

Surgical Anatomy of the Paranasal Sinuses

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Core Messages

- There are learned anatomical landmarks that can help surgeons perform safe endoscopic sinus surgery.
- All sinuses are lined by a respiratory pseudostratified epithelium, which is directly attached to bone and is referred to as mucoperiosteum. The middle meatus is the area that is most commonly involved in the pathophysiology of chronic rhinosinusitis.
- The sphenoethmoid recess drains the posterior ethmoid and sphenoid sinuses and is referred to as the “posterior ostiomeatal complex.”
- The tail of the superior turbinate constitutes a very important surgical landmark in the sphenoethmoid recess as it points medially toward the natural ostium of the sphenoid sinus.
- Removing the uncinate process is the first step of most endoscopic sinus surgeries.
- The posterior fontanelle can have an opening to the maxillary sinus, the accessory ostium, that could be mistaken for the natural ostium during surgery if an incomplete uncinectomy is performed.
- The most common anatomical variation in the maxillary sinus is the infraorbital ethmoid cell or Haller cell.
- During endoscopic sinus surgery, supraorbital ethmoid cells can be mistaken for the frontal sinus by inexperienced surgeons.
- The sphenoethmoid (or Onodi) cell is intimately related to the optic nerve.
- Many factors contribute to make the frontal sinus infundibulum one of the most challenging areas to access in endoscopic sinus surgery.

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Introduction

Understanding the anatomy of the paranasal sinuses is probably the most important prerequisite for endoscopic sinus surgery (ESS). As a matter of fact, most feared complications of ESS are the result of an uncontrolled maneuvering beyond the boundaries of the sinuses, mainly into the orbit or through the base of the skull. Even with the most experienced surgeons, these complications are still encountered, facilitated by some preexisting anatomical variants or pathological modifications caused by the underlying disease. Many constant landmarks have been described by different authors since ESS was first introduced in the late 1970s. These anatomical landmarks let beginners achieve a good spatial orientation when navigating within the sinuses, and help them perform the most complete sinus surgery while minimizing the risk to the patient. However, there is a definite learning curve that can make one divide ESS into increasing levels of difficulty in surgical skills, starting with the simple nasal endoscopy and ending with the most advanced frontal sinus procedures. In addition to the understanding of the anatomy, a thorough knowledge of the embryology, pathology and imaging of the sinuses is also very important for a comprehensive management of sinuses problems, but these topics are beyond the scope of this chapter.

Introduction to the Anatomy of the Paranasal Sinuses

The literature on the anatomy and physiology of the sinuses extends back to Galen (AD 130–201) who referred to the “porosity” of the bones of the head. Leonardo Da Vinci (1452–1519), whose classical sections of the head illustrate the maxillary antrum and the frontal sinus, apparently recognized the existence of these cavities as separate functional entities. He referred to the maxillary sinus as “the cavity of the bone which supports the cheek.” Highmore (1651) was the first to give a detailed description of the maxillary antrum (antrum of Highmore) [2]. However, it was only in the late nineteenth century that the first detailed and systematic anatomical and pathological descriptions of the paranasal sinuses were published by Zuckerkandl. These descriptions became even more valuable as they could be applied directly to patients and their problems. The invention of the X-ray technique did not add much to the anatomical knowledge of the sinuses, and computed tomography (CT), available since the mid-1970s, made again the relationship between the largest sinuses and the ethmoids very clear, applying the knowledge that had been developed more than 100 years ago. Comparisons of CT with the drawings of Onodi, Grunwald and Zuckerkandl demonstrate the incredible accuracy of these pioneers’ knowledge [17].

The paranasal sinuses form a complex unit of four paired air-filled cavities at the entrance of the upper airway. They start developing from ridges and furrows in the lateral nasal wall as early as the eighth week of embryogenesis, and they continue their pneumatization until early adulthood [4]. Each one is named after the skull bone in which it is located [8, 19]. However, during the development of a sinus, pneumatization may involve adjacent bones, as is the case for the ethmoid sinus developing into the frontal, maxillary or sphenoid bone, and for the maxillary sinus extending into the zygomatic bone.

All sinuses are lined by a respiratory pseudostratified epithelium, composed of four major types of cells:

1. Ciliated columnar cells
2. Nonciliated columnar cells
3. Goblet type mucous cells
4. Basal cells

This mucosa is directly attached to bone and is referred to as mucoperiosteum. Although it is somewhat thinner, the mucoperiosteum of the sinuses is continuous with that of the nasal cavity through the various ostia of the sinuses [8]. The ostium is a natural opening through which the sinus cavity drains

into the airway, either directly into the nasal cavity (i.e., sphenoid ostium), or indirectly by means of more complex anatomical structures (i.e., frontal recess). The most important progress offered by the concept of functional ESS compared with older surgical approaches to the paranasal sinuses is the acknowledgement of the essential role of the sinus ostia and mucosa in the surgical management of inflammatory disease of the paranasal sinuses. By achieving an adequate drainage around the natural ostium, the mucosal disease and subsequent symptoms could become reversible in many cases.

The Nasal Cavity

The nasal cavity is the first cavity encountered by the surgeon during ESS. Its lateral and posterior-superior walls contain the openings for the paranasal sinuses, and its posterior-inferior wall leads to the nasopharynx through the choana. The identification of the choana and its relations to the posterior nasal septum and the eustachian tube opening (torus tubarius) in the nasopharynx is very important at the beginning of every ESS (Fig. 2.1). When polyps obstruct the nasal airway in its inferomedial part, reestablishing the patency of the nasal cavity should be performed first to allow for a good visualization of the choana at any time and provide a drainage route for the blood into the nasopharynx [5].

The turbinates, or conchae, are constant ridges of the lateral nasal wall. The inferior turbinate is a separate structure deriving embryologically from the maxilloturbinal. It inserts anteriorly on the maxilla and posteriorly on the palatine bone. The other turbinates, also called ethmoid turbinates, develop from the ethmoturbinals into a common structure or conchal lamina described by Mouret in 1922. This bony plate is attached all along the junction between the ethmoid roof and the cribriform plate. All the ethmoid turbinates originate from this bony lamina: one middle turbinate and one superior turbinate that are constant, and occasionally a supreme turbinate [3].

The lateral part of the nasal cavity is thus subdivided by the turbinates into four meati (Fig. 2.2). The inferior meatus is the space between the lateral side of the inferior turbinate and the medial wall of the maxillary sinus. It contains the distal opening of the nasolacrimal duct, covered by a mucosal valve (Hasner’s valve). The middle meatus is the space lateral to the middle turbinate, and is often functionally referred to as the ostiomeatal complex [18]. It contains the drainage pathways for the anterior ethmoids, the maxillary and the frontal sinuses. The middle meatus is the area that is most commonly involved in the pathophysiology of chronic rhinosinusitis.

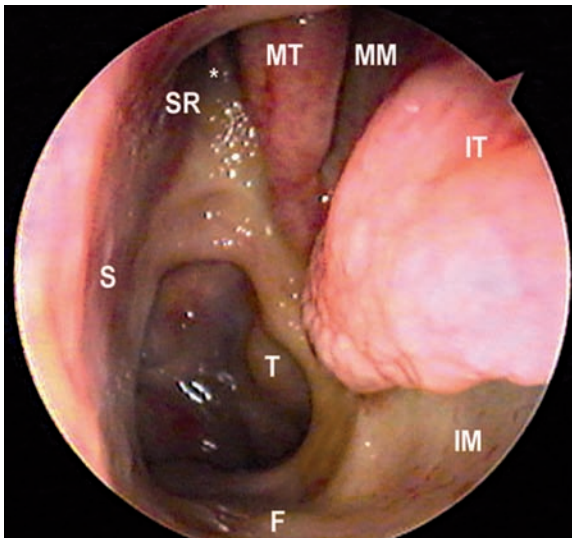


Fig. 2.1. Endoscopic view of the posterior part of a left nasal cavity showing the choana and the torus (T). Turning clockwise around the choana, the following structures and spaces can be recognized: the sphenoethmoid recess (SR), the tail of the superior turbinate (asterisk), the tail of the middle turbinate (MT), the middle meatus (MM), the tail of the inferior turbinate (IT), the inferior meatus (IM), the floor of the nose (F) and the nasal septum (S). Keeping this orientation in mind becomes more important when one or more of these structures are distorted or hidden by the disease

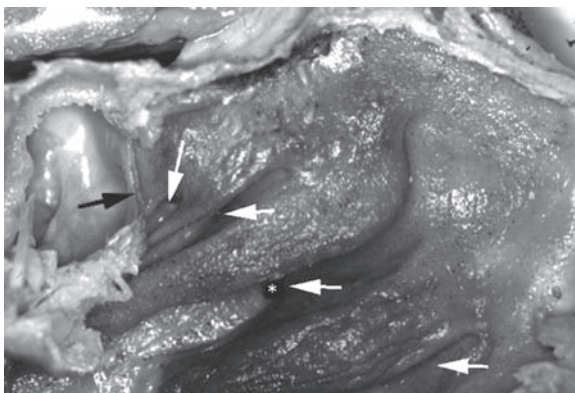


Fig. 2.2. Sagittal view of a left lateral wall of the nose showing the four turbinates. The white arrows point to the four meati. Note the accessory ostium of the maxillary sinus in the posterior fontanelle (marked by an asterisk). The black arrow points to the anterior wall of the sphenoid sinus. The middle, superior and supreme turbinates represent the third, fourth and fifth embryological lamellae. The first and second lamellae (uncinate and bulla) are hidden by the middle turbinate on this view

The middle meatus hosts from anterior to posterior the:

- Agger nasi cells
- Uncinate process
- Hiatus semilunaris
- Ethmoid bulla
- Sinus lateralis
- Posterior fontanelle

These structures will be detailed in the following paragraphs. The superior meatus is the lateral space between the superior and the middle turbinates. It drains the posterior ethmoid cells. The supreme meatus is the area above the superior turbinate, which drains the most posterior ethmoid cells.

The superior part of the nasal cavity is divided into the olfactory cleft anteriorly and the sphenoethmoid recess posteriorly. The olfactory cleft is located under the olfactory fossa between the insertion of the middle turbinate and the nasal septum. It lies just inferior to the cribriform plate. Keros (1965) described three types of olfactory fossa depending on how low the level of the cribriform plate is with relation to the roof of the ethmoids, this level being determined by the width of the lateral lamella of the cribriform plate which articulates with the roof of the ethmoids (Fig. 2.3).

The Keros classification is as follows:

- Type 1 corresponds to an olfactory fossa 1–3-mm deep in relationship to the roof of the ethmoids.
- Type 2 is 4–7-mm deep.
- Type 3 refers to a depth of 8 mm and above [18].

Recognizing the relationship between the cribriform plate, the fovea ethmoidalis and the insertions of the middle and superior turbinates is very important to avoid an inadvertent breaking into the anterior skull base, especially in the anterior ethmoid where the junction between the conchal lamina and the ethmoid roof is the least-resistant zone [10]. Posterior to the olfactory cleft, and as the roof of the nasal cavity becomes more inferior, the sphenoethmoid recess lies between the tail of the superior turbinate and the posterior-superior septum, just above the choana (Fig. 2.1) [18]. This recess drains the sphenoid sinus and the posterior ethmoids via the superior and supreme meati. Functionally, this area is referred to as the “posterior” ostiomeatal complex, in contrast to the “anterior” ostiomeatal complex in the middle meatus. The tail of the superior turbinate constitutes a very important surgical landmark in the sphenoeth-

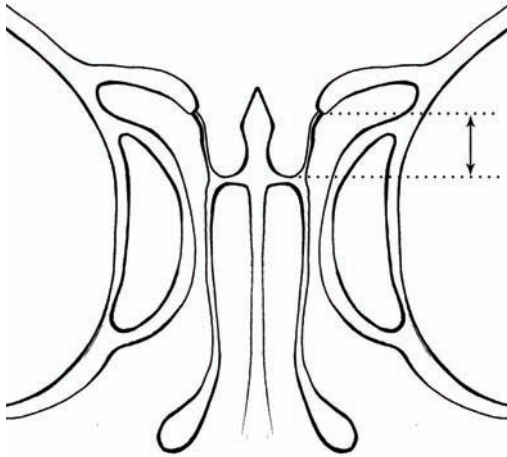


Fig. 2.3. Coronal view of the olfactory clefts and fossae, in a plane transecting the ethmoid bullae. The *arrow* measures the length of the lateral lamella of the cribriform plate, defining the type of olfactory fossa according to Keros. Note the insertion of the basal lamella of the middle turbinate on the cribriform plate, as well as the relatively thicker fovea ethmoidalis lateral to the cribriform plate. The intracranial bony spur that continues the septum corresponds to the crista galli. In most of the cases, the cribriform plate is symmetrical, however, an asymmetric skull base is an anatomical variant that should be recognized on a preoperative CT scan

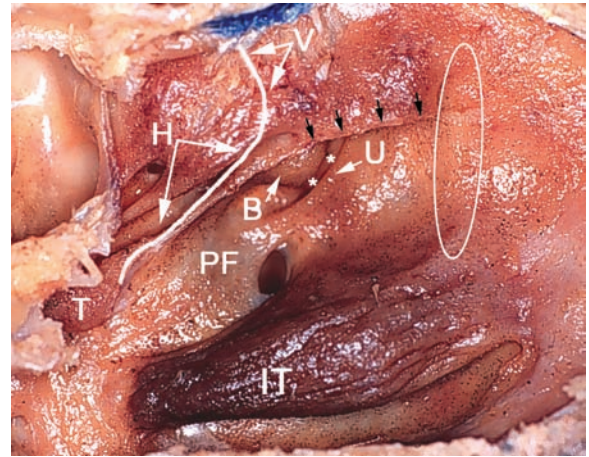


Fig. 2.4. Sagittal view of the left lateral wall of the nose after a partial middle turbinectomy exposing the contents of the middle meatus: The *black arrows* point to the resection margin anteriorly, and the *white line* draws the vertical (V) portion and the horizontal (H) portion of the basal lamella of the middle turbinate. The sagittal most anterior part of the basal lamella inserts on the anterior skull base marked in methylene blue. The uncinate process (U) and the ethmoid bulla (B) border the hiatus semilunaris marked by *asterisks*. Also note the prominence of the lacrimal bone (*circled*), the posterior fontanelle (PF) with the accessory ostium of the maxillary sinus, and the tail (T) of the middle turbinate

moid recess as it points medially toward the natural ostium of the sphenoid sinus [16].

The Uncinate Process and the Maxillary Sinus

The uncinate process is a very important surgical landmark in the lateral nasal wall for endonasal sinus surgery. Although considered part of the ethmoid labyrinth since it derives from the descending portion of the first ethmoturbinal, the uncinate process is typically discussed when addressing the maxillary sinus because of its intimate relationship with the maxillary ostium. The uncinate process is a crescent-shaped bony structure that typically projects from posteroinferior (at the palatine bone and inferior turbinate) to anterosuperior where it runs along the lateral nasal wall attaching to the ethmoid crest of the maxilla, the lacrimal bone, the skull base or the lamina papyracea. Its anterior-inferior margin has no bony attachments, and posteriorly it attaches to the ethmoid process of the inferior turbinate (Fig. 2.4) [4]. Its anterior convex part forms the anterior boundary of the (anterior) ostiomeatal complex, where the maxillary, anterior ethmoid and frontal sinuses drain. It endoscopically hides the hiatus semilunaris, which could

fairly be represented by the space between the uncinate and the ethmoid bulla. The uncinate process can be displaced medially by polypoid disease or laterally against the orbit as in maxillary sinus hypoplasia. Removing the uncinate process is the first step of most endoscopic sinus surgeries. When performing this, one must keep in mind the anterior insertion of the uncinate process in order to avoid injuries to the medial orbital wall (lamina papyracea). This step usually reveals the natural ostium of the maxillary sinus. The superior border of the maxillary sinus ostium identifies the level of the orbital floor.

The maxillary sinus is the largest and most constant of the paranasal sinuses. It is the first sinus to develop in utero. After birth, it undergoes two periods of rapid growth, between birth and 3 years of life, then between ages 7 and 18 years. The maxillary sinus has a pyramidal shape with an anterior wall corresponding to the facial surface of the maxilla. Its posterior bony wall separates it from the pterygomaxillary fossa medially and from the infratemporal fossa laterally. Its medial wall does not contain any bone; it is formed by the middle meatus mucosa, a layer of connective tissue and the sinus mucosa [19]. This is best recognized at the level of the posterior fontanelle which corresponds to the area between the tails of the middle and inferior turbinates, behind the hiatus semilunaris and under the ethmoid bulla. The poste-

rior fontanelle can have an opening to the maxillary sinus, the accessory ostium, which could be mistaken for the natural ostium during ESS if an incomplete uncinectomy is performed (Fig. 2.4). A smaller anterior fontanelle is located between the anterior part of the uncinate superiorly and the insertion of the inferior turbinate inferiorly. The floor of the maxillary sinus is formed by the alveolar process of the maxillary bone and the hard palate. It lies at the same level of the floor of the nose in children, and 5–10 mm under the floor of the nose in adults [19]. The roof of the maxillary sinus corresponds to the floor of the orbit, and frequently shows a posteroanterior bony canal for the distal part of the second branch of the trigeminal nerve. The most common anatomical variation in the maxillary sinus is the infraorbital ethmoid cell, or Haller cell; Haller cells are pneumatized ethmoid cells that project along the floor of the orbit, arising most often from the anterior ethmoids [11, 14]. They can in some cases compromise the patency of the maxillary sinus infundibulum, and in other cases can be involved in the chronic polypoid disease, which will mandate opening them. In addition to this, removing the infraorbital ethmoid cell will allow an accurate identification of the floor of the orbit and the posterior wall of the maxillary sinus, which represent reliable surgical landmarks in the presence of advanced disease or distortion of the middle meatal anatomy.

The Ethmoid Labyrinth

Located lateral to the olfactory cleft and fossa, between the lateral nasal wall and the medial orbital wall, the ethmoid sinus is the most compartmentalized paranasal sinus. At birth, only a few cells are pneumatized, but in adulthood their number can go beyond 15 cells. The frontal bone in its posterior extension covers the roof of the ethmoid sinus, forming the so-called fovea, or foveolae ethmoidales [18]. The anterior and posterior ethmoid arteries, terminal branches of the internal carotid artery via the ophthalmic artery, run along the roof of the ethmoid from lateral to medial. The width of the ethmoid increases from anterior to posterior because of the conelike structure of the orbit.

The ethmoid sinus is referred to as the ethmoid labyrinth because of the complexity of its anatomy, due to the honeycomb-like appearance of its air cells with intricate passageways and blind alleys. Rhinologists have tried to simplify its difficult anatomy by considering the sinus as a series of five obliquely oriented parallel lamellae. These derive from the ridges in the lateral nasal wall of the fetus called ethmoturbinals [4, 15]. The lamellae are relatively constant

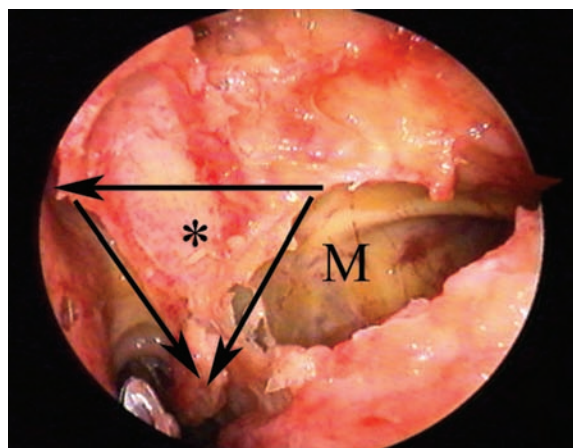


Fig. 2.5. Triangular zone of safe entry (asterisk) into the inferior-posterior ethmoid air cells through the basal lamella of the middle turbinate. The base of the triangle corresponds to a horizontal line drawn from the medial floor of the orbit (posteriorly) to the nasal septum. The other two lines correspond to the cut edge of the middle turbinate lamella and the vertical ridge (cut edge of the posterior fontanelle) of the middle meatal maxillary sinusotomy (M)

and easy to recognize intraoperatively. The first and most anterior lamella corresponds to the uncinate process, which embryologically represents the basal lamella of the first ethmoturbinal. The second lamella is the ethmoid bulla, or bulla ethmoidalis as first referred to by Zuckerkandl, the largest and most constant anterior ethmoid cell [14]. It has a round shape with thin walls, extending from the lamina papyracea laterally and bulging into the middle meatus medially (Fig. 2.3). Rarely, when nonpneumatized, a bony projection from the lamina papyracea results and is referred to as the torus lateralis. The most important lamella is the third one, the ground or basal lamella of the middle turbinate, not only defining the anatomical separation between the anterior and the posterior ethmoid cells, but also creating a bony septation that dictates the drainage pattern of the ethmoid cells into the middle meatus (for the anterior ethmoid cells) and the superior and supreme meati (for the posterior ethmoid cells). It thus represents the surgical posterior limit for an anterior ethmoidectomy. Its S-shaped insertion with a sagittal anterior third and a vertical middle third gives the middle turbinate its mechanical stability, and its posterior horizontal part at the level of the tail of the middle turbinate represents the most straightforward way for entry into the posterior ethmoids (Figs. 2.4, 2.5). The fourth lamella is the basal lamella of the superior turbinate and the fifth is the basal lamella of the supreme turbinate [4, 15].

Besides the bony lamellae, particular groups of ethmoid cells have been identified, and recognizing them helps understanding the pathophysiology and spread

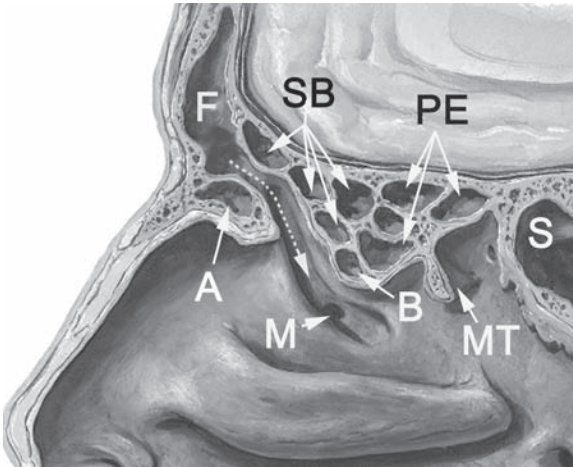


Fig. 2.6. Parasagittal view of a right frontal recess. The aggr nasi (A) and suprabullar (SB) cells are, respectively, the anterior and posterior boundaries of the frontal recess (*dotted arrow*). The anterior portion of the middle turbinate, missing on this view, represents its medial limit. Note the frontal sinus (F), the ethmoid bulla (B), the posterior ethmoid cells (PE) and their relation to the tail of the middle turbinate (MT), the sphenoid sinus (S) and the natural ostium of the maxillary sinus (M).

of sinus disease, as well as performing the most complete ethmoid surgery with the least surgical complications. The aggr nasi cells are the most anterior ethmoid cells, and are endoscopically visualized as a prominence anterior to the insertion of the middle turbinate. From Latin, *aggr* means mound or eminence, and aggr nasi refers to the pneumatized superior remnant of the first ethmoturbinal which persists as a mound anterior and superior to the insertion of the middle turbinate. Rarely, the pneumatization can extend inferiorly to involve the anterosuperior part of the uncinate process, which as described previously derives from the descending portion of the first ethmoturbinal. The aggr nasi pneumatization can also have a significant impact on the uncinate process insertion, as well as on the patency of the frontal recess (Fig. 2.6) [15, 18]. Accurate identification of the aggr nasi is the key to the surgical access to the frontal recess [20].

The middle turbinate can sometimes be pneumatized, resulting in a concha bullosa with a pneumatization usually originating from the frontal recess or the aggr nasi. The concha bullosa is a normal variant that in itself does not require surgery; however, extensive pneumatization may narrow the ostiomeatal complex and contribute to sinus disease [9]. Conchal cells are ethmoid air cells that invade the middle turbinate in its anterior aspect, whereas interlamellar cells, originally described by Grunwald, arise from pneumatization of the vertical lamella of the middle turbinate from the superior meatus [18].

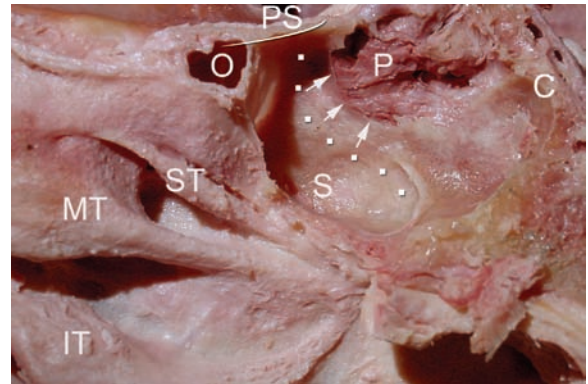


Fig. 2.7. Sagittal view of a right lateral wall of the nose showing the sphenoid sinus and the pituitary gland (P). The arrows point to the sphenoid side of the floor of the sella turcica, separating the planum sphenoidale (PS) anteriorly from the clivus (C) posteriorly. The right carotid artery prominence is marked with a *dotted line*. A right Onodi cell (O) hides the optic nerve prominence, and the direction of the right optic nerve is represented by a *plain line*. Note the relationship of the tail of the superior turbinate (ST) with the ostium of the sphenoid sinus

The supraorbital ethmoid cells (also referred to as suprabullar cells) are anterior ethmoid cells that arise immediately behind the frontal recess and extend over the orbit through pneumatization of the orbital plate of the frontal bone. They can compromise posteriorly the frontal sinus drainage, in a similar way as the aggr nasi anteriorly (Fig. 2.6). During ESS, supraorbital cells can be mistaken for the frontal sinus by inexperienced surgeons. Transillumination of these cells with a telescope reveals the light in the inner canthal area, rather than the supraorbital area when the frontal sinus is transilluminated [14].

The sphenoethmoid cells, or Onodi cells, are another important group of ethmoid cells, with reference to Adolf Onodi from Budapest who studied the relationship of the ethmoid and the optic nerve [11, 17]. In this case, the posterior ethmoid cells extend superiorly or laterally to the sphenoid sinus, and the pneumatization can reach the posterior clinoid process. The sphenoethmoid cell is intimately related to the optic nerve, whether the latter is prominent or not in its lateral wall (Fig. 2.7). Also, if large enough, the carotid artery can bulge through its posterior wall. Thus, attempts to open the sphenoid through a sphenoethmoid cell can result in serious damage to the optic nerve or the carotid artery. These important structures are usually related to the lateral wall of the sphenoid sinus; however, accurate identification of these structures and possibly Onodi cells on a preoperative CT scan is the best way to avoid such severe complications.

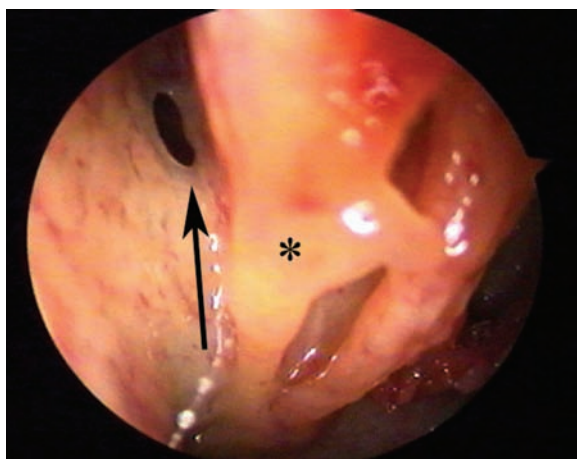


Fig. 2.8. Tail of the superior turbinate as a sphenoid ostium. The sphenoid ostium is found superomedial (arrow) to the tail of the superior turbinate (asterisk)

The Sphenoid Sinus

The sphenoid sinuses are located at the skull base at the junction of the anterior and middle cerebral fossae. Their growth starts between the third and fourth months of fetal development, as an invagination of the nasal mucosa into the posterior portion of the cartilaginous nasal capsule. Between birth and 3 years of age, the sphenoid is primarily a pit in the sphenothmoid recess. Pneumatization of the sphenoid bone starts at age three, extends toward the sella turcica by age seven, and reaches its final form in the mid-teens [15, 19]. The two sinuses generally develop asymmetrically, separated by the intersinus bony septum. In some cases, because of this asymmetry, the intersinus septum goes off the midline and can have a posterior insertion on the bony carotid canal, in the lateral wall of the sphenoid [16]. For this reason, care must be taken when removing the septum in these cases, as a brisk avulsion may result in carotid rupture. Pneumatization of the sphenoids can invade the anterior and the posterior clinoid processes as well as the posterior part of the nasal septum, the Vomer. The sphenoid sinus drains through a single ostium into the sphenothmoid recess: this ostium is classically situated 7 cm from the base of the columella at an angle of 30° with the floor of the nose in a parasagittal plane, and this usually corresponds to a location halfway up the anterior wall of the sinus. Endoscopically, the posteroinferior end of the superior turbinate points superiorly and medially toward the ostium and thus represents a very important landmark to identify it (Fig. 2.8). When polypoid changes are present distorting the normal anatomy, the ostium can be located adjacent to the nasal septum, at the level of the posterior orbital floor seen through the middle meatal sinusot-

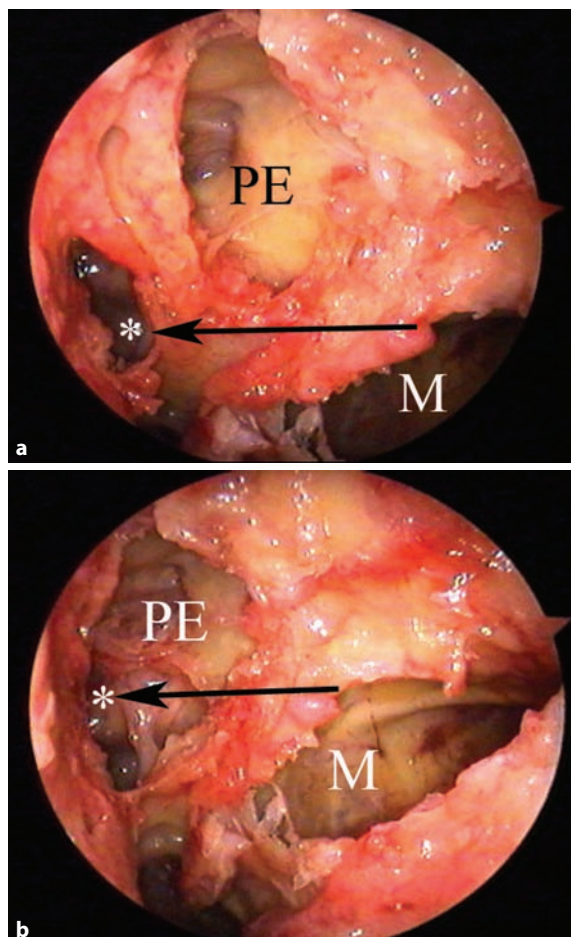


Fig. 2.9. **a** Anatomic landmarks for a sphenoid sinusotomy. In advanced disease the sphenoid (asterisk) is safely entered at the level of the posterior orbital floor (arrow), approximately 7 cm from the anterior columella, and adjacent to the nasal septum. This also corresponds to the level of the sphenoid natural ostium. **b** Completed sphenoidotomy. Endoscopically, most of the posterior ethmoid cavity (PE) is located superior to a line drawn at the level of the posterior orbital floor. By contrast, the sphenoid sinus (asterisk) and the maxillary sinus (M) are below this line

omy, usually within 10–12 mm from the superior arch of the choana, and approximately 7 cm from the columella [5, 12] (Fig. 2.9).

The superior wall of the sphenoid sinus usually represents the floor of the sella turcica (Fig. 2.7).

Depending on the extent of pneumatization, the sphenoid sinus can be classified into three types:

1. *Conchal*: the area below the sella is a solid block of bone without pneumatization.
2. *Presellar*: the sphenoid is pneumatized to the level of the frontal plane of the sella and not beyond.
3. *Sellar*: the most common type, where pneumatization extends into the body of the sphenoid beyond

the floor of the sella, reaching sometimes the clivus [6, 16].

The lateral wall of the sphenoid sinus can show various prominences, the most important being the carotid canal and the optic canal: the internal carotid artery is the most medial structure in the cavernous sinus, and rests against the lateral surface of the sphenoid bone. Its prominence within the sphenoid varies from a focal bulge to a serpiginous elevation marking the full course of the intracavernous portion of the carotid artery from posteroinferior to posterosuperior (Fig. 2.10). In some cases, even without advanced sinus disease, dehiscence in the bony margin can be present, and this should be particularly looked for on the CT scan [16].

The optic canal is found in the posterosuperior angle between the lateral, posterior and superior walls of the sinus, horizontally crossing the carotid canal from lateral to medial (Fig. 2.10). Pneumatization of the sphenoid above and below the optic canal can result, respectively, in a supraoptic recess and an infraoptic recess (the opticocarotid recess). The infraoptic recess lies between the optic nerve superiorly and the carotid canal inferiorly, and can sometimes pneumatize the anterior clinoid process [15].

The canals of two other nerves can be encountered in the lateral wall of the sphenoid sinus, below the level of the carotid canal:

- The second branch of the trigeminal nerve superiorly through the foramen rotundum
- The vidian nerve in the pterygoid canal inferiorly (Fig. 2.10).

In some cases, these nerves are easily identified on a coronal CT scan defining the superior and the inferior borders of the entry into the so-called lateral recess in an extensively pneumatized sphenoid sinus.

The Frontal Sinus

The frontal sinus is intimately related to the anterior ethmoid in both its embryology and its anatomy. It has been suggested that the frontal sinus develops from an upward extension of the anterior ethmoid cells into the most inferior aspect of the frontal bone between its two tables. However, Stammberger considers that the frontal sinus develops from the frontal recess, which is embryologically the superior continuation of the groove between the first ethmoturbinal (aggr nasi and uncinate process) and the second ethmoturbinal (bullae ethmoidalis). At birth, the fron-

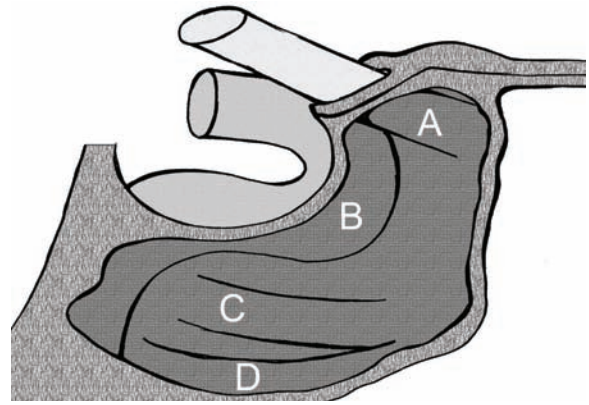


Fig. 2.10. Simplified drawing of a lateral wall of the left sphenoid sinus. The optic canal (A) runs from anterolateral to posteromedial in the most superior aspect of the lateral wall. The carotid prominence (B) is usually seen at the junction of the posterior and lateral walls. Note the supraoptic recess (above A) and the infraoptic or opticocarotid recess (between A and B). The canals for the second branch of the trigeminal nerve (C) and the vidian nerve (D) can sometimes be endoscopically identified, and define the superior and inferior boundaries for the lateral recess (between C and D) in a very pneumatized sphenoid

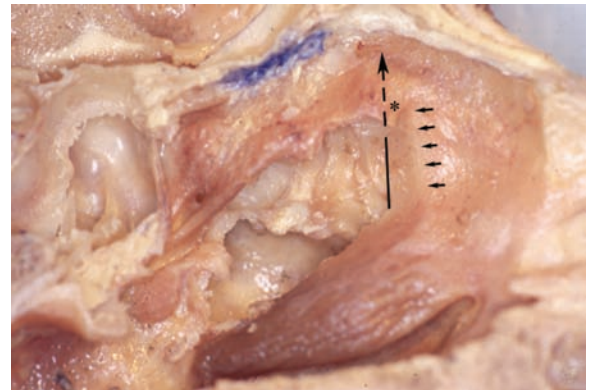


Fig. 2.11. Frontal sinus orientation. The correct trajectory into the frontal sinus is along a line (dotted line) parallel to the convexity of the nasolacrimal apparatus (small arrows), starting at the maxillary natural ostium area, and extending several millimeters behind the anterior attachment of the middle turbinate (asterisk)

tal sinus is a small blind pouch often indistinguishable from the anterior ethmoid cells. Starting around 2 years of age, pneumatization of the frontal sinus will become significant in early adolescence, and complete in the late teens. The right and left frontal sinuses develop independently, and are often asymmetrical. As with the sphenoid sinus, it is not uncommon to find one “dominant” frontal sinus, one or two hypoplastic

frontal sinuses, one aplastic frontal sinus, and more rarely bilaterally aplastic sinuses [7].

The frontal sinus lies within the frontal bone between a thick anterior table and a relatively thin posterior table, separating the sinus from the frontal lobe of the brain posteriorly. It has classically been described as a pyramid: its medial wall corresponds to a bony septum, the intersinus septum, which can sometimes be pneumatized, forming an intersinus cell. The floor of the frontal sinus corresponds to the anterior roof of the orbit, and the thin bone at this level, in a similar way as the posterior table, can be eroded by a mucocele [7].

The frontal sinus drainage pathway has an hourglass shape, and opens in the nose at the level of the frontal recess (Fig. 2.6). The narrowest point of this tract is called the frontal infundibulum or ostium, and is located at the most inferomedial aspect of the sinus.

The frontal ostium is bounded by:

- The roof of the agger nasi anteroinferiorly
- The roof of the bulla ethmoidalis or suprabullar cells posteriorly
- The lamina papyracea laterally
- The lamella of the middle turbinate anteriorly

If the bulla ethmoidalis does not have an anterior insertion on the skull base, the frontal recess communicates with the suprabullar recess [20], and depending on the anterior insertion of the uncinate process, the frontal recess will drain medial or anterior to the uncinate (when it inserts on the lamina papyracea) and lateral or posterior to the uncinate into the anterior ethmoid (when the uncinate inserts on the skull base or on the middle turbinate) [13].

Besides the different anterior ethmoid cell groups that could be related to the frontal infundibulum, other cells can originate from the frontal recess and, when present, are called the frontal infundibular cells.

Bent and Kuhn classified the frontal cells into four types:

1. Type 1 is a single air cell above the agger nasi.
2. Type 2 is a group of small cells above the agger nasi but below the orbital roof.
3. Type 3 is a single cell extending from the agger nasi into the frontal sinus.
4. Type 4 is an isolated cell within the frontal sinus not contiguous with the agger nasi [1].

Many factors contribute to make the frontal sinus infundibulum one of the most challenging areas to access in ESS: the small diameter, the anterior location

and orientation within the frontal bone, as well as the anatomical relationship with the orbit, the skull base and the different groups of cells make the endoscopic anatomy very difficult to understand. The keys to achieving a good and safe visualization of the frontal sinus are opening the agger nasi cells and palpating with a probe to identify the posterior wall of the frontal sinus away and in front of the anterior ethmoid artery. The roof of the suprabullar and agger nasi cells should be down-fractured and removed carefully to visualize the infundibulum (Fig. 2.6). The trajectory for entry into the frontal infundibulum should be in the direction of a line drawn parallel to the convexity of the lacrimal bone, a few millimeters behind the anterior attachment of the middle turbinate, starting at the coronal plane of the natural ostium of the maxillary sinus [5] (Fig. 2.11).

Conclusion

The anatomy of the paranasal sinuses, despite its obvious complexity, can be comprehensively understood by subdividing the sinuses into different groups similar in their embryology and function. Even with the most sophisticated radiological techniques and surgical navigation tools, the safety of endoscopic sinus surgery still depends to a great extent on the surgeon's knowledge and experience. The preoperative imaging, mandatory before any ESS, helps the surgeon to recognize anatomical and pathological variants, in order to reduce the risk of complications while achieving an adequate surgery.

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