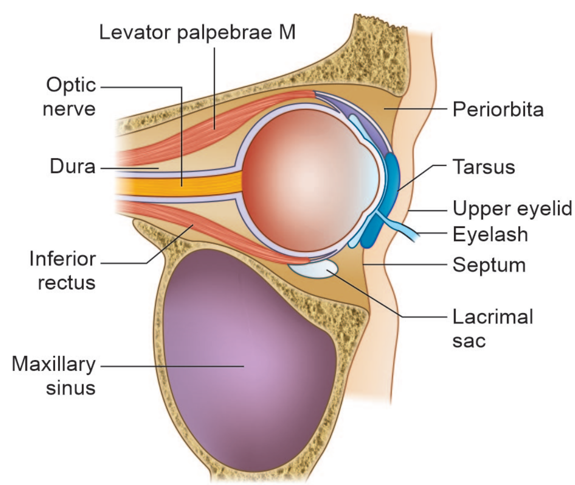


Fig. 1.19: Orbit and related structures

– Repair of orbital floor fractures
– Maxillectomy

Inferior orbital fissure: The lateral wall and floor of the orbit are separated posteriorly by this fissure. It dirrectly communicates with the MCF. Zygomatic branch of maxillary nerve and ascending branch of pterygopaltine ganglion pass through the fissure. Other structures which pass are inferior division of ophthalmic veins and infraorbital vessels.

Periorbita

- It is the periosteum lining the bony walls.
- It is continuous with the dura mater at the optic foramen and superior orbital fissure.
- Inferiorly and medially, it splits to line the fossa and to invest the lacrimal sac.
- Superiorly, it forms the pulley of the superior oblique tendon.
- Septa pass from the periorbita to divide the orbital fat into lobules.

Orbital Septum/Palpebral Fascia

- It is a fibrous sheet that stretches across the entrance of the orbit and is continuous with the periorbita at the rim.
- It is related to the posterior aspect of orbicularis oculi muscle.
- In the upper lid, it unites with the levator aponeurosis and in the lower lid, it fuses with the tarsus and sheath of the inferior rectus.

Bulbar Fascia/Tenon's Capsule

Fibrous sheath surrounding the globe, except the cornea that facilitates eye movement.

Muscular Fascia

- Made up by the fusion of the fibrous sheaths of the EOM.
- Surgical space between the periosteum and the muscular fascia—peripheral space.
- Surgical space deep to the muscular fascia, within the muscle cone—central space.

Orbital Vessels

- Main blood supply to orbit—ophthalmic artery branch of internal carotid artery. It enters through optic foramen.
- Anterior/posterior ethmoid arteries are branches from the ophthalmic artery.
- Parts of inferior orbit are supplied by the infraorbital artery, branch of internal maxillary artery.
- The superior ophthalmic vein and superior branch of inferior ophthalmic vein drain into cavernous sinus through superior orbital fissure.
- Inferior branch of inferior ophthalmic vein communicates with pterygoid plexus by passing through inferior orbital fissure.

APPLIED ANATOMY OF NASOLACRIMAL SYSTEM (Fig. 1.20)

The lacrimal apparatus consists of the following structures:

- Lacrimal gland
- Lacrimal canaliculi
- Lacrimal sac
- Nasolacrimal duct.

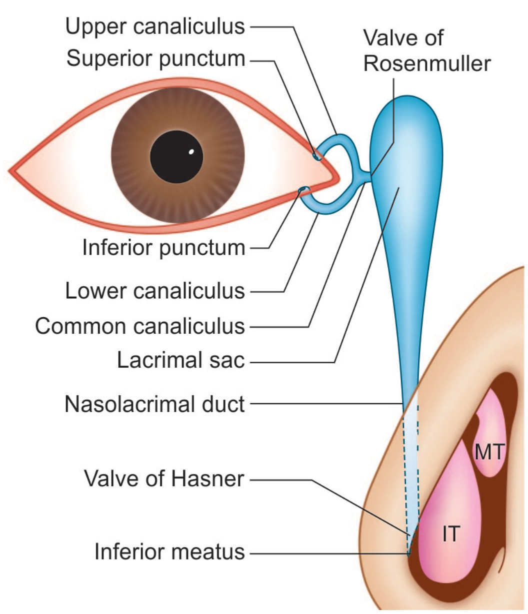


Fig. 1.20: The drainage of lacrimal secretions to inferior meatus (IT–inferior turbinate, MT–middle turbinate)

The lacrimal sac rests on a depressed area on the medial aspect of inferior orbital rim called lacrimal fossa formed by the maxillary and lacrimal bones. The fossa has two crests. The anterior lacrimal crest is a part of lacrimal bone and posterior lacrimal crest belongs to lacrimal bone. Medial to the anterior lacrimal crest on the frontal process of maxilla is a groove called sutura longitudinalis imperfecta of Weber that carries two twigs of infraorbital artery supplying the bone and nasal mucosa and can cause bleeding unless anticipated during dacryocystorhinostomy.

The nasolacrimal system consists of two systems:

A. Secretory System

- Basic secretors
  - Goblet cells in conjunctiva
  - Accessory lacrimal glands of subconjunctiva of upper lid
  - Tarsal meibomian glands
- Reflex secretors, lacrimal gland in the lacrimal fossa in the lateral orbit superiorly and anteriorly.

B. Excretory System

- In each eyelid, there is an opening located medially at the margin called punctum which leads to the respective canaliculus
- Canaliculus has two components as follows:
  - Vertical component—2 mm in length
  - Horizontal component—8 mm in length

    They joint together to form common canal that empties into lacrimal sac through valve of Rosenmuller that consists of mucosal fold and is related to orbicularis oculi.
- Lacrimal sac is situated in lacrimal fossa situated in anterior part of medial orbital wall.
- Lacrimal sac empties into nasolacrimal duct (NLD) which measures about 12 mm in length. Although the maxillary line and the head of the middle turbinate are often considered useful guides to the position of the ipsilateral NLD, their spatial relationship to the NLD is not consistent (Ali, et al. 2014). The duct has a valve in the distal end called valve of Hasner. It is not exactly a true valve but rather surrounded by cavernous space of the inferior turbinate (Bloching 2007) canaliculi and sac are lined by stratified squamous epithelium.

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