Section I Basic Science and Patient Assessment

1 Nasal and Paranasal Sinus Anatomy and Embryology

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Summary

Understanding the anatomy and embryology is the foundation for understanding function, disease, and treatment. The nose and paranasal sinuses serve important functions for our safety and comfort. Their intricate anatomy and physiology must be maintained for our general health. Diseases affecting them can readily lead to symptoms and complications. Common symptoms of disease include nasal obstruction, facial pain, cough, bleeding, swelling, and olfactory loss, but these symptoms can also be associated with poorly controlled asthma and pneumonia, as well as orbital and intracranial complications. As demonstrated throughout this chapter, surgeons interested in this area must be intimately familiar with anatomy to safely improve quality of life.

Introduction

The nose and paranasal sinuses serve important functions for our general health, safety, and comfort. Evidence of the anatomical importance of these structures is seen in the fact that respiration normally occurs through the nasal airway as opposed to the larger oral airway. Thus, simply stated, the primary function of the nose and paranasal sinuses is to couple the lungs to the external environment through a variety of important functions.

Because of their intricate anatomical design, the nose and paranasal sinuses condition the air that we breathe and prepare it for delivery to the lungs. The nasal passage's ciliated respiratory epithelium lining, referred to as mucosa, produces a mucous blanket that is distributed across an undulated surface area. From an evolutionary point of view, this results in an effective system of humidification and temperature control that permits humans to comfortably inhabit arid as well as frigid climates. The mucosa of the nasal passages and its mucous blanket also aids with our host defense mechanisms. The mucous blanket traps foreign particles, such as bacteria, mold, and toxic substances, so that they can be imperceptibly swallowed into the stomach, where they are neutralized by acid. This mucous blanket contains immunoglobulin A (IgA) and antimicrobial peptides, such as beta-defensin-2, produced by the innate immunity of the mucosa. The nasal passages house the nerve endings that help with early detection of toxic substances, as well as enjoyment of odors that embellish gustation (e.g., the aroma of coffee, the bouquet of wine, and the flavor of beef).

Although the importance of nasal resistance is still debated as it relates to obstructive sleep apnea, nasal resistance appears to play an important role in normal pulmonary function. There is evidence that nasal resistance is involved in adequate diaphragmatic excursion during inspiration and that it is necessary to slow expiration, thereby permitting proper oxygen and carbon dioxide exchange in the lungs.[1]

Critical to understanding nasal and paranasal pathophysiology is a review of nasal and paranasal sinus anatomy and embryology. In this chapter we first review embryology, then review the surface anatomy of the external nose, the nasal framework, and the nasal musculature, along with their blood supply and innervation. Next, we present the anatomy of the nasal cavity, nasal septum, and lateral nasal wall with their blood supply and innervation. Lastly, we review the anatomy of the paranasal sinuses especially as it is relevant to sinus surgery.

Development of the Nose and Paranasal Sinuses

Embryology of the Nose

At the end of the fourth week of fetal development, mesenchymal cells of neural crest origin start to aggregate to form the facial prominences in the midface. On either side of the frontonasal prominences, nasal placodes, bilateral thickening of surface ectoderm, are formed. During the fifth week, the nasal placodes invaginate to form the nasal pits, and the tissue ridges surrounding the pits form the lateral and medial nasal prominences. The maxillary prominences continue to expand medially, shifting the medial nasal prominences toward the midline in the following 2 weeks. The two medial nasal prominences eventually fuse, giving rise to the medial portion of the upper lip and anterior palate (**Fig. 1.1a**). Cleft lip is associated with inadequate contact between the maxillary prominences and the intermaxillary segment. Cleft palate occurs secondary to failure of the lateral palatine processes to properly fuse. The furrow between the lateral nasal prominence and the maxillary prominence involutes to become the nasolacrimal duct. Ultimately, the external nose is derived from five different facial prominences; the frontal prominence forms the nasal bridge, the fused medial nasal prominences give rise to the tip, and the lateral nasal prominences become the alae.[2,3]

Note

Cleft lip is associated with inadequate contact between the maxillary prominences and the intermaxillary segment. Cleft palate occurs secondary to failure of the lateral palatine processes to properly fuse.

During the sixth week of development, the nasal pits deepen to form a primitive nasal cavity. The oronasal membrane initially separates the nasal cavity from the oral cavity but subsequently breaks down to give rise to the primitive choana. With the development of the secondary palate, the definitive choana is formed at the junction of the nasal cavity and the pharynx. The nasal septum is developed from the frontonasal prominence that extends caudally to fuse with the palate.[2]

Embryology of the Paranasal Sinuses

The precise embryology of the lateral nasal wall and paranasal sinuses is somewhat disputed in the literature.[3–7] However, the traditional teaching is that there are a series of folds on the lateral nasal wall called the ethmoturbinals that appear during the eighth week of gestation (**Fig. 1.1b**). Five to seven folds initially appear, but after a process of fusion and regression, three or four folds remain by week 15. These folds are considered ethmoid in origin, and they ultimately become upper turbinates in the lateral nasal wall.[8] The first ethmoturbinal regresses during the development period and remains as its rudimentary form; the ascending portion becomes the agger nasi, and the descending portion forms the uncinate process. The second ethmoturbinal eventually develops into the middle turbinate, and the third ethmoturbinal forms the superior turbinate. The fourth and fifth ethmoturbinals are thought to fuse and become the supreme turbinate. A separate ridge of maxillary origin known as the maxilloturbinal is formed inferior to the ethmoturbinals, giving rise to the eventual inferior turbinate. Interestingly, some researchers hold that the inferior, middle, and superior turbinates are identifiable at week 8 and that they develop directly from the cartilaginous nasal capsule; therefore, they propose that the embryologic terms used above are unnecessary[5] (**Fig. 1.1c**).

The primary furrows that form between the ethmoturbinals ultimately give rise to the various meatus and recesses. The first primary furrow is formed between the first and second ethmoturbinals. The descending portion of the first primary furrow forms the ethmoid infundibulum, hiatus semilunaris, and middle meatus. The ascending portion participates in the formation of the frontal recess. The second and third primary furrows become the superior and supreme meatus, respectively.

In addition to the development from the ridges and furrows, the paranasal sinuses receive contribution from a cartilaginous capsule that surrounds the nasal cavity. Some investigators proposed that this cartilaginous nasal capsule plays the main role in the development of the paranasal sinuses and lateral nasal wall structures, and that the development of the ridges and furrows is a secondary phenomenon.[5] The detailed mechanism of the development of the paranasal sinuses is still debated, but it is clear that all the paranasal sinuses originate from the ethmoid region.[9]

The maxillary sinus develops as an outpouching between the middle and inferior turbinates. It is the first sinus to develop, beginning its invagination process during the third gestational month. It continues to undergo growth after birth, with periods of rapid growth typically at the times of dental development.[10] The ethmoid sinus is thought to start out as multiple invaginations from the lateral wall of the nasal capsule around the fifth month of development.[10] The sphenoid sinus

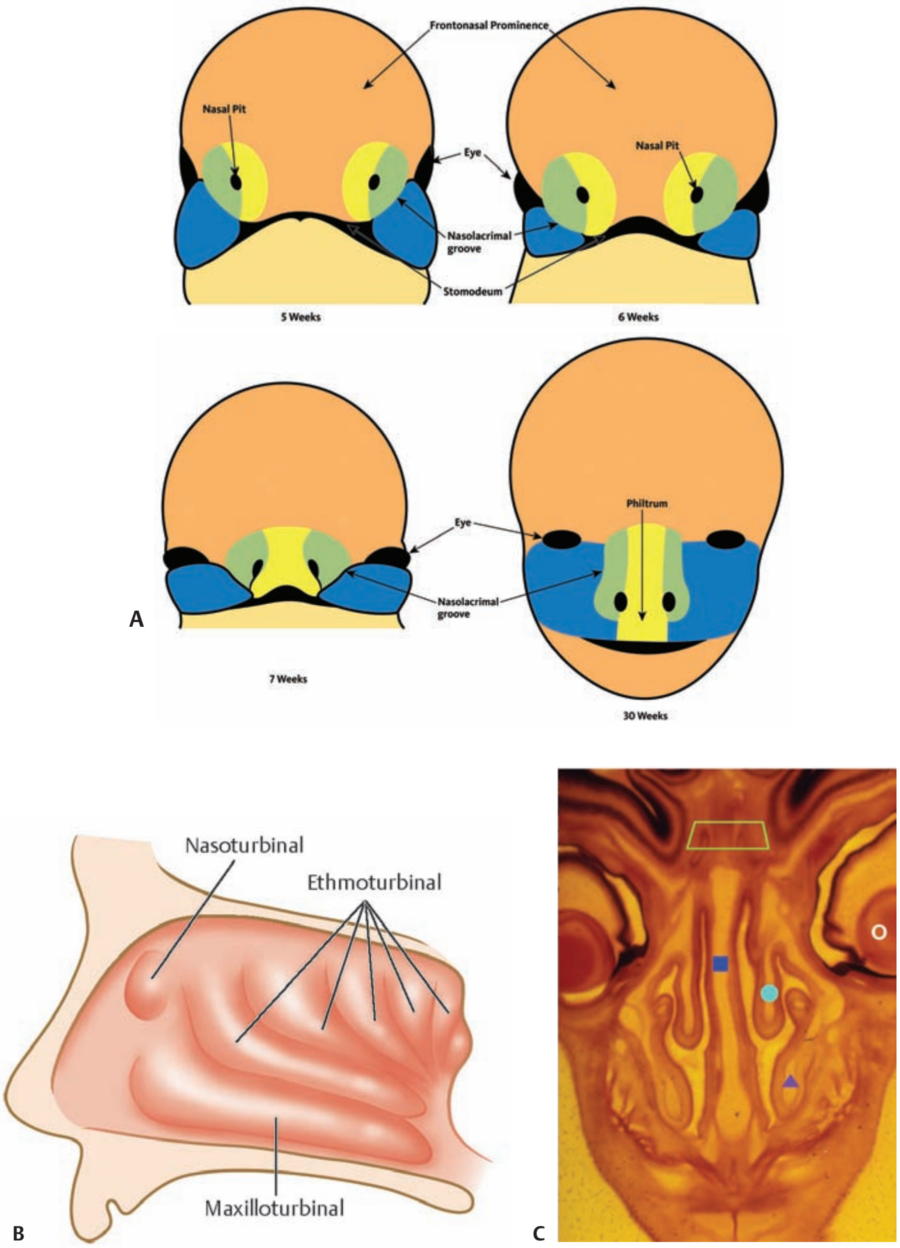


Fig. 1.1a–c

a Coronal depictions of embryologic developments of the midface and the nose at 5, 6, 7, and 30 weeks. Yellow = medial nasal prominence. Green = lateral nasal prominence, blue = maxillary prominence, light tan = mandibular prominence.

b Sagittal schematic drawing representing the regions of the ethmoturbinals, maxilloturbinal, and nasoturbinal in an 8-week-old embryo.

c Coronal histomicrograph of 8-week-old embryo (Carnegie Collection stage 23, courtesy of David H. Henick, MD) that demonstrates early development of the inferior turbinate (*purple triangle*), middle turbinate (*aqua circle*), brain (*green trapezoid*), left eye (*white O*), and nasal septum (*blue square*).

originates from an outpouching from the posterior aspect of the nasal capsule during the third month of gestation. Though minimal in size at birth, the sphenoid bone undergoes pneumatization during childhood, and the sinus reaches its adult size between the ages of 9 and 12.[8] The development of the frontal sinus starts with the anterior pneumatization of the frontal recess into the frontal bone around week 16 of gestation. Several folds and furrows develop within the frontal recess that eventually give rise to the agger nasi cell (first frontal furrow), frontal sinus proper (second frontal furrow), and anterior ethmoid cells (third and fourth frontal furrows).[11] Pneumatization into the frontal bone does not start until 6 months to 2 years after birth, and radiologic evidence of the sinus is not usually seen until the age of 6 or 7. The two frontal sinuses are typically asymmetric, with 10 to 12% of the adult population displaying only one pneumatized frontal sinus.[12] Up to 4% of the population lacks both frontal sinuses.[13]

Beyond the scope of this chapter, but worth noting, is that there are a variety of congenital malformations that can occur as a result of abnormal nasal and paranasal sinus development. Notable abnormalities include congenital midline masses such as encephaloceles, nasal gliomas, and dermoid cysts. Also observable at the midline of the posterior nasal airway in the nasopharynx are Thornwaldt cysts.

The External Nose

Surface Anatomy

Familiarizing oneself with the surface anatomy of the nose and its relationship to the facial contours is essential not only for aesthetic nasal surgery, but also for effective communication with other physicians. Traditionally, the ideal face is thought to be divided into aesthetic thirds of approximately equal length: upper, middle, and lower thirds[14] (**Fig. 1.2**). The upper third spans from the trichion to the glabella, where the trichion is the junction between the hairline and the forehead, and the glabella is the anteriormost point of the forehead at the midline. The middle third covers the structures from the glabella to the subnasale, which is the midline point of where columella transitions to the upper lip. The lower third of the face refers to the segment from the subnasale to the menton. The menton is the most inferior point of the chin. These surface landmarks are shown in **Fig. 1.2,** along with other anatomical landmarks of the face, and their definitions are found in **Table 1.1.**

Table 1.1 Terms and definitions of surface landmarks of the nose

Terms	Definitions
Trichion	Midline point at the junction between the hairline and forehead skin
Glabella	Midline point of the most prominent portion of the forehead
Radix	Deepest point of the surface anatomy of the lateral nasal profile just inferior to the glabella; often used interchangeably with nasion
Nasion	Midline point where nasal bones meet with the nasal process of the frontal bone; often used interchangeably with radix
Rhinion	Junction of the bony and cartilaginous dorsum
Nasal tip	Anteriormost point of the nose
Subnasale	Midline point where the columella merges with the upper lip
Pogonion	Anteriormost point of the chin
Menton	Inferiormost point of the chin

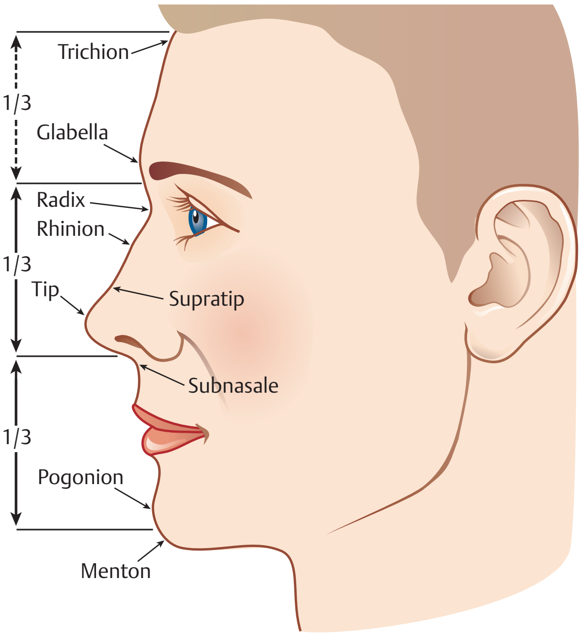
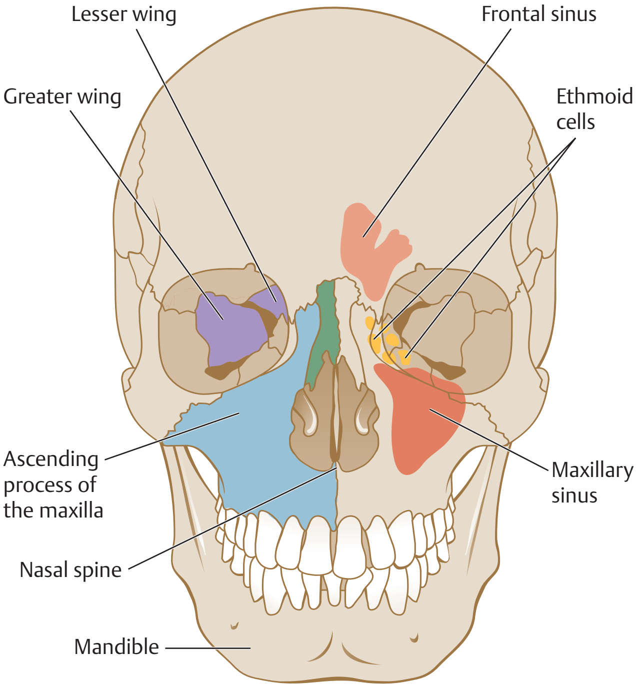


Fig. 1.2 Surface anatomy of the external nose and face (lateral view).

Nasal Framework

The nose is a pyramidal structure that consists of bony, cartilaginous, and membranous elements. It sits on an almond-shaped bony opening into the skull called the pyriform aperture, which is bounded by the alveolar processes of the maxillae (**Fig. 1.3**). The alveolar processes come together in the midline and project upward to form the anterior nasal spine. This fusion of the alveolar processes is where the nasal septum attaches to the floor of the nasal airway.[15]

The nasal pyramid consists of two nasal bones that articulate with both the nasal process of the frontal bone superiorly at the nasion and with the ascending processes of the maxilla laterally. The deepest point along the nasal profile ascending toward the glabella is called the radix.



AQ1 **Fig. 1.3** Schematic drawing of the human skull demonstrating the relationship of bones to one another. Blue = maxilla, yellow = frontal bone, green = zygoma, purple = sphenoid, red midline = nasal bone, Day-Glo pink = lacrimal bone, Day-Glo green = lamina papyracea, Day-Glo yellow = palatine bone. On the left half of the drawing, observe the relative positioning of the maxillary, frontal, and ethmoid sinuses. Note the ascending (frontal) process of the maxilla, nasal bones, and frontal bone along the piriform aperture.

The nasion is the midline point deep to the radix that represents the suture line between the nasal and frontal bones (**Figs. 1.2 and 1.4**). The terms *radix* and *nasion* are often used interchangeably, but they technically represent two distinct anatomical landmarks. The ascending processes of the maxilla are beveled laterally in an interlocking fashion with the nasal process of the frontal bone, anchoring them firmly to the pyriform aperture[16] (**Fig. 1.3**). Internally, this is also the approximate area known as the agger nasi, or nasal mound (see below).

The lower half of the nasal pyramid consists mostly of paired cartilages: upper lateral cartilages and lower lateral cartilages, along with several smaller sesamoid cartilages (also known as accessory cartilages) (**Fig. 1.4**).

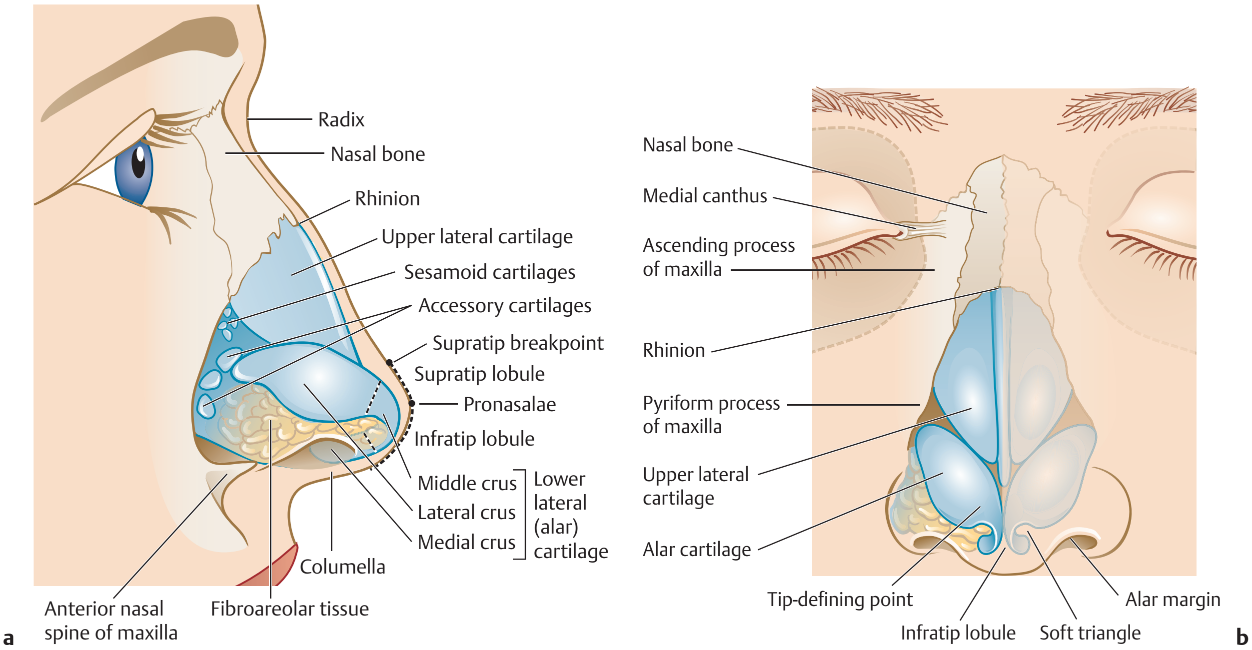


Fig. 1.4 a, b Schematic drawing of nasal framework.

The triangular upper lateral cartilages articulate with the nasal and maxillary bones superiorly and overlap with the lower lateral cartilages inferiorly. They are contiguous with the septal cartilage superiorly, adding to the integrity of the cartilaginous nasal dorsum.[16]

The lower lateral cartilages are thin, curved structures that form the shape of the nasal tip and define the integrity of the nostrils. Each lower lateral cartilage is divided into the medial crus and the lateral crus. The broader lateral crus extends posterolaterally into the ala of the nose, maintaining the patency of the nostril, whereas the narrower medial crus extends caudally along the free edge of the nasal septum, delineating the projection of the nasal tip. There is dense connective tissue binding the upper lateral cartilages to the lower lateral cartilages, and the multiple small accessory (sesamoid) cartilages embedded within fibroareolar tissue add to the integrity of the nasal alar structure.[16]

Nasal Musculature

The muscles of the nose can be categorized into elevators, depressors, dilators, and compressors.[17] The elevators are the procerus, the levator muscle of the upper lip and ala, and the anomalous nasi. The depressor muscles of the nose are the alar portion of the nasalis muscle and the depressor nasi septi labii. The anterior dilator naris works to dilate the nostrils, whereas the transverse portion of the nasalis and the compressor narium minor are the compressors[15] (**Fig. 1.5**). All the nasal muscles are innervated by the zygomatic and buccal branches of the facial nerve (cranial nerve [CN] VII), although the procerus receives contribution from the frontal branch of the facial nerve as well.[17]

Blood Supply to the External Nose

The blood supply to the external nose varies, but it receives contributions from the external carotid via the facial artery, and the internal carotid via the ophthalmic and infraorbital arteries.[15,16] The lateral nasal artery arises from the angular artery (from the facial artery) that anastomoses with the dorsal nasal artery (from the ophthalmic artery). This arcade receives additional contributions from the infraorbital branch of the internal maxillary artery and the external nasal artery, which is the terminal branch of the anterior ethmoid artery (**Fig. 1.6**). The venous drainage of the external nose is performed by the angular vein and the ophthalmic vein, which in turn can communicate with the cavernous sinus.

Innervation of the External Nose

The skin of the external nose is innervated by the trigeminal nerve system. The supratrochlear and infratrochlear branches of the ophthalmic nerve (CN V1) supply the skin of the root, bridge, and upper half of the side of the nose. The infraorbital branch of the maxillary nerve (CN V2) supplies the skin of the lower half of the side of the nose. The external nasal branch of the anterior ethmoid nerve exits between the nasal bone and the upper lateral cartilages to supply the skin over the dorsum of the nose.[16]

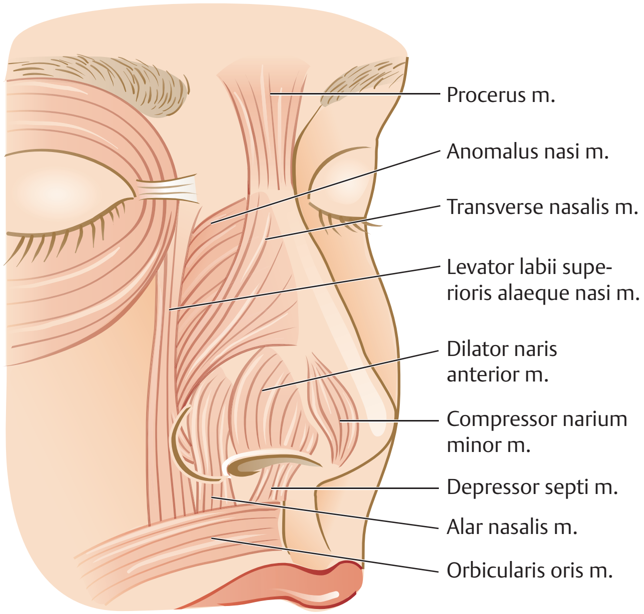


Fig. 1.5 Schematic drawing of nasal musculature.

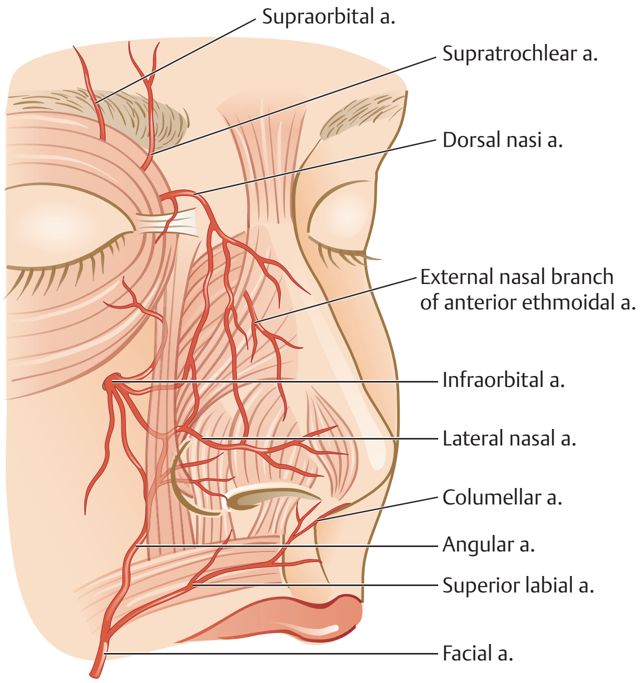


Fig. 1.6 Schematic drawing demonstrating the blood supply and innervation of the external nose. Note that the external nasal artery is the distalmost branch of the anterior ethmoid artery, which arises within the orbit and courses intracranially before emerging externally.

The Nasal Cavity

Nasal Vestibule and Nasal Valve

The nasal vestibule is a dilation inside the nostril that corresponds to the ala of the external nose. It is lined with skin that contains hair (vibrissae), sweat glands, and sebaceous glands. Separating the nasal vestibule from the rest of the nasal cavity is a ridge along the lateral nasal wall called the limen nasi (limen vestibuli). It corresponds to the caudal end of the upper lateral cartilage and marks the transition from the keratinizing squamous epithelium to the pseudostratified columnar ciliated epithelium of the mucous membrane.[16] The mucous membrane contains numerous mucous and serous glands.

The nasal valve itself is a slitlike structure associated with the entrance to the nasal passages. The nasal valve has both external and internal components. It has been described anatomically as the cross-sectional area of the nasal cavity with the greatest overall resistance to airflow, thus acting as the dominant determinant for nasal inspiration. Even the smallest lesion in the area can substantially affect the overall airflow through the nasal passage (**Fig. 1.7a**). The external nasal valve is defined as the area in the nasal vestibule under the nasal ala, formed by the caudal septum, the medial crura of the alar cartilages, the alar rim, and the nasal sill. The internal nasal valve is located ~1.3 cm from the nares (nostril opening) and corresponds to the region under the upper lateral cartilages, bound medially by the dorsal septum, inferiorly by the head of the inferior turbinate, and laterally by the upper lateral cartilage[18] (**Fig. 1.7b**).

Although the exact teleological reason for the nasal valve is still debated, several theories exist. Inhalation against resistance in the upper airway yields higher intrathoracic pressure, which in turn promotes the alveolar gas exchange by prolonging the expiratory phase of breathing. Also, the nasal valve disrupts laminar airflow within the nasal cavity, and the resulting turbulent flow increases the interface time between odorants and the olfactory neuroepithelium.

Note

The external nasal valve is defined as the area in the nasal vestibule under the nasal ala, formed by the caudal septum, the medial crura of the alar cartilages, the alar rim, and the nasal sill. The internal nasal valve is located ~1.3 cm from the nares (nostril opening) and corresponds to the region under the upper lateral cartilages, bound medially by the dorsal septum, inferiorly by the head of the inferior turbinate, and laterally by the upper lateral cartilage.[18]

Nasal Septum

The nasal septum serves as both a functional and an aesthetic unit, dividing the nasal cavity into right and left sides and providing major support for the external nose

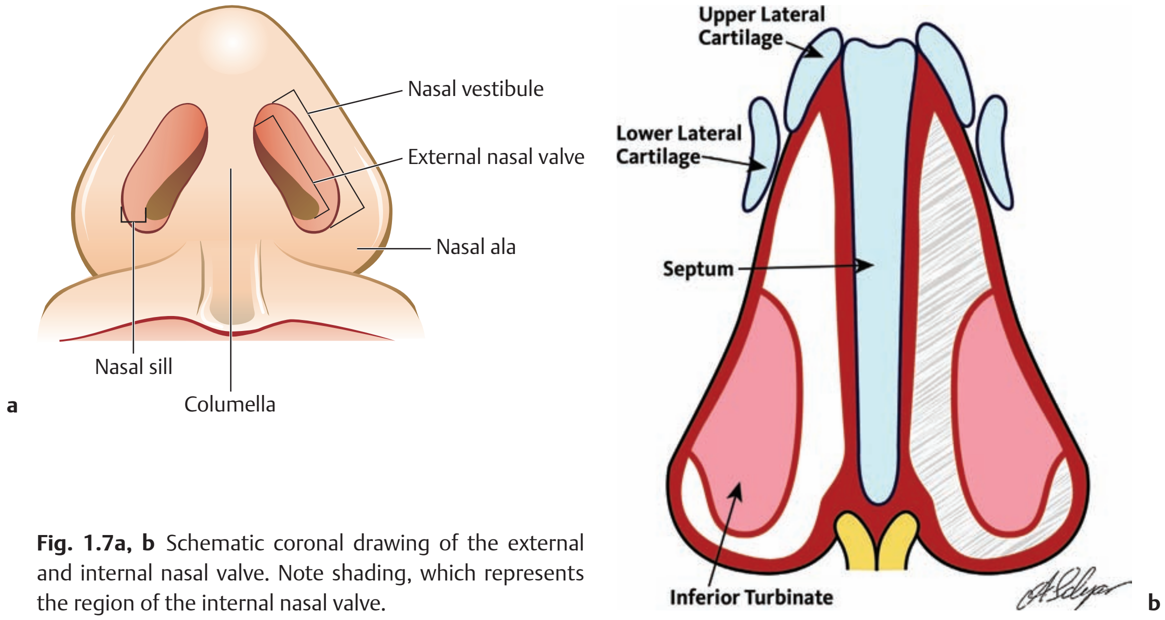


Fig. 1.7a, b Schematic coronal drawing of the external and internal nasal valve. Note shading, which represents the region of the internal nasal valve.

and an extended surface area for the mucosa. The septum extends from the columella to the rostrum of the sphenoid sinus, where the posterior choanae open into the nasopharynx. The septum has three components: the membranous septum, the cartilaginous septum, and the bony septum. The majority of the septum is formed by the perpendicular plate of the ethmoid bone posteriorly and the quadrangular (also known as quadrilateral) cartilage anteriorly. The vomer (Latin for "plowshare") is a wedge-shaped bone situated in the posteroinferior portion of the septum. In the inferior portion of the septum, the nasal crests of the maxillary and palatine bones attach to the cartilaginous and bony septum at the floor of the nasal cavity (**Fig. 1.8**).

The membranous portion of the septum, the caudalmost portion, is composed of skin and connective tissue. It is supported anteriorly by the medial crura of the lower lateral cartilages. The cartilaginous septum, which sits just posterior to the membranous septum, is formed predominantly by the quadrangular cartilage. The quadrangular cartilage flares superiorly to fuse with the upper lateral cartilages at the nasal dorsum. Posteriorly, it gives rise to a thin, tail-like process that inserts between the vomer and the ethmoid bone. The cartilage widens inferiorly at the base as it articulates with the maxillary crest and the anterior septal body[17] (**Fig. 1.9**). The anterior septal body is an area of thickened mucosa with underlying pseudoerectile tissue that is located just

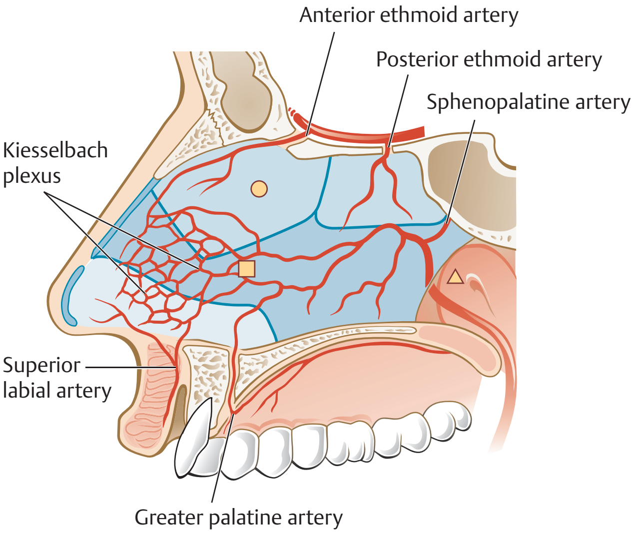


Fig. 1.8 Schematic sagittal drawing of the nasal septum and its blood supply/innervation. Square = quadrilateral cartilage, circle = perpendicular plate of the ethmoid, triangle = vomer, FO = fila olfactoria, CP = cribriform plate, IF = incisive foramen with nasopalatine nerve and artery. Note that the stippled blue area known as Kiesselbach plexus is susceptible to epistaxis and tissue necrosis.

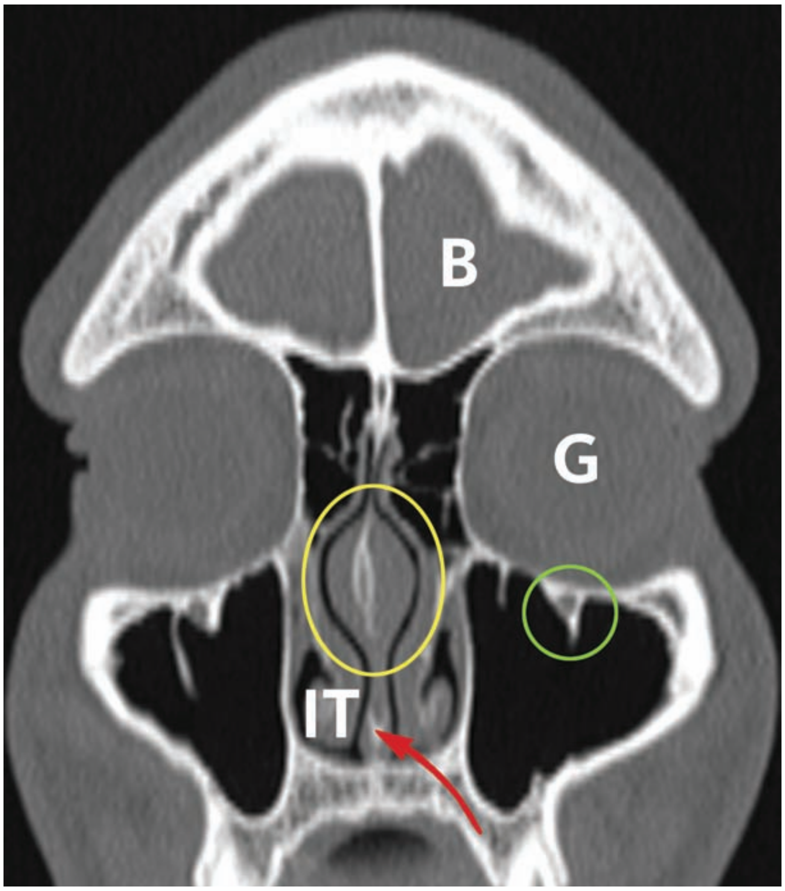


Fig. 1.9 Coronal computed tomography (CT) image demonstrating the anterior septal body (*yellow circle*) and the maxillary crest where septal cartilage is inserted inferiorly (*red arrow*). Note the position of the infraorbital nerves below each orbit (*green circle*). G = globe, B = brain, IT = inferior turbinate.

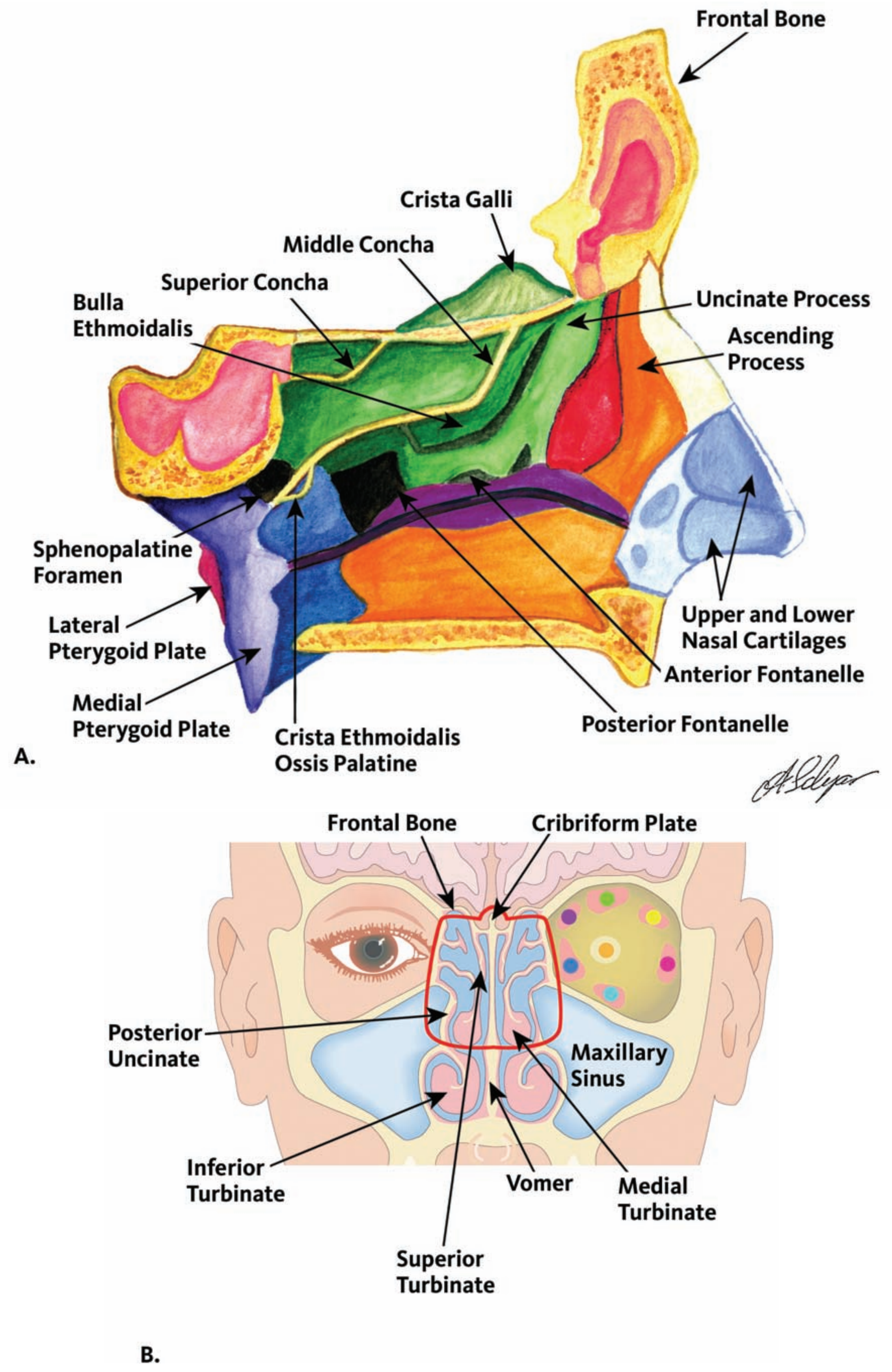
anterior to the leading edge of the middle turbinate. The pseudoerectile tissue of the nasal airway appears to have an important role in the "nasal cycle" that helps maintain normal nasal physiology. The bony septum lies posterior to the cartilaginous septum and consists of the perpendicular plate of the ethmoid bone and the vomer. It is a common site of septal deviation and septal spurs. Septal deviation is very common and has a variety of shapes. In one anatomical study of adult skulls, only 21% of the nasal septa were straight; 37% deviated, and 42% kinked.[19] The perpendicular plate of the ethmoid complex articulates with the frontal and nasal bones superiorly and with the sphenoid bone posteriorly. As seen in **Fig. 1.8,** it articulates with the vomer and the quadrangular cartilage as well. The alae of the vomer rest on the sphenoid rostrum. Along the inferior border of the quadrangular cartilage lies a small bar of cartilage called the vomeronasal cartilage, which is the site of the rudimentary vomeronasal organ (of Jacobson).[17] The superior aspect of the septum is partially covered by olfactory neuroepithelium that is responsible for the sense of smell. The olfactory neuroepithelium provides direct communication between the external environment and the brain by sending fibers centrally through the porous cribriform plate to synapse with the olfactory bulb. The region situated between the uppermost septum and the lateral nasal wall is referred to as the olfactory cleft (see below). Additionally, sensory fibers of CN V descend through the cribriform plate to supply the nasal cavity.

Note

Septal deviation is very common and has a variety of shapes. In one anatomical study of adult skulls, only 21% of the nasal septa were straight; 37% deviated, and 42% kinked.

Lateral Nasal Wall

Whereas the medial wall of the nasal cavity is relatively simple in its anatomy, the lateral nasal wall displays complicated anatomy with multiple raised structures, clefts, and openings, working as the interface between the paranasal sinus cavities and the nasal cavity. The osteology of the lateral nasal wall is depicted schematically in **Fig. 1.10a.** Seen on the lateral nasal wall are three or four turbinates (or conchae) that are thin, medially projecting scrolls of bone (**Fig. 1.10b**) covered by mucous membrane.[2] They are the inferior turbinate, middle turbinate,


Frontal Bone
Crista Galli
Middle Concha
Superior Concha
Bulla Ethmoidalis
Uncinate Process
Ascending Process
Sphenopalatine Foramen
Lateral Pterygoid Plate
Medial Pterygoid Plate
Crista Ethmoidalis Ossis Palatine
Posterior Fontanelle
Anterior Fontanelle
Upper and Lower Nasal Cartilages
A.
Frontal Bone
Cribriform Plate
Posterior Uncinate
Maxillary Sinus
Inferior Turbinate
Vomer
Medial Turbinate
Superior Turbinate
B.

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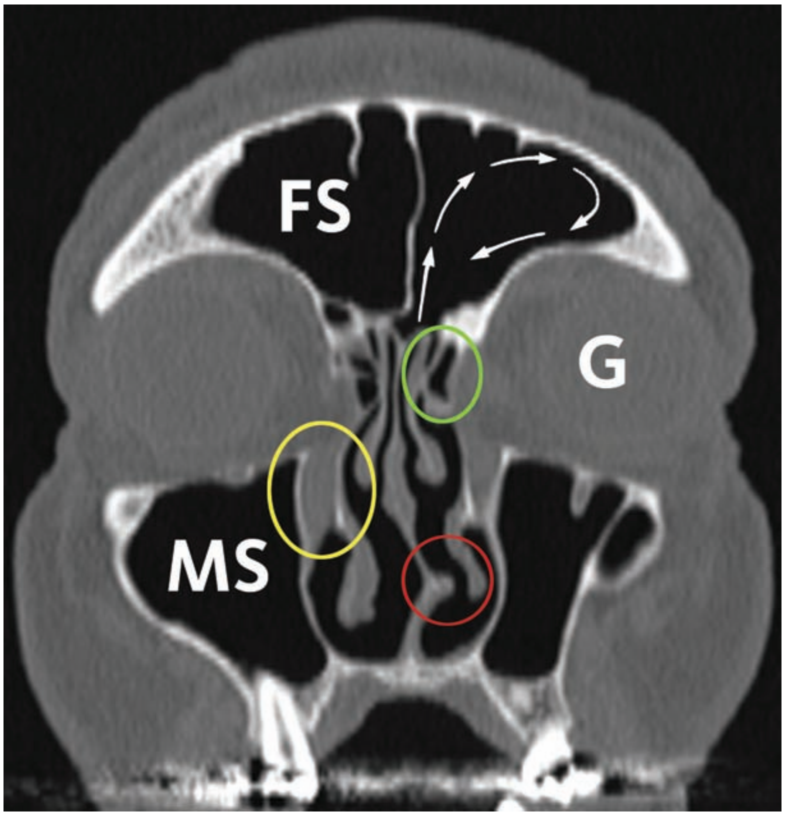

Fig. 1.11 Reconstructed coronal CT scan of the paranasal sinuses demonstrating the lacrimal duct (*yellow*) bilaterally draining into the inferior meatus. Note the agger nasi cell (*green*) and septal spur (*red*) adjacent to the inferior turbinate in the nasal airway, which is decongested prior to the time of imaging. The left frontal sinus (FS) demonstrates the direction of mucociliary clearance within the frontal sinus. MS = maxillary sinus, G = globe.

superior turbinate, and occasionally the supreme turbinate, going from inferior to superior along the wall. The space lateral and inferior to each turbinate is named according to the structure with which it is associated. For example, the inferior meatus lies underneath the inferior turbinate (**Figs. 1.10b and 1.11**). As stated previously, only the inferior turbinate is embryologically a separate bone. The other turbinates are part of the ethmoid complex.

Like the anterior septal body, the inferior turbinate is lined with pseudoerectile tissue and is covered by a thick mucous membrane. The inferior meatus houses the opening to the nasolacrimal duct (valve of Hasner), which is usually located superolaterally in the anterior portion of the inferior meatus (**Fig. 1.11**). Thus, any effort to enter the maxillary sinus from the inferior meatus is typically advised through the thinner bone more posteriorly, where the risk of lacrimal duct injury is less.

Note

Only the inferior turbinate is embryologically a separate bone. The other turbinates are part of the ethmoid complex.

Tips and Tricks

Any effort to enter the maxillary sinus from the inferior meatus is typically advised through the thinner bone more posteriorly, where the risk of lacrimal duct injury is less.

Fig. 1.10a, b

a Schematic sagittal drawing showing the lateral nasal wall osteology. Note that the nasal concha/turbinates are cut away and that the middle turbinate divides the anterior from the posterior ethmoid sinuses. Note also that the position of the crista ethmoidalis can vary depending on the location of the sphenopalatine foramen. The ascending process of the maxilla correlates with the agger nasi, observed on the endoscopic view. From anterior to posterior (right to left): faint yellow = nasal bone, orange = maxilla, red = lacrimal bone, green = ethmoid, purple = inferior turbinate, dark blue = palatine bone.

b Schematic coronal image of the nasal cavity and sinuses demonstrating the relationships of intact turbinates to one another. The ethmoid complex is circled in red. Note the schematic depiction of orbital musculature and the centrally positioned optic nerve (*orange*) relative to the ethmoid (clockwise): superior rectus (*green*), inferior oblique (*yellow*), lateral rectus (*pink*), inferior rectus (*turquoise*), medial rectus (*blue*), and superior oblique (*purple*). The last two extraocular muscles are at greatest risk for inadvertent injury during sinus surgery.

The middle turbinate attaches posterolaterally adjacent to the crista ethmoidalis of the perpendicular process of the palatine bone (**Fig. 1.10a**) and courses anteriorly and superiorly to attach vertically at the lateral lamella of the cribriform plate. In between, it attaches laterally to the lamina papyracea or the medial wall of the maxillary sinus. Variations in the shape of the middle turbinate include the paradoxical middle turbinate, where the curvature is convex laterally, and the concha bullosa, where the turbinate is pneumatized, forming its own sinus. The middle meatus is bounded superiorly by the lateral attachment of the middle turbinate, inferiorly by the insertion of the inferior turbinate, laterally by the uncinate process, and medially by the middle turbinate itself. The ostiomeatal complex and the related structures within the middle meatus are discussed in a later section.

The superior turbinate is much smaller than the middle or the inferior turbinate and is situated directly behind the middle turbinate. It is identified as a distinctive ridge that has a shorter vertical height compared with the middle turbinate as it descends from the skull base. Posteriorly, it is continuous with the superior aspect of the posterior middle turbinate along the skull base (**Fig. 1.12**). The olfactory neuroepithelium extends from the cribriform plate to populate the superior portion of the superior turbinate; surgically, this is an important concept, as the turbinates, along with the nasal septum, play a significant role in olfaction. The extent and the distribution of the olfactory neuroepithelium vary from individual to individual but often appear to involve a superior portion of the medial middle turbinate as well.[17]

The supreme turbinate is a far less developed structure along the lateral nasal wall and is seen only as a small cleft above the superior turbinate. The reported prevalence of the structure in specimens ranges from 17 to 60%.[3,16] When the corresponding supreme meatus is present, it drains the posterior ethmoid cells the majority of the time.

Blood Supply to the Nasal Cavity

Like the blood supply of the external nose, the blood supply to the nasal cavity comes from both the internal and the external carotid systems.[3,15,16] The ophthalmic artery, via the anterior and the posterior ethmoid arteries, supplies the upper and anterior aspects of the nasal cavity, whereas the internal maxillary artery, via the sphenopalatine artery, supplies the posterior part of the nose. Branches of the facial artery, via the angular and the superior labial arteries, deliver the blood to the nasal vestibule (see **Fig. 1.6**).

The sphenopalatine artery, which derives from the internal maxillary artery, passes through the sphenopalatine foramen and divides into the posterior lateral nasal and posterior septal arteries. It is not unusual for the artery to divide more proximally before exiting the foramen. A branch or multiple branches may exit through separate foramina. One study found that 97% of the cadaver specimens studied had two or more branches of the artery distal to the sphenopalatine foramen.[20] Thus, ligation of one vessel emerging from the sphenopalatine foramen is likely to be insufficient for the management of epistaxis. The position of the sphenopalatine foramen has been shown to have some variability along the lateral nasal wall as it relates to the attachments of the turbinates to the bony lateral wall. It is bound anteriorly by a constant elevation of the aforementioned palatine bone called the crista ethmoidalis (see **Fig. 1.10a**). This is an important clinical fact for the management of epistaxis. According to one study, more than 50% of the sphenopalatine foramina are situated

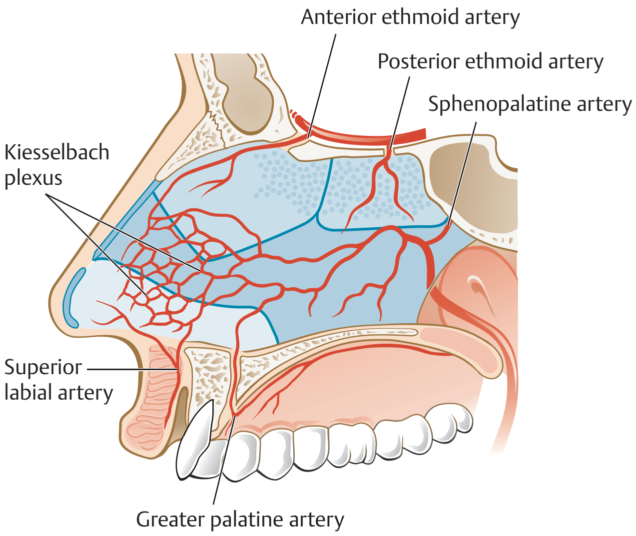

Fig. 1.12 Schematic sagittal drawing of lateral nasal wall blood supply and innervation. Light blue stippling indicates the approximate location of the olfactory neuroepithelium.

between the superior and middle meatus, whereas 37% are in the superior meatus.[21] An accessory foramen was present in 50% of the population, with the majority of these situated in the middle meatus. The posterior lateral nasal artery, the larger of the two branches of the sphenopalatine artery, courses along and then supplies the middle and inferior turbinates (**Fig. 1.12**). The posterior septal artery exits the sphenopalatine foramen and runs along the sphenoid rostrum to supply the posterior portion of the nasal septum. This artery is the source of the blood supply for the pedicled nasoseptal flap described for skull base reconstruction after endoscopic skull base resections.[22]

Note

Ligation of one vessel emerging from the sphenopalatine foramen is likely to be insufficient for the management of epistaxis.

The sphenopalatine foramen is bound anteriorly by a constant elevation of the aforementioned palatine bone called the crista ethmoidalis. This is an important clinical fact for the management of epistaxis.

This artery is the source of the blood supply for the pedicled nasoseptal flap described for skull base reconstruction after endoscopic skull base resections.

The descending palatine artery, which is another branch of the internal maxillary artery, travels a short distance in the pterygopalatine fossa and then enters the greater palatine canal. As it exits via the greater palatine foramen opposite the second molar, it branches into the greater and lesser palatine arteries, which then traverse into the hard palate of the oral cavity through their respective canals. They supply the hard and soft palates, as well as the inferoposterior portion of the nasal cavity. The greater palatine artery, as it courses along the palate, anastomoses with the nasopalatine branch of the sphenopalatine artery coming through the incisive foramen and supplies the anterior portion of the septum.

The anterior and posterior ethmoid arteries branch from the ophthalmic artery within the orbit and then enter the nasal cavity through the lamina papyracea of the ethmoid just below the horizontal plate of the frontal bone. They course across the skull base at variable heights toward the cribriform plate[23] and penetrate the lateral lamella of the cribriform plate before traveling anteriorly in the ethmoid sulcus. There they both provide a meningeal branch to the dura mater and occasionally to the falx cerebri, prior to passing into the nasal cavity.[24] After exiting the orbit, the anterior ethmoid artery enters the anterior cranial fossa through the cribriform plate before sending branches back intranasally to the nasal septum and externally to the nasal dorsum as the external nasal artery. The position of the anterior ethmoid artery relative to the skull base is of clinical importance during endoscopic anterior ethmoidectomy, as its injury could theoretically cause it to retract into the orbit, leading to a retro-orbital hematoma and resulting in blindness or even cerebrospinal fluid (CSF) leak (**Fig. 1.13**). Stammberger found that in 29 of 40 skulls, the anterior ethmoid artery

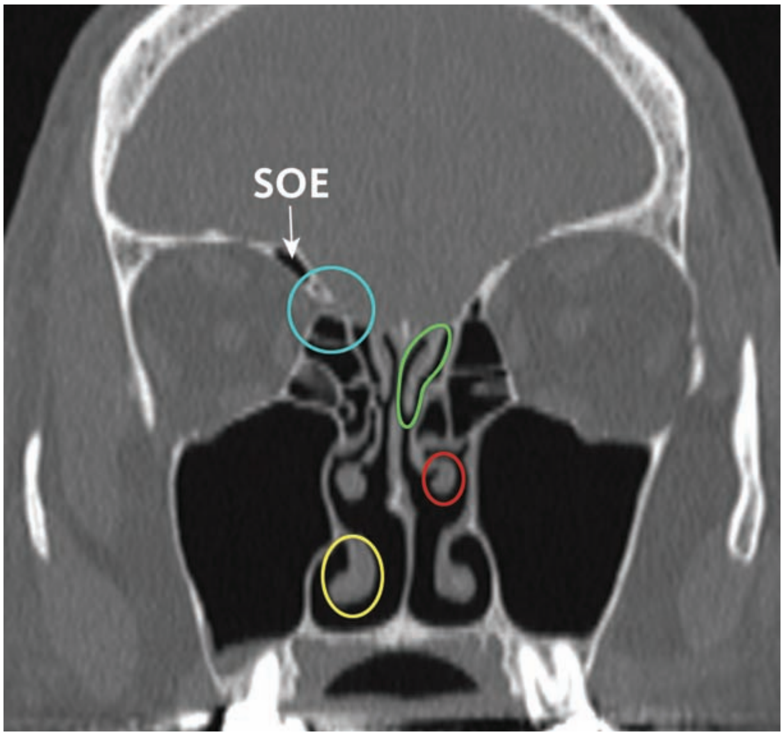

Fig. 1.13 Reconstructed coronal CT scan of the paranasal sinuses demonstrating the course of the anterior ethmoid neurovascular bundle (*blue*) across the skull base. Note the pneumatization of the supraorbital ethmoid cell (SOE) above the anterior ethmoid artery, which is typically partially covered by dura mater. Inferior turbinate (*yellow*), middle turbinate (*red*), superior turbinate (*green*).

was surrounded by dura along its entire ethmoidal portion, whereas it entered the dura only during its passage through the ethmoid sulcus in 8 of the 40 skulls. In only 3 of 40 cases did the artery remain extradural along its entire course.[23] This finding once again suggests that an injury to the anterior ethmoid artery poses two obvious risks–CSF leak and hemorrhage that results in poor surgical visualization or orbital hematoma. The anterior ethmoid artery supplies the anterior portions of the middle and inferior turbinates, as well as the corresponding portion of the anterior septum. The posterior ethmoid artery, the smaller of the two, supplies the superior turbinate and the corresponding posterior portion of the septum. The positions of these arteries along the skull base are variable, but the ratio of 24–12–6 mm is commonly quoted as the average distance from the anterior lacrimal crest to the anterior ethmoid artery, from the anterior ethmoid artery to the posterior ethmoid artery, and then from the posterior ethmoid artery to the optic canal, respectively.[25] However, a more recent study of dry bones shows a wider range of distances among the frontomaxillary suture, anterior ethmoid foramen, posterior ethmoid foramen, and optic canal than previously described.[26] Having basic knowledge of the distances between these important structures will be of great benefit in the operating room.

Note

The position of the anterior ethmoid artery relative to the skull base is of clinical importance during endoscopic anterior ethmoidectomy, as its injury could theoretically cause it to retract into the orbit, leading to a retro-orbital hematoma and resulting in blindness or even cerebrospinal fluid leak.

The superior labial artery arises from the distal portion of the facial artery and supplies the nasal vestibule and the anterior septum after anastomosing with the septal tributaries from the sphenopalatine system. The anterior portion of the nasal septum where the arterial supplies aggregate is known as Kiesselbach plexus, or Little area.[15] It receives contributions from the anterior ethmoid, superior labial, sphenopalatine, and greater palatine arteries. It is recognized as the source of epistaxis in 90% of cases.[27] This is also a watershed area, referring to the fact that this area receives dual blood supply from the most distal branches of the internal (via ethmoid arteries) and external carotid arteries (via facial artery and sphenopalatine arteries). This area is particularly vulnerable to ischemia with its terminal blood supply; therefore, Little area is a common site of nasal septal perforation with cocaine use, trauma, or even septoplasty (see **Fig. 1.8**).

The venous drainage of the nasal cavity parallels the arterial supply. The veins that drain through the sphenopalatine foramen empty into the pterygoid plexus, whereas the ethmoid veins drain into the superior ophthalmic vein, which in turn drains into the cavernous sinus. One notable plexus of veins is the so-called Woodruff plexus, found in the posteroinferior meatus, which is clinically associated with posterior epistaxis.

Note

The anterior portion of the nasal septum is particularly vulnerable to ischemia with its terminal blood supply; therefore, Little area is a common site of nasal septal perforation with cocaine use, trauma, or even septoplasty.

One notable plexus of veins is the so-called Woodruff plexus, found in the posterior inferior meatus, which is clinically associated with posterior epistaxis.

Innervation of the Nasal Cavity

In addition to the special sensory function provided by the olfactory nerve (CN I), the nasal cavity is the site for general sensory function associated with the ophthalmic and maxillary divisions of the trigeminal nerve, as well as autonomic innervation via the facial nerve and the sympathetic chain. Although CN 0 and the vomeronasal organ are present and have functions for pheromone sensing in lower life forms, their existence and function in humans are viewed skeptically by most anatomists.[3]

The general sensory fibers to the mucous membrane of the nasal cavity are provided by multiple branches derived from the ophthalmic and maxillary divisions of the trigeminal nerve. The ophthalmic division of the trigeminal nerve enters the posterior orbit via the superior orbital fissure, giving rise to the nasociliary nerve. This nerve in turn divides into the anterior and posterior ethmoid nerves, which travel alongside the anterior and posterior ethmoid arteries, respectively. The anterior ethmoid nerve further divides into internal and external branches that descend along the anterior septum. They supply the anterior lateral nasal wall and the dorsum of the external nose, respectively. The posterior ethmoid nerve innervates the posterior and superior portions of the septum, as well as the corresponding lateral nasal wall[17] (see **Figs. 1.6, 1.8, and 1.12**).

The maxillary division of the trigeminal system passes through the inferior orbital fissure, travels across the roof of the pterygopalatine fossa, and then enters the infraorbital canal to deliver innervation to the middle third of the face, including a portion of the lining of the vestibule. A branch known as the anterosuperior alveolar nerve comes off the infraorbital nerve within the canal. This descends within the anterior wall of the maxillary sinus and gives off a nasal branch that supplies the upper incisors and canine teeth, as well as the anterior portions of the inferior meatus and the nasal cavity floor.[17] This is of clinical importance during tumor removal from the maxillary sinus, Caldwell-Luc approaches, or orbital decompression surgery when the maxillary nerve is at greatest risk for injury. As a result of such nerve injury, patients can develop permanent paresthesias, numbness, or pain that can be debilitating (see **Fig. 1.9**).

Caution

The anterosuperior alveolar nerve is of clinical importance during tumor removal from the maxillary sinus, Caldwell-Luc approaches, or orbital decompression surgery when the maxillary nerve is at greatest risk for injury. As a result of such nerve injury, patients can develop permanent paresthesias, numbness, or pain that can be debilitating.

Sensory innervation to the internal lining of the nasal cavity that derives from the maxillary division of the trigeminal nerve is supplied via the pterygopalatine ganglion, which lies within the pterygopalatine fossa. The nasal branches from the ganglion pass through the sphenopalatine foramen along with the sphenopalatine artery and give off multiple branches that supply temperature, pain, and touch sensations to the mucosa of the nasal cavity. The lateral posterosuperior nasal branches emerge from the sphenopalatine foramen and supply the middle and inferior turbinates. The medial posterosuperior nasal branches cross the face of the sphenoid and the roof of the nose, then descend along the septum as the nasopalatine nerve innervating the posterior septum. This nerve travels parallel to the nasal floor through a bony canal, eventually exiting through the incisive foramen. Vigorous reduction of the maxillary crest during septoplasty may put the nasopalatine nerve at risk (see **Fig. 1.8**), resulting in postoperative anesthesia or paresthesia of the portion of the palate behind the central incisors. Other maxillary nerve branches pass through the floor of the pterygopalatine fossa to enter the oral cavity as the greater palatine nerve. This nerve also provides sensation to the mucous membrane over the posterior part of the inferior turbinate and the inferior meatus.[16,17]

Caution

Vigorous reduction of the maxillary crest during septoplasty may put the nasopalatine nerve at risk, resulting in postoperative anesthesia or paresthesia of the portion of the palate behind the central incisors.

Both sympathetic and parasympathetic nerve fibers control the vascular and glandular structures of the nasal mucosa. Although some sympathetic fibers reach the nasal cavity via the nasociliary nerve, the main autonomic pathway is through the pterygopalatine ganglion and its branches. Most of the parasympathetic fibers are derived from the facial nerve originating from the superior salivary nucleus in the brainstem. At the first genu, the parasympathetic fibers to the nose travel past the geniculate ganglion as the greater superficial petrosal nerve, and upon being joined by the deep petrosal nerve, which contains the sympathetic fibers from the superior cervical ganglion, traverse the vidian (pterygoid) canal and enter the pterygopalatine fossa as the vidian nerve. The preganglionic fibers of the vidian nerve synapse in the pterygopalatine ganglion; the postsynaptic postganglionic fibers innervate the mucous membranes of the nose and the hard palate. They have vasodilatory and secretory effects within the nasal cavity and innervate the lacrimal gland to control lacrimation.[16,17] Damage to the vidian nerve can occur during the surgical approach to the lateral pterygoid recess of the sphenoid sinus for encephaloceles descending through a congenital dehiscence of Sternberg canal or in the management of juvenile nasopharyngeal angiofibroma. Such injury can lead to the unintended consequence of dry eye.[28,29] Alternatively, some experts have advocated endoscopic vidian neurectomy as a treatment for rhinitis.[30]

Caution

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Pterygopalatine Fossa

The pterygopalatine fossa is a space located lateral to the nasal cavity and posterior to the maxillary sinus. It is situated medial to the infratemporal fossa and anteroinferior to the middle cranial fossa. It houses various vascular and neural structures and serves as a conduit to adjacent structures via multiple fissures, canals, and foramina. Contained within the fossa are the maxillary division of the trigeminal nerve (CN V_2), the pterygopalatine ganglion, and the third part of the internal maxillary artery. The pterygoplatine fossa can be thought of as a box with openings on five sides. In the posterior wall, the vidian canal and foramen rotundum, which contain the vidian nerve and the maxillary nerve (CN V_2), respectively, open to the middle cranial fossa, and the pharyngeal canal opens to the nasopharynx. The pharyngeal canal (also known as the palatovaginal canal) contains a branch of CN V_2 called the pharyngeal nerve. Through the superior wall lies the previously mentioned sphenopalatine foramen, which connects to the nasal cavity and contains the sphenopalatine artery and nerve. The inferior orbital fissure in the anterior wall of the “box” connects the pterygopalatine fossa to the orbit and contains the infraorbital artery and nerve. Inferiorly, the pterygopalatine fossa continues into the pterygopalatine canal, which connects to the roof of the oral cavity. This canal contains the descending palatine artery and nerve and eventually leads to the greater and lesser palatine foramina. Lastly, through the lateral wall of the “box,” the pterygopalatine fossa communicates with the infratemporal fossa through the pterygomaxillary fissure. The internal maxillary artery passes through the fissure.

The Paranasal Sinuses

There are four paired sinus cavities that arise and pneumatize at different times during development. They are the maxillary, sphenoid, frontal, and ethmoid sinuses. The ethmoid sinuses are further divided into anterior and posterior sinuses by the basal lamella of the middle turbinate. The nasal cavity can be viewed as a box that is open at either end—the pyriform aperture and the choana–with a roof, a floor, and two side walls. The center piece of the “box” is the ethmoid complex, with which all other sinuses border and are intimately related (see **Figs. 1.3, 1.13, and 1.14**). Development of the paranasal sinuses varies from individual to individual and can be affected by disease states. For example, patients with cystic fibrosis often have underdeveloped paranasal sinuses in comparison to age- and gender-matched controls.[31] Anatomical nomenclature for the paranasal sinuses has been the subject of great discussion, as there is global variation for terminology.[32] Along with their function of warming and humidifying of the inspired air, the sinuses may theoretically serve an evolutionary purpose by acting as a protective barrier for the brain. Another theory regarding the role of the sinuses in evolutionary development is that the pneumatization of the facial skeleton made the head lighter, allowing human ancestors to stand upright. Furthermore, the sinuses may have aided the development of verbal communication by serving as the resonance chamber of the human voice, much like the hollow cavity of a string instrument.

Note

Patients with cystic fibrosis often have underdeveloped paranasal sinuses in comparison to age- and gender-matched controls.

Maxillary Sinuses

Each maxillary sinus is a space within the maxilla, shaped like a pyramid on its side. The base of the pyramid is along the lateral nasal wall, and the apex is pointing laterally toward the zygoma. The sinus is bounded anteriorly by the soft tissue of the face, posteriorly by the infratemporal fossa, superiorly by the orbital floor, inferiorly by the alveolar surface of the maxilla, and medially by the lateral nasal wall. The maxilla bone itself articulates with eight different bones: frontal, ethmoid, palatine, nasal, zygomatic, lacrimal, inferior turbinate, and vomer (see **Fig. 1.3**). It is the largest sinus, with an average volume of ~14 mL.[17]

The drainage pathway from the maxillary sinus is situated on the most superior part of the medial wall of the sinus, through a narrow passageway called the ethmoid infundibulum. The ostium of the maxillary sinus opens into the posteroinferior half of the ethmoid infundibulum in a crevice created by the uncinate process of the ethmoid. The mucus generated within the maxillary sinus is mobilized by the cilia against gravity, up from the sinus floor toward the maxillary sinus ostia in a stellate pattern (**Fig. 1.14a**). The uncinate process of the ethmoid bone forms a significant portion of the medial antral wall within the middle meatus.[33] The bony medial wall of the maxillary sinus frequently has dehiscences through the anterior and posterior fontanelles, and perforated mucosa over these dehiscences results in accessory ostia. This is seen in 10 to 28% of the population.[3] The cause of these perforations is not known, but they can result in naturally recurring recirculation of mucus back into the maxillary sinus. This is reported to be associated with episodes of recurring acute rhinosinusitis.

Note

The cause of perforations in the bony medial wall is not known, but they can result in naturally recurring recirculation of mucus back into the maxillary sinus. This is reported to be associated with episodes of recurring acute rhinosinusitis.

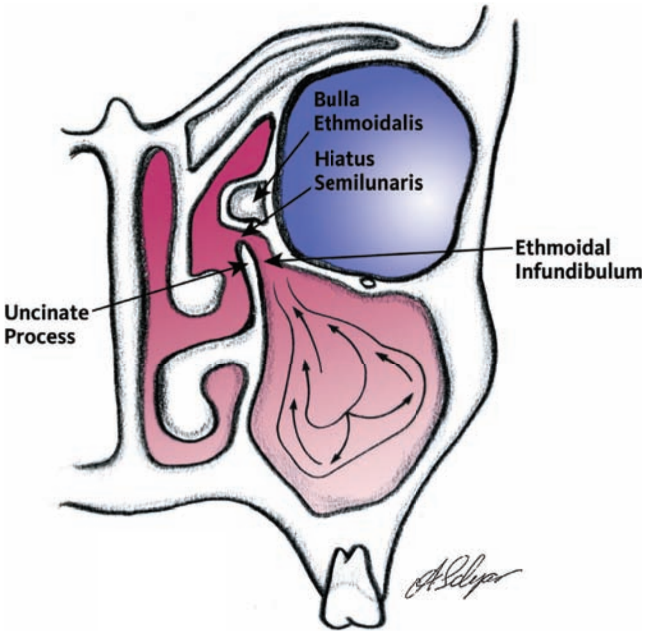
Another anatomical variation is the infraorbital ethmoid cell (Haller cell), which is an ethmoid cell that pneumatizes into the roof of the maxillary sinus/floor of the orbit and lies lateral to the ethmoid bulla (**Fig. 1.14b**). It is seen in ~4% of the population. It is thought to originate from the anterior ethmoid sinuses in 88% of cases and from the posterior ethmoid in 12% of cases.[8] It can be located close to the ethmoid infundibulum and the maxillary sinus ostium, and if diseased, it can interfere with the mucociliary clearance.[32]

The maxillary sinus draws its blood supply from the internal maxillary artery system via the posterosuperior alveolar, infraorbital, and anterosuperior alveolar arteries. The corresponding nerves, as well as the greater palatine nerve, provide the innervation to the sinus. Venous drainage is performed by the facial vein anteriorly and the maxillary vein posteriorly.[3,16]

Sphenoid Sinuses

The sphenoid sinuses are centrally located in the skull base and are intimately related to the sella turcica

Fig. 1.14a–c The ethmoid complex.
a Schematic drawing in the coronal plane of the anterior ethmoid sinus. Note the star-shaped pattern of mucociliary clearance emanating from the floor of the maxillary sinus against gravity to the natural ostial region.
b Reformatted coronal CT scan demonstrating the anterior ethmoid complex (*yellow*) at the middle turbinate attachment to the cribriform plate with bilateral concha bullosa (*red*), EI = ethmoid infundibulum, and small infraorbital ethmoid cell (Haller cell) (*green arrow*). IN = infraorbital nerve, B = brain, red star = concha bullosa.
c Axial CT scan of the ethmoid complex in the superior nasal cavity. Note the left posterior sphenoethmoid cell pneumatizing posteriorly into the face of the left sphenoid sinus (*red oval*). RS = right sphenoid, LP = lamina papyracea, OF = optic foramen, G = globe, olfactory cleft (*blue*) at cribriform plate, PPE = perpendicular plate of the ethmoid. Note the soft tissue swelling consistent with chronic rhinosinusitis in the right anterior ethmoid.



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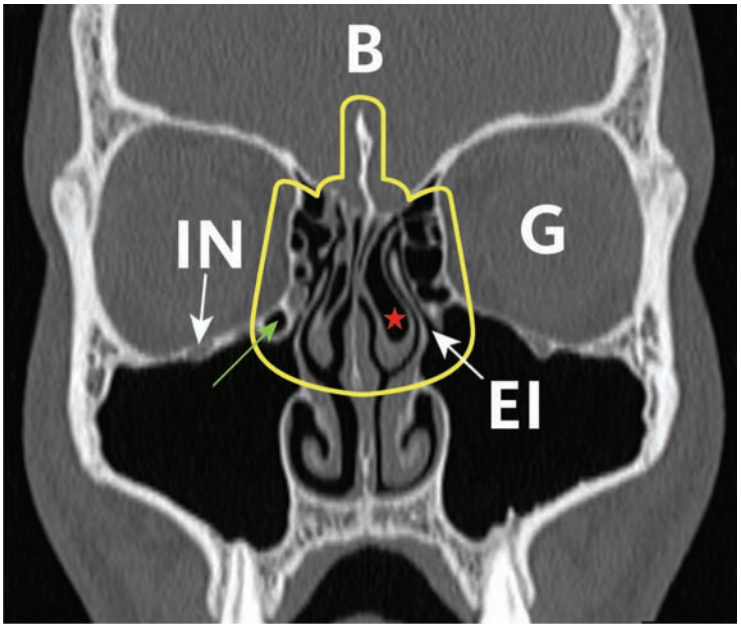

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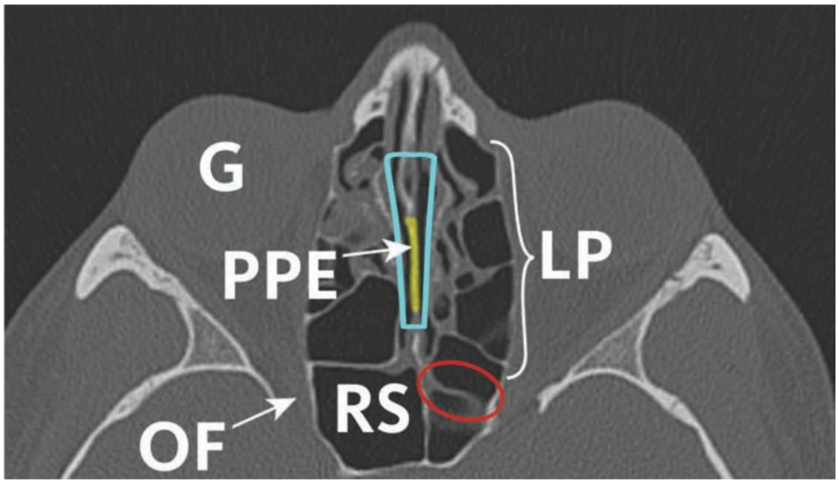

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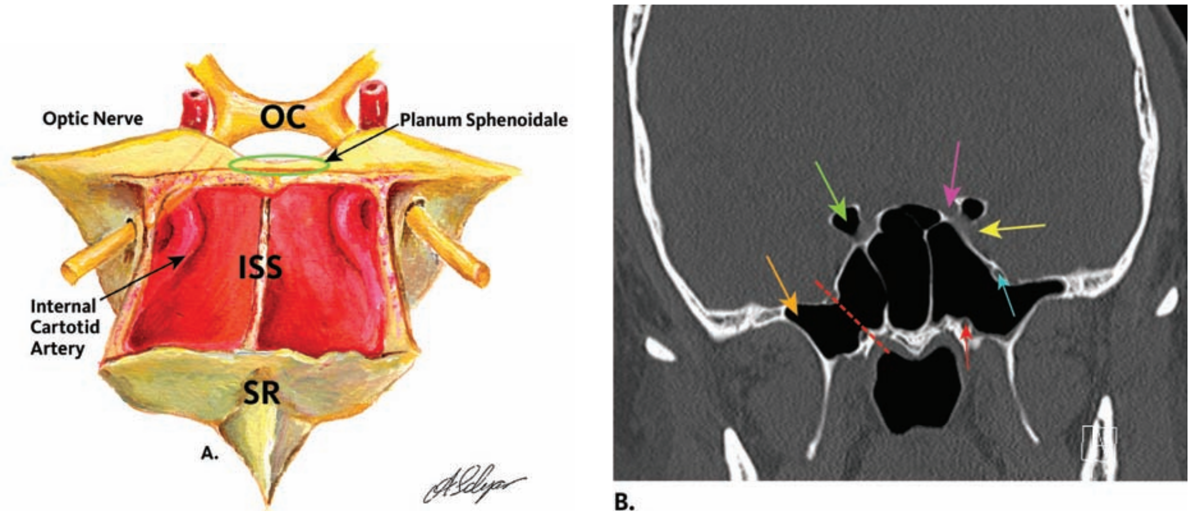

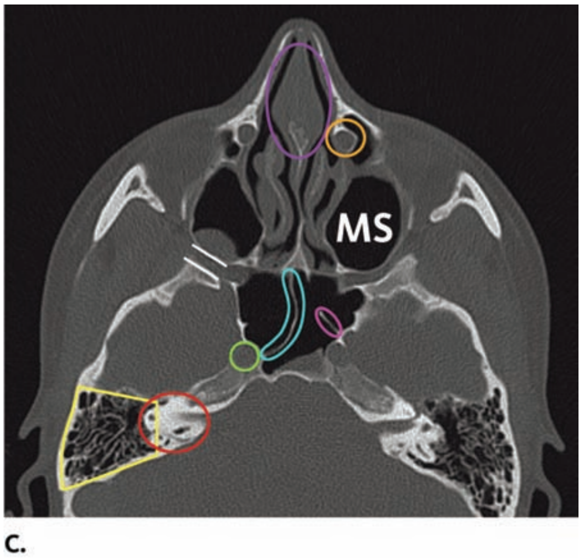

Fig. 1.15a–c Sphenoid sinus.

a Schematic drawing in the coronal plane with the sphenoid rostrum (anterior wall) removed. Note the relationship between the optic nerve and carotid artery. OC = optic chiasm, ISS = intersinus septum, SR = sphenoid rostrum.

b Coronal CT (follow arrows clockwise starting with green) anterior clinoid process pneumatized to create the opticocarotid recess (*green*), optic nerve (*pink*), internal carotid artery (*yellow*), foramen rotundum (*blue*), and canal of the vidian (*red arrow*). Note the space lateral to the dotted red line drawn from the foramen rotundum to the canal of the vidian represents the pterygoid recess of the sphenoid sinus (*orange*).

c Axial CT of the demonstrating the intersinus septum (*blue*) attaching posterior to the right carotid artery (*green*) with a partial septum (*pink*) adjacent to the left carotid artery. Note the anteroposterior dimension of the pterygomaxillary space (*white lines* to left) posterior to the maxillary sinus (MS to right), and lacrimal duct (*orange circle*) anteriorly adjacent to the anterior septal body (*large pink circle*). Note the relative position of the mastoid air cells (*yellow*) and petrous apex with cochlea (*red circle*).

posteriorly, cavernous sinuses and internal carotid arteries laterally, and optic nerves superiorly (**Fig. 1.15a**). Also, the maxillary division of the trigeminal nerve and the vidian nerve neighbor the sinus (**Fig. 1.15b**). The sphenoid sinus drains through the sphenoethmoid recess, which is located in the space between the superior turbinate, septum, and skull base.

The sphenoid bone, which is located at the most posterior portion of the nasal cavity, articulates with the ethmoid, frontal, vomer, occipital, parietal, temporal, zygomatic, and palatine bones. The sphenoid sinus does not begin its pneumatization process until the third year of life, and the pneumatization pattern varies greatly, ranging from being limited to the sphenoid bone itself to extending into the greater wing of the sphenoid, the pterygoid process, and even the occipital bone.[17] Different pneumatization patterns as related to the sella are demonstrated in **Fig. 1.16**. Pneumatization of the sphenoid sinus is classified into four categories: conchal, presellar, sellar, and postsellar, each type comprising 4.7, 4.7, 25, and 65% of sphenoid pneumatization patterns, respectively.[34] As a result, the volume of the sphenoid sinus cavity varies greatly, ranging between 0.5 and 30 mL.[16] The paired sphenoid sinuses are frequently asymmetric, with the intersinus septum taking on various orientations. The intersinus septum may lie obliquely, anchoring itself to the internal carotid artery or the optic nerve, as seen in **Fig. 1.15c**. Its insertions onto the carotid artery were noted in 37.5% of specimens, and dehiscences were noted in 19.5% of specimens.[34] This is of significant clinical importance for transsphenoidal surgery and other procedures within the sphenoid sinus. Separate from the intersinus septum that divides the left from the right

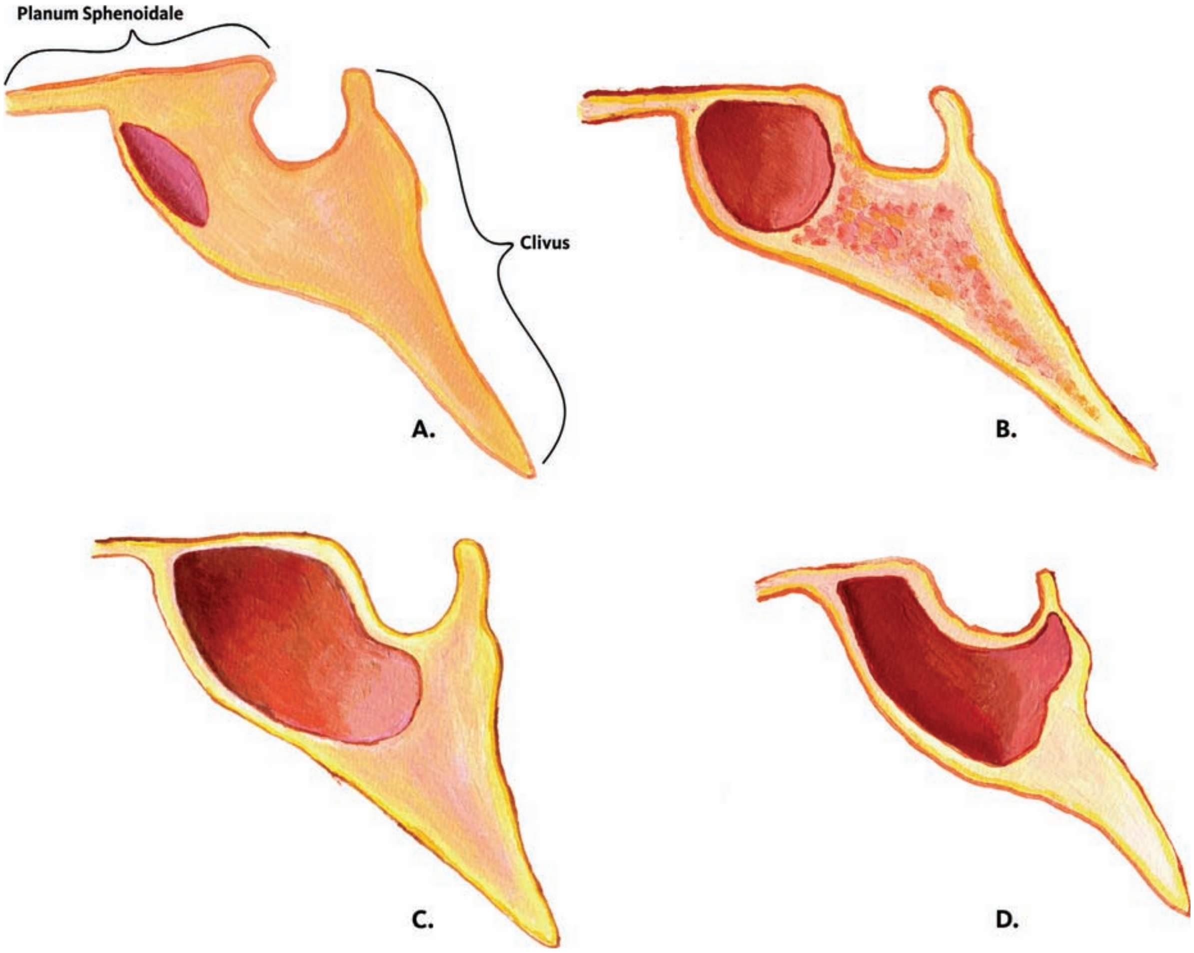

Fig. 1.16a–d Sagittal depiction of pneumatization patterns of the sphenoid sinus. Note the saddle-shaped depression of the sella turcica between the posterior planum sphenoidale and the clivus.
a Conchal type.
b Presellar.
c Sellar.
d Postsellar.

sphenoid are occasional incomplete septations, which are commonly inserted onto the carotid artery. The depression of the posterior wall of the sphenoid sinus between the bulges created by the optic canal superiorly and the internal carotid artery inferiorly is referred to as the opticocarotid recess (OCR) (also known as the infraoptic recess), and it corresponds to the anterior clinoid process of the lesser wing of the sphenoid bone. Occasionally, the anterior clinoid process itself can be pneumatized, forming a recess within the sphenoid sinus (**Figs. 1.15b and 1.17**). Other recesses (e.g., pterygoid recess) within the sphenoid sinus can be more or less prominent depending on pneumatization patterns. Again, this is of clinical importance in the management of lateral sphenoid sinus encephaloceles associated with Sternberg canal.

Note

The intersinus septum may lie obliquely, anchoring itself to the internal carotid artery or the optic nerve. Its insertions onto the carotid artery were noted in 37.5% of specimens, and dehiscences were noted in 19.5% of specimens.

The posterior wall of the sphenoid sinus is part of the clivus (Latin for “slope”), which is an anatomical region comprised of the sphenoid and occipital bones extending from the foramen magnum to the posterior boundary of the sella turcica called the dorsum sellae (**Fig. 1.16**). It slopes posteriorly and inferiorly to form part of the posterior fossa floor. A chordoma, a tumor that is thought to arise from the cellular remnants of a notochord, is the most common tumor of the clivus.

Note

A chordoma, a tumor that is thought to arise from the cellular remnants of a notochord, is the most common tumor of the clivus.

A highly pneumatized posterior ethmoid cell occasionally extends posteriorly and “invades” the superior, lateral, and posterior portions of the sphenoid bone. Because of its placement superior to the sphenoid sinus proper, the sphenoethmoid cell (also known as the Onodi cell) has an intimate relationship to the optic nerve (**Figs. 1.14c and 1.17**). The sphenoethmoid cell may pneumatize a variable extent around the optic nerve, which can be manifested simply as a lateral bulge, or in extreme cases, appear to cross through the center of the cell.[35] There may be a bony dehiscence of the optic canal, and one must take caution not to injure the optic nerve during a dissection into this cavity.[36] The exact incidence of sphenoethmoid cells is unclear, but endoscopic dissection studies suggest an incidence as high as 42%, whereas computed tomography (CT) imaging studies suggest a lower incidence of 7%. It has been noted that genetic factors may also play a role, as sphenoethmoid cells appear to be more common in Asian patients.[37]

The sphenoid sinus derives its blood supply from the posterior septal branches of the sphenopalatine artery and the posterior ethmoid artery. The innervation of the sinus is provided by branches of the pterygopalatine branch of the maxillary nerve (CN V_2) and some contributions from the posterior ethmoid branch of the nasociliary nerve (CN V_1). The venous drainage is via the maxillary vein and the pterygoid venous plexus.[3,16]

Frontal Sinuses

Of the four pairs of sinuses, the frontal sinuses are the last to develop, as they are typically absent at birth and begin to substantially develop around the seventh year of life.[38,39] The frontal bone consists of a vertical portion that forms the forehead and a horizontal portion that forms

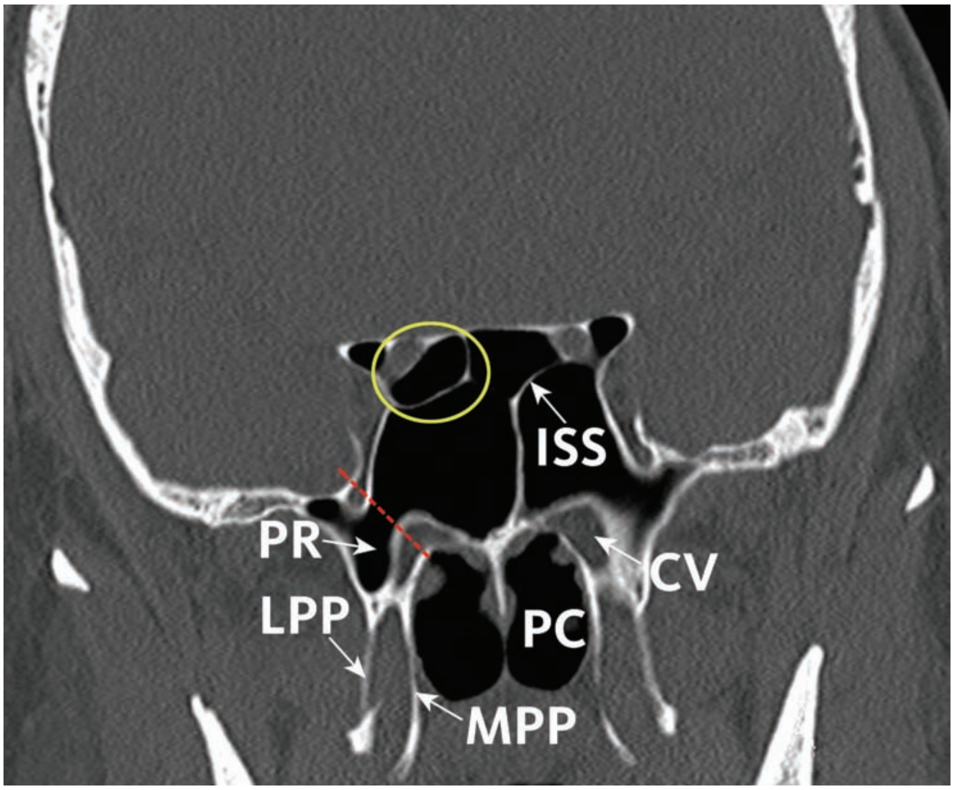

Fig. 1.17 Coronal CT of the sphenoid sinus. Note the appearance on coronal imaging of a sphenoethmoid cell (Onodi cell) (*yellow circle*) through which an optic nerve is coursing at 10 o’clock. Note the intersinus septum (ISS) attached to the left optic nerve. Note the variation in pneumatization of the pterygoid recess (PR) in this image lateral to the position of the foramen rotundum and the canal of the vidian (CV) (*red dotted line*). Also observe the medial and lateral pterygoid plates (MPP and LPP) of the sphenoid bone at the level of the posterior choanae (PC).

the roof of the orbit and the floor of the anterior cranial fossa. It articulates with the ethmoid, lacrimal, maxillary, nasal, parietal, sphenoid, and zygomatic bones.[11] The frontal sinus is formed by the pneumatization of the vertical part of the frontal bone and is variably pneumatized, typically resulting in asymmetric frontal sinus cavities.

The drainage passageway of the frontal sinus is an hourglass-shaped area composed of three different components (**Fig. 1.18**). The top portion of the hourglass is the frontal infundibulum, which is the inferiormost aspect of the frontal sinus. The narrow portion of the hourglass is the frontal sinus ostium that sits in the posteromedial part of the sinus at the inferior end of the frontal infundibulum. The inferior portion of the hourglass is the frontal recess, a narrow cleft within the anterior ethmoid complex that is akin to an upside-down funnel.[11,32] Because there is no distinct tubal structure, the term *nasofrontal duct* should be avoided. Mucus generated within the frontal sinus circulates around the sinus in a superolateral-to-inferomedial direction before draining out through the frontal recess[17] (see **Fig. 1.11**). Narrowing in any of these structures or disease within the anterior ethmoid sinus can result in frontal sinusitis.

Anatomical variations are common in the frontal sinus and have been discussed in great detail elsewhere.[11,40,41] There are several types of ethmoid air cells that can affect the drainage pathways of the frontal sinus. Several different classification systems are available for these, but none is widely agreed upon. The most common system is referred to as the Bent and Kuhn system, which addresses the need for a more exact definition of the frontal sinus cells separate from other types of anterior ethmoid cells.[42] Four different types were described. Type I represents a single cell above the agger nasi cell. Type II refers to a tier of two or more cells superior to the agger nasi cell. Type III represents a single, massive cell that pneumatizes superiorly into the frontal sinus. Type IV frontal cell has the appearance of being contained entirely within the frontal sinus on coronal CT scan and may appear as a cell within a cell (**Fig. 1.19**). All of these types of frontal sinus cells (I–IV) are believed to drain directly into the ethmoid sinuses instead of into the frontal sinus. Also, the shape of the frontal sinus at the midline can be altered by two structures. Along the posteroinferior table of the midline of the frontal sinuses lies the crista galli (Latin for "cock's crest," as seen on the head of a rooster). This is a thin crest of ethmoid bone to which the falx cerebri attaches intracranially. It can be filled with marrow, or it may be pneumatized (**Fig. 1.20**). When pneumatized, it can drain directly into either the frontal sinus or the ethmoid sinuses. Along the anterior table or floor of the frontal sinus at the midline, a sinus can develop called an intersinus septal cell (see **Fig. 1.19**). It is formed by pneumatization of the frontal bone between the two frontal sinuses. The presence of the cell can narrow the frontal recess on either side,

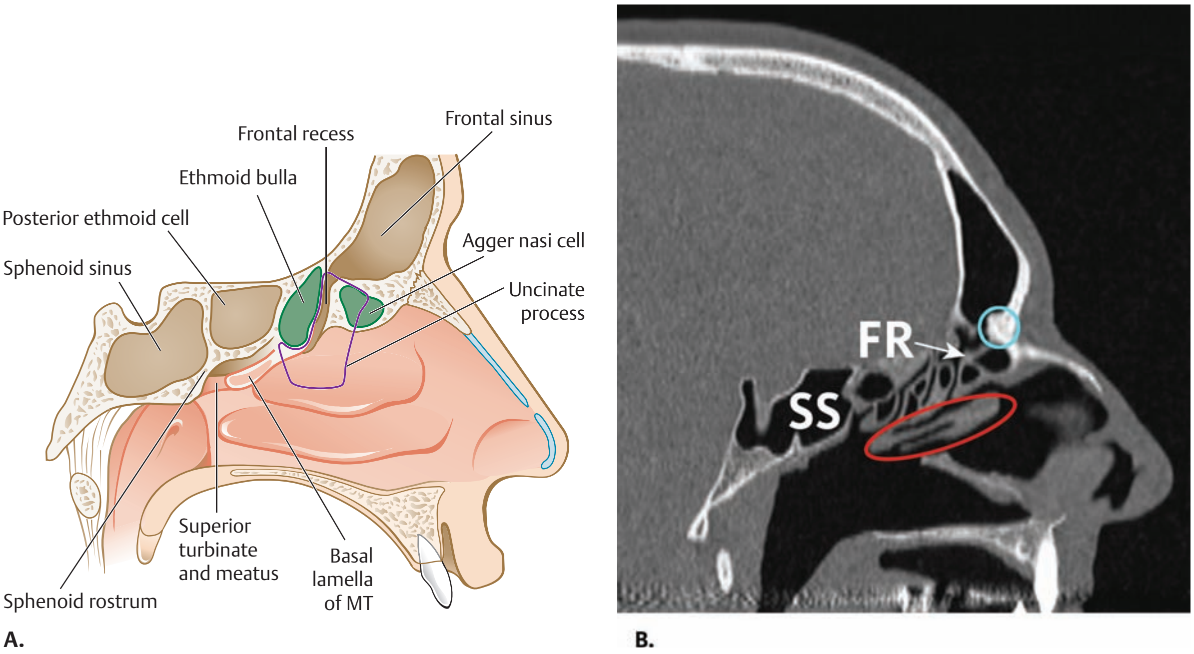

Fig. 1.18a, b
a Schematic sagittal drawing of frontal sinus drainage. MT, middle turbinate.
b Sagittal CT image of the "nasofrontal beak" (*blue*) adjacent the frontal recess (FR). Note the relative position of the sphenoid sinus (SS). Middle turbinate (*red circle*).

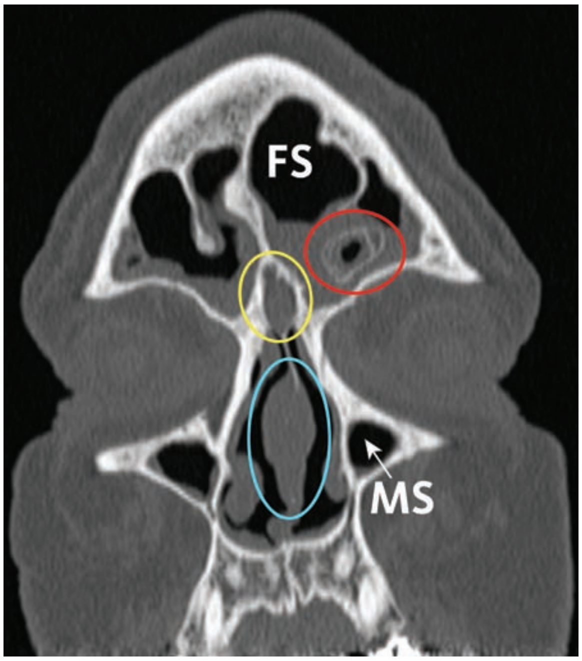

Fig. 1.19 Coronal CT of the frontal sinus (FS) with mucosal swelling (*gray*) and isolated type IV frontal sinus cell on the subject's left-hand side (*red circle*). Notice the intersinus septal cell opacified at the midline (*yellow*) and the position of the anterior septal body (*blue*) and maxillary sinus (MS).

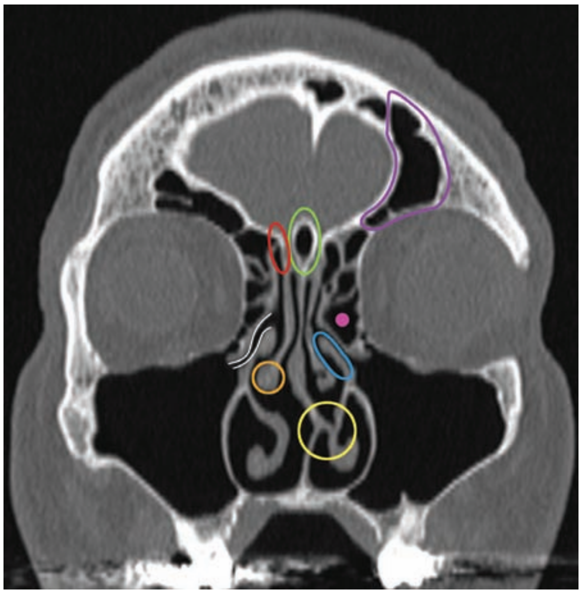

Fig. 1.20 Coronal CT image of pneumatized crista galli (*green*). Note the position of the supraorbital ethmoid compartment (*purple*) to the posterior aspect of the frontal sinus region and the middle turbinate (*orange*) attached superiorly to the lateral lamella of the cribriform plate (*red circle*). Observe the ethmoid bulla (*pink dot*), uncinate process (*blue*), ethmoid infundibulum (*parallel white lines*), and septal spur (*yellow*) impacting on the left inferior turbinate (IT) in a previously decongested nasal airway.

contributing to obstruction or giving rise to symptoms by harboring mucosal sinus disease within itself. The cell also typically drains into the frontal recess on either side.[11] Occasionally, it can appear in association with the crista galli.

The boundaries of the frontal recess are the posterior wall of the agger nasi anteriorly, the anterior wall of the ethmoid bulla posteriorly, the lamina papyracea laterally, and the middle turbinate medially[32] (see **Fig. 1.18a**). The frontal recess most commonly drains medial to the uncinate process and lateral to the middle turbinate into the middle meatus. The pattern of drainage and topography of this region is greatly affected by the anatomy of the anterior ethmoid sinuses. Of some clinical significance for Draf III or modified Lothrop procedures of the frontal sinus is the "nasofrontal beak"[43] (see **Fig. 1.18b**). This is a term used by surgeons, but it is not listed in the *Terminologia Anatomica*. It has gained acceptance among surgeons to refer to the area on sagittal CT imaging of the frontal recess.[44] It represents the beaklike structure of frontal bone that develops at the confluence of the nasal processes of the frontal bone with the nasal bones.

The agger nasi is seen as the prominence on the lateral nasal wall across from the leading edge of the middle turbinate. It is the intranasal representation of the ascending process of the maxilla externally. A majority of the time, this mound is pneumatized, giving rise to the agger nasi cell, which is the anteriormost ethmoid cell. Frequently, the frontal sinus is difficult to visualize endoscopically until the posterior and medial walls of the cell are removed. When pneumatized more posteriorly and laterally, the agger nasi cell can narrow the frontal recess and interfere with the drainage of the frontal sinus.[11]

Tips and Tricks

Frequently, the frontal sinus is difficult to visualize endoscopically until the posterior and medial walls of the cell are removed. When pneumatized more posteriorly and laterally, the agger nasi cell can narrow the frontal recess and interfere with the drainage of the frontal sinus.

The supraorbital ethmoid cell is formed by pneumatization of the horizontal portion of the frontal bone at the orbital roof from the ethmoid cells. The presence of a supraorbital ethmoid cell is occasionally recognized as a multiply septated frontal sinus in a coronal CT image. It frequently follows the contour of the orbital roof, pneumatizing laterally and superiorly over the orbit. The supraorbital ethmoid cell is easily mistaken for the frontal sinus proper; however, its drainage pathway is separate

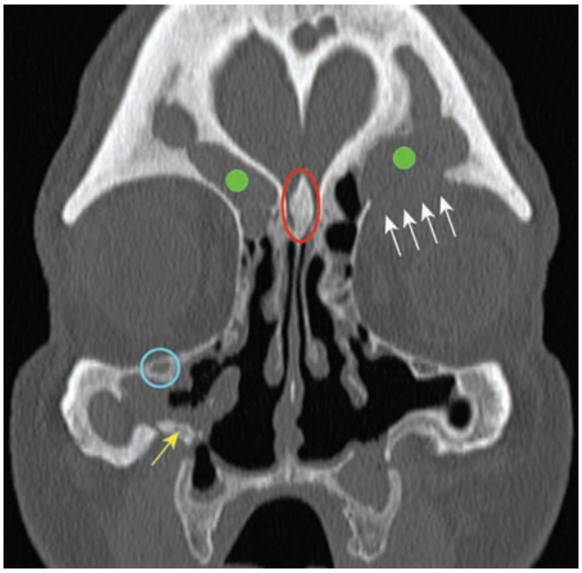

Fig. 1.21 Coronal CT scan of a patient with a history of multiple prior sinus surgeries demonstrating the appearance of supraorbital ethmoid mucoceles (*green dots*). Note the dehiscence of bone overlying the left orbit (*white arrows*) and bony disruption of the maxillary sinuses (*yellow arrows*) from prior Caldwell-Luc surgery with inferior turbinate resections. The crista galli (*red circle*), which is not pneumatized, and the infraorbital nerve (*blue circle*) are also seen.

from the frontal recess, typically posterior and lateral to it[11] (**Figs. 1.20 and 1.21**).

The blood supply to the frontal sinus is provided by the supraorbital and supratrochlear arteries that are derived from the ophthalmic artery. The innervation of the sinus is supplied by the supraorbital and supratrochlear nerves off the frontal nerve, which is a branch of the ophthalmic division of the trigeminal nerve. The venous drainage is to the superior ophthalmic vein, which in turn drains to the cavernous sinus.[3,11,16]

The mucosa of the frontal sinus has its venous drainage through small vascular pits on the cortical bone called the Breschet canal. These are mucosa-lined foramina and also mark the exit points of the diploic veins of Breschet. These veins provide direct communication between frontal sinus mucosal capillaries with the dural sinuses and the marrow cavity of the frontal bone. This communication allows frontal sinusitis to develop into osteomyelitis and intracranial infection.

Note

The diploic veins of Breschet provide direct communication between frontal sinus mucosal capillaries with the dural sinuses and the marrow cavity of the frontal bone. This communication allows frontal sinusitis to develop into osteomyelitis and intracranial infection.

Ethmoid Sinuses

The ethmoid sinuses are the keystone of the paranasal sinuses. All of the other paranasal sinuses ventilate and drain through the clefts created within the ethmoid complex. The sphenoid sinuses typically drain through the sphenoethmoid recess, the maxillary through the ethmoid infundibulum, and the frontal sinuses through the frontal recess. At the midline, the ethmoid complex is divided by the perpendicular plate of the ethmoid, which is continuous with the cribriform plate of the ethmoid superiorly. The ethmoid sinuses are located in the upper part of the lateral nasal wall just lateral to the medial wall of the orbit (lamina papyracea of the ethmoid). These sinuses display the most complex anatomy and variability of all the sinuses. The ethmoid complex are divided into multiple separate cavities called the ethmoid air cells, which arranged like honeycombs, and as a whole can be thought of as a rectangular box that is open on either end. The olfactory bulbs rest on top of the box, and the olfactory neuroepithelium lines the inner roof of the box. The ethmoid complex articulates with 15 bones: paired frontal, sphenoid, nasal, maxillary, lacrimal, palatine, and inferior turbinate bones, along with the unpaired vomer. The boundaries of the sinus are the middle and superior turbinates medially, the lamina papyracea laterally, the perforated frontal bone superiorly, and the face of the sphenoid posteriorly[32] (see **Figs. 1.3 and 1.10a**).

The length of the lateral lamella of the cribriform plate determines the height of the ethmoid cavity. It is important to recognize that the superior extent of the anterior ethmoid roof lateral to the middle turbinate can be significantly higher than the cribriform plate. The height of the ethmoid roof can also be asymmetric between the left and the right sides. Keros classified different configurations of the ethmoid roof with respect to the increasing length of the lateral lamella,[45] as seen in **Fig. 1.22.**

The divisions within the ethmoid sinus are formed by a series of parallel lamellae that are obliquely oriented. The first lamella is the uncinate process, the second is the ethmoid bulla, the third is the basal lamella of the middle turbinate, and the fourth is the lamella of the superior turbinate. As mentioned previously, the basal lamella of the middle turbinate also serves as the partition between the anterior and the posterior ethmoid sinuses.[8] The two ethmoid complexes have distinct embryologic development and mucociliary clearance patterns: the frontal, maxillary, and anterior ethmoid sinuses drain into the middle meatus, whereas the posterior ethmoid cells drain into the superior and supreme meatus. The anterior ethmoid cells are generally smaller than the posterior ethmoid cells.

The uncinate process is a sagittally oriented structure shaped like a hook that traverses anterosuperior to posteroinferior. The superior aspect of this structure most frequently attaches laterally to the lamina papyracea, but it can attach superiorly to the skull base or medially to the

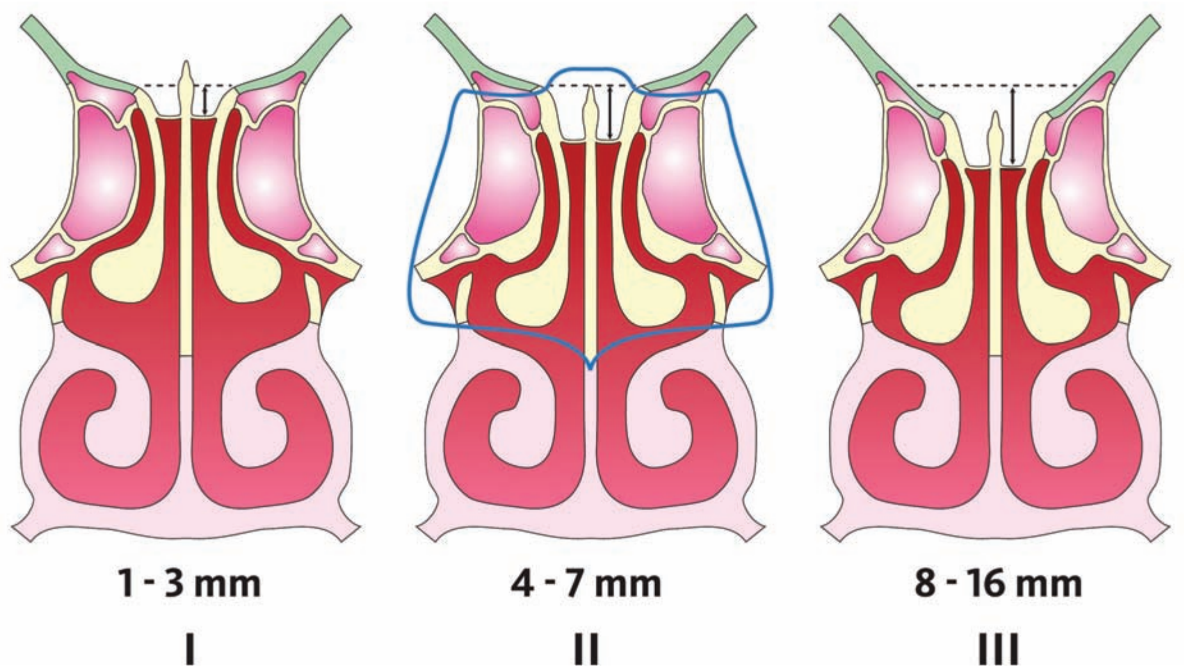

Fig. 1.22 Schematic drawing of the Keros classification that measures the depth of the olfactory fossa (horizontal portion of the cribriform plate to the height of the fovea ethmoidalis). This classification system emphasizes the potential for intracranial entry while working medial within the ethmoid at its superior extent. Note that the "roof" of the ethmoid sinuses is actually comprised of frontal bone (*green*), and the ethmoid complex (*yellow*) is highlighted by the blue circle in the central drawing.

middle turbinate[32] (**Fig. 1.23**). The uncinate has three layers: nasal mucosa, ethmoid bone, and infundibular mucosa. The position and orientation of the uncinate could vary depending on the anatomy of the maxillary sinus or disease process (see the discussion of maxillary sinus above). In a hypoplastic or atelectatic maxillary sinus, the uncinate is drawn laterally against the orbit, as in silent sinus syndrome.

The second lamella, the ethmoid bulla, is the largest and the most constant anterior ethmoid cell. It is located just posterior to the uncinate process and is based on the lamina papyracea (see **Figs. 1.14a and 1.20**). On a coronal CT image, it appears as a cell with its base on the medial wall of the orbit.

Located between the uncinate process and the ethmoid bulla is the hiatus semilunaris, which is a crescent-shaped gap between the posterior margin of the uncinate and the anterior wall of the ethmoid bulla (see **Figs. 1.14a, 1.18a, and 1.20**). It is a two-dimensional gateway that opens into the ethmoid infundibulum.[32]

The ethmoid infundibulum, on the other hand, is a three-dimensional passageway through which the secretions of the anterior ethmoid cells, the maxillary sinus, and sometimes the frontal sinus drain into the middle meatus. The boundaries of the infundibulum are the uncinate process medially, the lamina papyracea laterally, the ethmoid bulla posteriorly, and the ascending process of the maxilla and lacrimal bone anteriorly[8] (**Figs. 1.14a,b and 1.20**).

The ostiomeatal unit refers to a group of middle meatal structures rather than a specific anatomical structure. It is a functional unit formed by the uncinate process, ethmoid infundibulum, anterior ethmoid cells, and ostia of the anterior ethmoid, maxillary, and frontal sinuses. An obstruction in this area could result in disease in multiple neighboring sinuses.

The posterior ethmoid sinus lies posterior to the basal lamella of the middle turbinate. It is bounded laterally by the lamina papyracea, medially by the vertical portions of the superior and supreme turbinates, posteriorly by the face of the sphenoid sinus, and superiorly by the ethmoid roof (frontal bone). As mentioned earlier, invasion of the posterior ethmoid air cell into the sphenoid sinus results in the sphenoethmoid cells (Onodi cells).

The blood supply to the ethmoid sinus is derived from the posterior lateral nasal branches of the sphenopalatine artery. The anterior ethmoid cells receive blood supply via branches of the anterior ethmoid artery, whereas some posterior ethmoid cells are supplied by branches of the posterior ethmoid artery. The venous drainage is through the maxillary vein and the ophthalmic vein via the ethmoid veins. The innervation of the anterior ethmoid sinus is via the nasociliary branch of the ophthalmic division of the trigeminal nerve, and that of the posterior ethmoid sinus is via the posterolateral nasal branch of the sphenopalatine nerve, which is a branch of the maxillary division.[3,16]

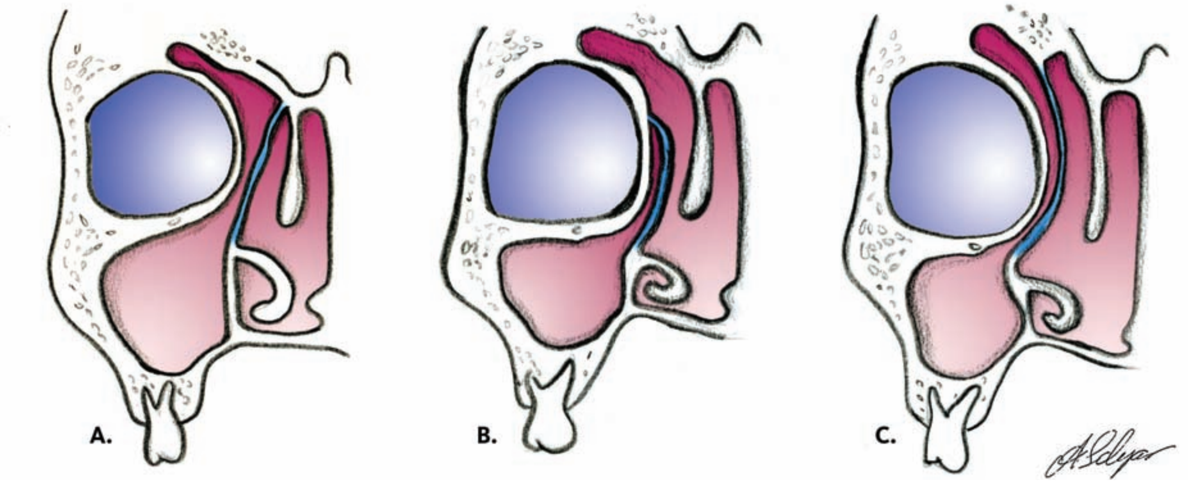

Fig. 1.23a–c Schematic coronal drawing representing variations in the superior attachments of the uncinate process of the ethmoid.
a Medially to the skull base or middle turbinate.
b Laterally to the lamina papyracea.
c Superiorly to the skull base.

Key Points

- The maxillary sinus is the first to develop, followed by the ethmoid, sphenoid, and frontal sinuses. The frontal sinuses are not present at birth and only start to appear at age 6 to 7 years.
- The internal nasal valve is the area bounded medially by the dorsal septum, inferiorly by the head of the inferior turbinate, and laterally by the upper lateral cartilage. It is the narrowest part of the nasal airway and also the segment where the airflow is the fastest.
- The Kiesselbach area is a common source of epistaxis, because it receives contributions from the anterior ethmoid, superior labial, sphenopalatine, and greater palatine arteries. Also, it is a vulnerable area for ischemia, as it is a watershed area of those arteries.
- The uncinate process is a part of the ethmoid bone, and its inferior aspect forms a significant portion of the medial wall of the maxillary sinus within the middle meatus. Its superior aspect has different attachments, but most commonly it inserts onto the lamina papyracea. Its midportion lies anterior to the bulla ethmoidalis.
- The ethmoid roof is formed by the frontal bone, and the distance between the ethmoid roof and the horizontal plate of the cribriform plate measures the depth of the olfactory fossa. Keros classification describes the varying depth and the potential for intracranial entry during work within the ethmoid sinuses.

Acknowledgments

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Review Questions

1. Which of these structures is of different embryologic origin?
  a. Superior turbinate
  b. Middle turbinate
  c. Inferior turbinate
  d. Uncinate process

2. Which of the following terms describes the suture line of the nasal and frontal bones?
  a. Nasion
  b. Glabella
  c. Radix
  d. Rhinion

3. Injury to the following structure (coronal CT image pointing to the vidian canal) during access to the lateral recess of the sphenoid sinus would result in
  a. Decrease in salivation from the parotid gland due to injury of preganglionic parasympathetic nerve fibers

b. Decrease in nasal secretion due to injury of preganglionic parasympathetic nerve fibers
c. Dry eye due to injury of postganglionic parasympathetic nerve fibers
d. Decrease in salivation from the submandibular gland due to injury of postganglionic parasympathetic nerve fibers

4. After a septoplasty, the patient complains of numbness of the hard palate behind the central incisors. Which nerve was injured?
a. Anterior ethmoid nerve
b. Nasopalatine nerve
c. Greater palatine nerve
d. Nasociliary nerve

5. A vessel is encountered during sphenoidotomy along the face of the sphenoid sinus, ~4 mm below the sphenoid ostium. Which of the following structures would be found near the origin of the vessel?
a. Crista galli
b. Breschet canal
c. Opticocarotid recess
d. Crista ethmoidalis

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Queries:

AQ1: Author, Please make sure the colors mentioned in Figure 1.3 legend still match the drawing.

AQ2: Author, Christos, would you suggest any of our illustrator’s drawings as a suitable exchange for this one?