Radiology

The Preoperative Sinus CT: Avoiding a "CLOSE" Call with Surgical Complications[1]

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Although functional endoscopic sinus surgery is an effective means of treating patients with recurrent and refractory sinusitis, the procedure is not without risk of serious surgical complications. Preoperative computed tomography (CT) affords radiologists the opportunity to prospectively identify anatomic variants that predispose patients to major surgical complications; however, these critical variants are not consistently evaluated or documented on preoperative imaging reports. The purpose of this review is to illustrate important anatomic variants and landmarks on the preoperative sinus CT with a focus on those that predispose patients to surgical complications. These critical variants and landmarks can be quickly recalled and incorporated into the preoperative imaging report through the use of the mnemonic "CLOSE": Cribriform plate, Lamina papyracea, Onodi cell, Sphenoid sinus pneumatization, and (anterior) Ethmoidal artery. This approach will greatly enhance the value of the preoperative imaging report for referring otolaryngologists and help reduce the risk of surgical complications.

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Paranasal sinusitis is a common clinical condition that affects approximately 16% of adults in the United States each year (1). The disease has adverse impacts on both the quality of life for afflicted patients, as well as a substantial socioeconomic burden due to costs associated with medical care, decreased productivity, and absences from work or school (2). Acute uncomplicated sinusitis is a clinical diagnosis that is often successfully treated medically with antibiotic therapy. For patients with recurrent or refractory sinusitis, however, surgical intervention may be necessary to restore patency of sinus drainage pathways. The surgical procedures for treating sinusitis have evolved throughout the years to the minimally invasive endoscopic surgeries used in modern day practice. These procedures, although less invasive, are not without risk of complications, which may be serious, life threatening, or even fatal. Preoperative computed tomography (CT) imaging has become a mainstay in surgical planning prior to endoscopic surgery and affords the opportunity to identify anatomic variants that predispose patients to surgical complications. These critical areas, however, are not routinely or consistently documented in the preoperative imaging report. This review article will highlight and illustrate common anatomic variants of the paranasal sinuses with an emphasis on those that place patients at risk for surgical complications by utilizing the mnemonic "CLOSE": Cribriform plate, Lamina papyracea, Onodi cell, Sphenoid sinus pneumatization, and (anterior) Ethmoidal artery (Table , Movie [online]) (3). This mnemonic-based approach provides a simple means of recalling critical variants to review and document in the preoperative imaging report.

Components of the "CLOSE" Mnemonic

Critical Anatomic Structure	Ideal Imaging Plane	Items to Evaluate and Document/Report
Cribriform plate	Coronal	Keros classification (type I–III) Asymmetric Keros Bony dehiscence of skull base
Lamina papyracea	Coronal, axial	Remote orbital fracture Orbital prolapse into ethmoid sinus Presence of Haller cell Uncinate process contacting orbital wall
Onodi cell	Coronal	Presence or absence of Onodi cell Dehiscence of optic nerve within Onodi cell
Sphenoid sinus pneumatization	Sagittal, axial	Pneumatization pattern (conchal, presellar, sellar) Pneumatization into skull base & anterior clinoid Dehiscence of carotid canal Sinus septation inserting onto carotid canal Optic nerve dehiscence within sphenoid sinus
(Anterior) ethmoidal artery	Coronal	Identify ethmoidal notch Presence of supraorbital pneumatization

Source.—Modified from reference 3.

Essentials

- Evaluation of the cribriform plate includes assessment for bone integrity and measurement of the olfactory depths on each side.
- When evaluating the lamina papyracea, it is important to comment on remote medial orbital wall fractures, as well as the presence of Haller cells or uncinate process deviation.
- An Onodi cell refers to a sphenoethmoidal air cell above and lateral to the sphenoid sinus, placing the optic nerves at risk for intraoperative injury.
- Excessive sphenoid sinus pneumatization may result in dehiscence of the cavernous segments of the internal carotids arteries and/or optic nerves.
- The anterior ethmoidal arteries are susceptible to intraoperative injury with supraorbital pneumatization of ethmoid air cells above the anterior ethmoidal notch.

Overview of Paranasal Sinus Anatomy

The paranasal sinuses consist of paired frontal, ethmoid, maxillary, and sphenoid sinuses. The frontal sinuses are located superior to the orbits and ethmoid sinuses. Both the superior and posterior walls of the frontal sinus separate the sinus from the cranial vault. The floor of the frontal sinus consists of the orbital roof. The ethmoid sinuses are composed of multiple air cells and are located medial to the orbits, inferior to the frontal sinuses, and anterior to the sphenoid sinuses. The roof of the ethmoid sinus (fovea ethmoidalis) separates the ethmoid sinus from the anterior cranial fossa. The medial margins consist of the middle turbinates and lateral lamella, while the lateral margins are delineated by the medial orbital walls. The maxillary sinuses are located inferior to the orbits, with the orbital floor representing the roof of the maxillary sinus. Medially, the maxillary sinus extends to the lateral wall of the nasal cavity. Inferiorly, the maxillary sinus typically pneumatizes to the level of the maxillary dentition. The posterior wall of the maxillary sinus constitutes the anterior margin of the pterygopalatine

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Abbreviations:
FESS = functional endoscopic sinus surgery
OMC = ostiomeatal complex

Conflicts of interest are listed at the end of this article.

Figure 1

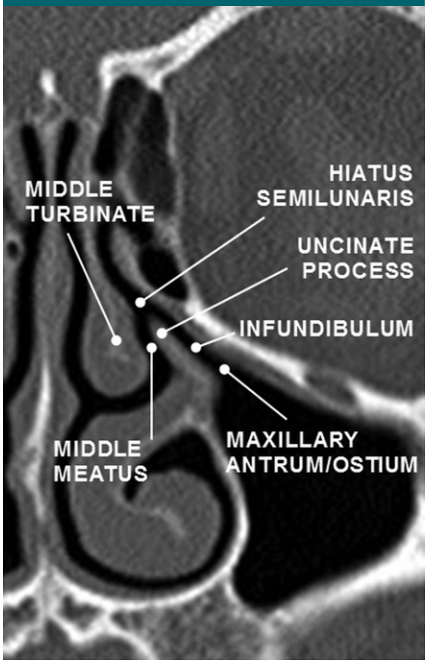


Figure 1: Coronal reformatted CT image demonstrates the normal anatomy of the OMC. The margins of the uncinate process, middle turbinate, and orbital walls delineate the sinus drainage pathway, which comprises the maxillary antrum (ostium), infundibulum, hiatus semilunaris, and middle meatus.

Figure 2

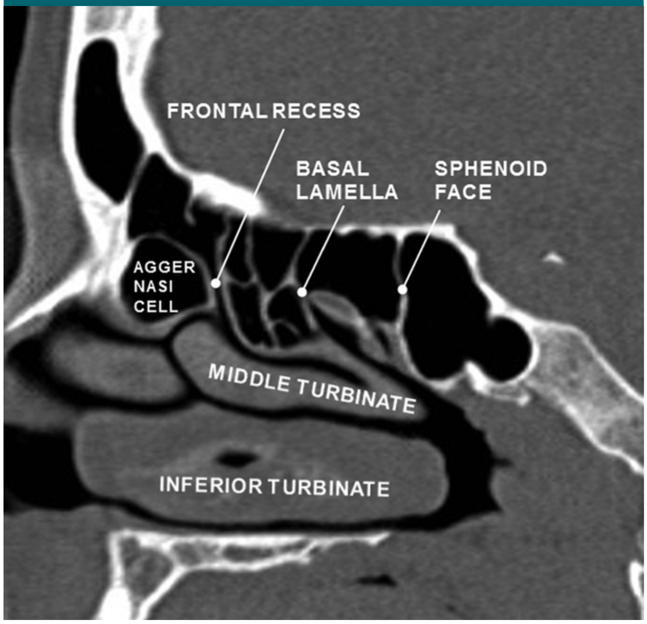


Figure 2: Frontal sinus outflow tract. Sagittal reformatted CT image shows the normal frontal recess, which is located posterior to the agger nasi cell. The basal lamella separates the anterior and posterior ethmoid sinus.

fossa. The sphenoid sinuses are located within the sphenoid bone posterior to the ethmoid sinuses. Depending on the degree of pneumatization, the roof, posterior walls, and lateral walls of the sphenoid sinus separate the sinus from the cranial vault. The anterior wall is shared with the posterior wall of the ethmoid sinus.

The primary drainage pathways for the paranasal sinuses consist of the ostiomeatal complex (OMC) anteriorly and the sphenoethmoidal recess posteriorly. The OMC is the final drainage pathway for the frontal, anterior ethmoid, and maxillary sinuses, while the sphenoethmoidal recess is the final drainage pathway for the posterior ethmoid and sphenoid sinuses.

Functional Endoscopic Sinus Surgery

The introduction of endoscopic surgical techniques during the 1980s drastically changed the treatment for patients with recurrent or refractory rhinosinusitis. More invasive external-approach procedures were replaced with functional endoscopic sinus surgery (FESS), which is now the standard of care for relieving obstructions associated with paranasal sinus drainage pathways (4–6). The goal of FESS in the setting of recurrent or refractory rhinosinusitis is to open the normal paranasal sinus drainage pathways by alleviating anatomic or pathologic obstructions. The clinical efficacy of FESS has been well established, with postoperative improvement in symptoms and quality of life reported in more than 75% of patients (7–9).

The principal target of FESS is the OMC, which is the primary drainage pathway for the maxillary, anterior ethmoid, and frontal sinuses. The bony margins of the OMC include the uncinate process, lateral margin of the middle turbinate, and the medial and inferior walls of the orbit. The bony margins delineate air channels or drainage pathways, including the maxillary antrum, infundibulum, hiatus semilunaris, and middle meatus, which are best evaluated on coronal CT images (Fig 1). An additional important sinus drainage pathway that may be targeted with FESS is the frontal recess, which is best evaluated on sagittal reformatted CT images and is located along the posterior margin of the agger nasi cell (most anterior ethmoid air cell) or other variants of frontal recess cells, when present (Fig 2) (10). The frontal recess drains into the infundibulum or middle meatus, depending on the anterior attachment site of the uncinate process (11).

Several common anatomic variants may adversely affect the OMC and frontal recess in some patients, resulting in a predisposition to recurrent or refractory rhinosinusitis secondary to sinus outflow narrowing and/or alteration of sinus ventilation and mucociliary clearance. In addition, these variants alter the surgical landscape in the region of the sinus outflow tracts. The anatomic variants that affect the OMC include the Haller cell, concha bullosa, paradoxical rotation of the middle turbinate, and nasal septal deviation, while prominent or variant frontal recess cells affect the frontal recess. Anatomic anomalies that

Figure 3

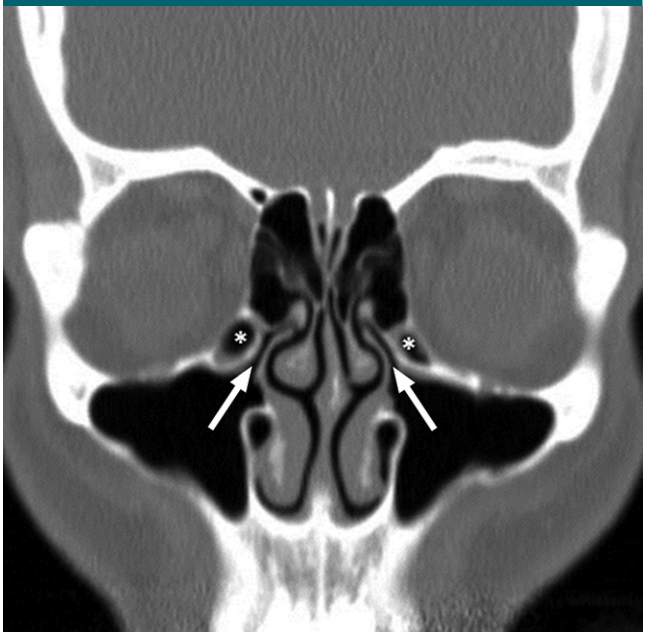


Figure 3: Coronal reformatted CT image depicts bilateral ethmoid air cells along the inferomedial orbital walls, consistent with Haller cells (*). There is associated narrowing of the infundibula bilaterally (arrows).

Figure 4

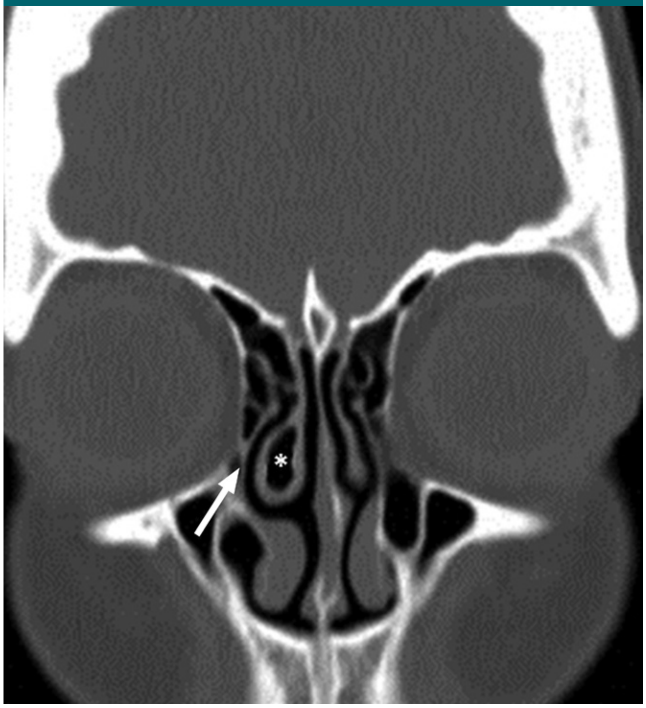


Figure 4: Coronal reformatted CT image demonstrates pneumatization of the right middle turbinate, consistent with a concha bullosa (*). There is lateral deviation of the posteromedial wall of the nasolacrimal duct and uncinate process, resulting in narrowing of the infundibulum (arrow).

narrow the OMC tend to contribute to recurrent acute sinusitis or limited chronic rhinosinusitis (12,13). Diffuse chronic rhinosinusitis, on the other hand, is more often related to inflammatory dysregulation as opposed to anatomic anomalies (13).

A Haller cell represents an ethmoid air cell that is located lateral to the maxillo-ethmoidal suture along the medial orbital floor (orbital surface of the maxillary bone), which may result in narrowing of the maxillary antrum and proximal infundibulum (Fig 3). Concha bullosa refers to pneumatization of the middle turbinate. When large, it may narrow the middle meatus and cause lateral deviation of the uncinate process, with resultant narrowing of the infundibulum (Fig 4). Occasionally, concha bullosa may be affected by inflammatory sinus disease and become opacified. With normal development, the middle and inferior turbinates both rotate outward. In the setting of paradoxical rotation, however, the middle turbinates rotate inward, which may result in narrowing of the middle meatus and potential lateral deviation of the uncinate process, with infundibular narrowing (Fig 5). Occasionally, pronounced nasal septal deviation with spurring may affect the sinus outflow pathways secondary to lateral displacement of the middle turbinate, with narrowing of the middle meatus.

Often times, these anatomic variants are incidental findings in patients with minimal or no sinus disease. In some patients, however, a combination of sinus outflow narrowing and alterations of normal airflow and mucous clearing associated with these variants may lead to recurrent or refractory sinusitis (12,13).

The agger nasi cell is a named frontal recess cell that represents the most anterior ethmoid air cell. It is present and pneumatized in the majority of patients and forms a portion of the anterior boundary of the frontal recess. Frontal cells are additional subsets of frontal recess cells, which like the agger nasi cell, comprise a portion of the anterior margin of the frontal recess. Frontal cells associated with the frontal recess are categorized into one of three types: type 1 cells are single cells above the agger nasi cell, type 2 cells consist of two or more small cells above the agger nasi cell, and type 3 cells refer to a large cell above the agger nasi cell with extension into the frontal sinus. Type 4 cells are rare frontoethmoidal cells that are entirely contained within the frontal sinus (10). Frontal cells are identified in roughly 20%–30% of patients undergoing initial FESS (14,15).

During FESS, an endoscope is placed into the nasal cavity through the nostril and advanced to the region of the OMC. Depending on the clinical scenario and anatomic configuration of the paranasal sinuses, FESS often includes uncinectomy and maxillary antrostomy with opening of the maxillary antrum and infundibulum, as well as any of the following additional procedures: turbinectomy and/

Figure 5

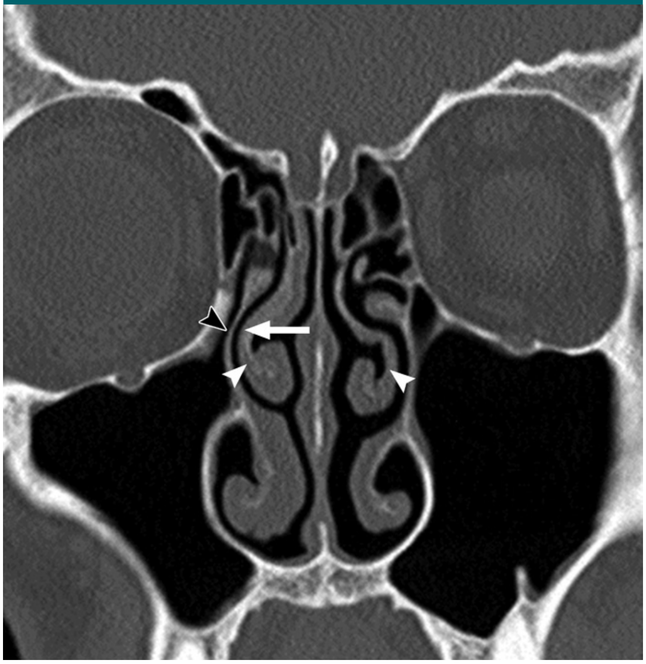


Figure 5: Coronal reformatted CT image demonstrates inward rather than outward rotation of the middle turbinates bilaterally, consistent with paradoxical rotation (white arrowheads annotate the middle turbinates). There is narrowing of the middle meatus (arrow) and infundibulum (black arrowhead) on the right.

or turbinoplasty, ethmoidectomy, and frontal sinusotomy/drillout (Fig 6). Precision is a necessity during FESS, since there is close proximity and variant anatomic relationships between critical structures. As a result, more extensive surgery is often associated with an increased risk of surgical complications.

Surgical complications associated with FESS are typically characterized as major or minor. Major complications include arterial vascular injury, optic nerve injury, orbital hematoma, cerebrospinal fluid leak, and nasolacrimal duct injury. When originally pioneered during the 1980s, major complication rates of FESS were reported in as many of 8% of cases (16). As surgeons obtained more experience with the procedure, however, major complication rates decreased substantially over the years. Additionally, the routine use of preoperative CT and intraoperative image guidance has resulted in improvement in both surgical outcomes and complications. More recent studies report a major complication rate of approximately 0.36%–1.3% (17–22). Complication rates are slightly higher for patients with prior FESS undergoing revision surgery (19).

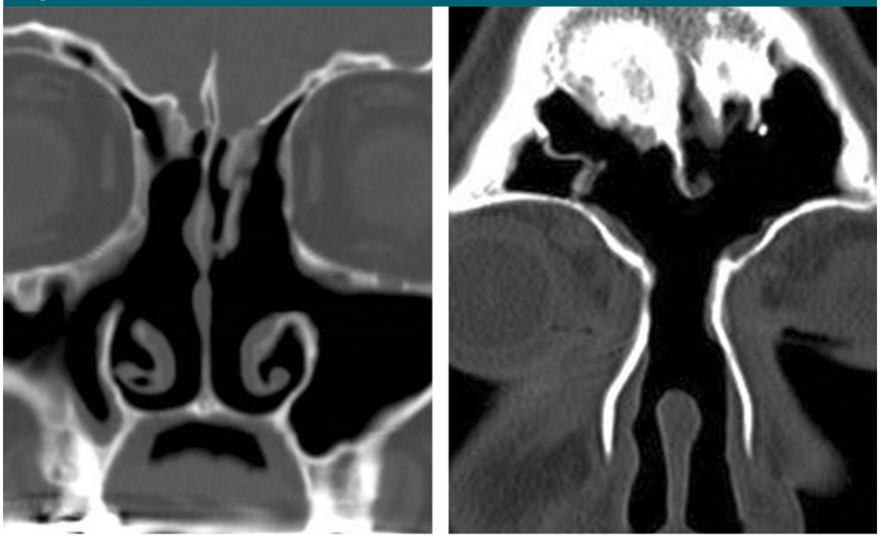
Preoperative Imaging

CT imaging of the paranasal sinuses has become standard of care for preoperative planning. Helical CT allows for rapid acquisition and multiplanar reformations, as opposed to direct coronal imaging that had been performed in years past. Utilization and review of multiplanar reformations has been shown to affect surgical planning in more than half of cases (23). Unenhanced axial images are typically obtained at 0.625-mm intervals, with reformatted images in the coronal and sagittal planes obtained at 1–2-mm intervals. Both high-resolution bone and soft-tissue algorithms should be obtained in all three imaging planes. With the advent and regular use of image guidance for intraoperative surgical anatomic verification, images are recommended to be stored in a format that is accepted by these systems when dedicated preoperative imaging is performed. Image guidance systems allow the surgeon to visualize CT images in all three imaging planes during FESS. Although specifications may vary slightly among the different vendors and systems available, imaging parameters for preoperative image-guidance studies include no gantry tilt; reformats in all three planes at 2 mm or less (1 mm is typically used); and inclusion of the ears, entire maxilla, tip of the nose, chin, and frontal sinuses.

Imaging is useful in evaluating the extent of disease, identifying anatomic variants that narrow or obstruct sinus outflow tracts, evaluating for anatomic variants that predispose patients to surgical complications, and for image-guidance during FESS. Most important, the preoperative imaging examination affords the radiologist an opportunity to identify danger areas for the otolaryngologist prospectively.

There remains a great disparity with regard to the content contained within preoperative sinus CT imaging reports. A standard report typically includes the extent and pattern of inflammatory sinus disease, secondary complications or findings associated with the sinus disease, anatomic variants predisposing to sinus outflow obstruction, and anatomic variants that predispose patients to surgical complications. A recent study by Deutschmann et al (24), however, found that 75% of surveyed otolaryngologists indicated that the preoperative imaging reports offered little in terms of management decisions compared with their own clinical assessment. In general, fellowship-trained neuroradiology reports were more comprehensive and clinically relevant compared with others, but still failed to consistently report on all findings that otolaryngologists felt were relevant to surgical planning. The most common anatomic structures or variants excluded from the imaging reports included the location and pneumatization

Figure 6



a. b.

Figure 6: Coronal reformatted CT images show varying degrees of postoperative changes associated with FESS to include **(a)** maxillary antrostomy, uncinectomy, turbinoplasty, and ethmoidectomy **(b)** and frontal drillout.

associated with the anterior ethmoidal artery, skull base integrity, and presence of an Onodi or sphenoethmoidal air cell. These were only documented consistently in approximately 10% of imaging reports. Overall, two-thirds of those surveyed stated that they would benefit from more clinically relevant information presented in the preoperative imaging reports, specifically in terms of anatomic variants that predispose to surgical complications (24).

Prior studies and review articles have outlined the anatomic structures that should be evaluated on the preoperative sinus CT (25–30), with a subset of those recommending use of a standardized checklist or template to ensure critical variants are evaluated and identified (26,27). For one reason or another, this information is not routinely utilized in daily imaging practices, despite the widespread availability of literature on this topic. The perception among referring otolaryngologists is that the recommended checklists and templates are too comprehensive and contain information that they feel is noncritical in terms of preoperative planning, making their implementation less practical. The final recommendation from the otolaryngology community was to develop a concise template for interpretation of the preoperative sinus CT that is focused on clinically relevant information to minimize the risk of surgical complications (24).

Preoperative Imaging Report

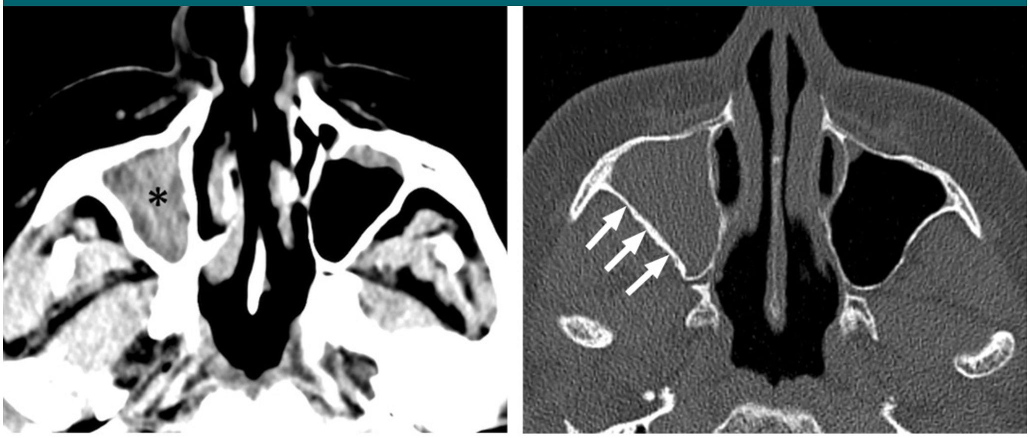
In concert with our otolaryngology colleagues, we developed a report template for preoperative sinus CT imaging that ensures critical anatomic variants are consistently evaluated and documented by using a mnemonic-based approach. Although the report format is standardized in terms of layout and ordering of content and findings, there remains a great deal of flexibility to allow radiologists to tailor the report for a specific patient (Appendix E1 [online]).

Each report begins with a description of paranasal sinus development, with a focus on under- or overpneumatization. The primary considerations are the presence of maxillary sinus hypoplasia and its effect on the OMC and the pneumatization pattern of the sphenoid sinus.

The next section of the report focuses on the sinus drainage pathways and patterns of inflammatory sinus disease. Inflammatory sinus disease may be sporadic or related to obstruction of particular outflow tract(s). The basic report structure includes evaluation of OMC and frontal recess patency on one side, along with a description of the associated inflammatory disease of the maxillary, anterior ethmoid, and frontal sinuses. This is then repeated for the contralateral side. If anatomic variants are present that affect the OMC or frontal recess drainage pathways, they are described along with the drainage pathway that is involved. The sphenoethmoidal recess patency and inflammatory disease of the posterior ethmoid and sphenoid sinuses are then described. Patterns of inflammatory disease that are relevant to management include the presence of polypoid or nonpolypoid mucosal thickening, frothy attenuation, and air-fluid levels, as well as intrasinus contents, such as mucous retention cysts, suspected fungal colonization, and sinoliths. Secondary findings or complications of inflammatory sinus disease, such as central increased attenuation (inspissated secretions and/or fungal colonization), osteitis, bony demineralization, or bony dehiscence, are described along with the opacification pattern of the affected sinus (Fig 7). Grouping the discussions of drainage pathway patency with inflammatory disease patterns, anatomic variants, and secondary findings that affect the specific outflow tract provides the otolaryngologists with pertinent and related information in one section of the report. The nasal cavity is then evaluated for pathologic or variant anatomic lesions that may affect surgical access during endoscopy.

The next section of imaging report is dedicated to a detailed assessment of surgical danger areas by using the "CLOSE" mnemonic (3). Information detailing the individual components of the mnemonic is presented in the Table and will be discussed in detail in the following section of this review. The mnemonic-based approach provides radiologists with a simple and expeditious means of recalling which critical structures need to be evaluated and documented in the preoperative imaging report. Each component of the mnemonic

Figure 7



a. b.

Figure 7: Images in a 79-year-old woman with secondary findings of chronic sinusitis. **(a)** Axial CT image in soft-tissue window demonstrates complete right maxillary sinus opacification with central increased attenuation, consistent with inspissated secretions and/or fungal colonization (*). **(b)** Corresponding image in bone window reveals diffuse thickening and sclerosis of the right maxillary sinus wall, consistent with osteitis due to chronic inflammation (arrows).

is described in the imaging report, with pertinent positives and negatives included. For example, if there is no Onodi cell on a preoperative CT scan, this is explicitly stated in the report. The listing of pertinent negatives is a point of emphasis with referring otolaryngologists, since they cannot assume that omission of a finding from a report constitutes absence of the finding, especially when dealing with findings that predispose patients to major surgical complications (24).

The final section of the preoperative imaging report includes an assessment of the remainder of the visualized structures on the CT examination to include the orbits, intracranial contents, soft tissues of the upper neck, skull base, and visualized portions of the craniocervical junction and cervical spine. This is particularly of interest to sinus surgeons, since they are not trained or experienced in identifying pathologic conditions outside of the sinuses.

"CLOSE" Mnemonic

Cribriform Plate

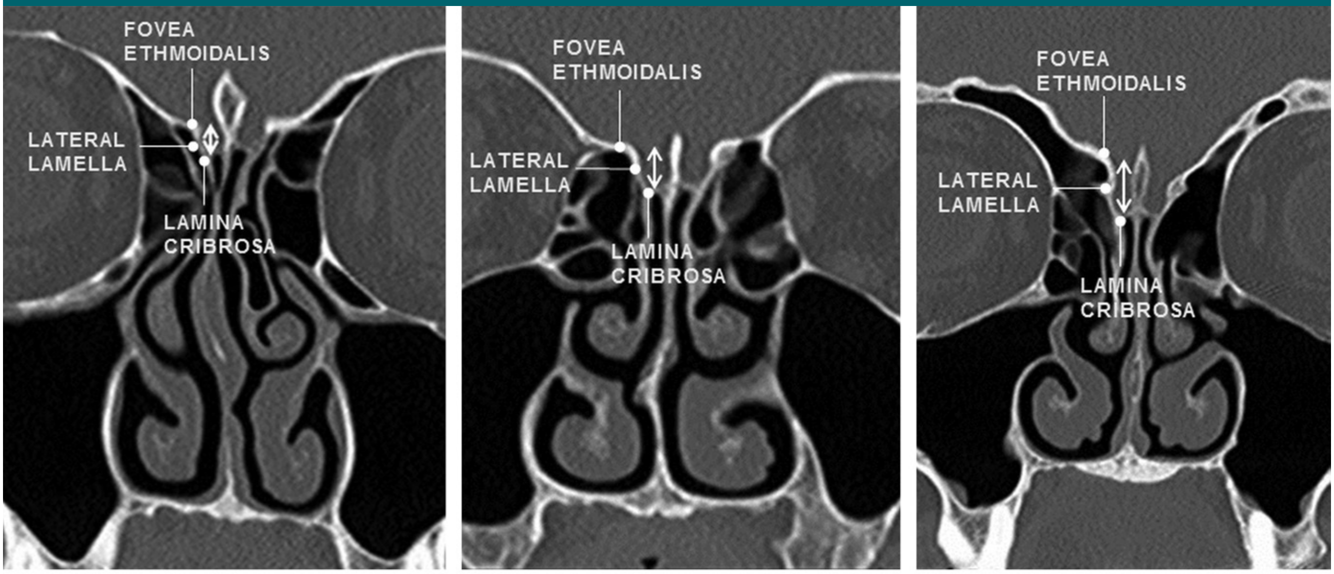
The cribriform plate refers to the horizontal lamina cribrosa, which is located midline and separates the roof of the nasal cavity from the anterior cranial fossa. It is best visualized and evaluated in the coronal plane. Along the midportion of the lamina cribrosa, there is a vertical crista galli, which extends intracranially between the olfactory fossae on either side. Small foramina in the cribriform plate allow for transit of olfactory perforators.

The lamina cribrosa forms the inferior boundary of the olfactory fossa, with the superior boundary consisting of the horizontal fovea ethmoidalis, which is the roof of the ethmoid sinus. The vertical distance between the lamina cribrosa and the fovea ethmoidalis represents the depth of the olfactory fossa, with the vertically oriented lateral lamella as its lateral border (Fig 8). The lateral lamella is the thinnest and most vulnerable bony portion of the skull base in terms of intraoperative injury, which is confounded by the attachment of the middle turbinate along the lateral margin of the cribriform plate. As the depth of the olfactory fossa increases, the lateral lamella becomes more vulnerable to intraoperative injury, either directly or through manipulation during turbinectomy or ethmoidectomy.

Disruption of the lateral lamella results in direct communication between the paranasal sinuses and intracranial compartment, often with a cerebrospinal fluid (CSF) leak, which may be identified intraoperatively or present more insidiously in the postoperative setting. CSF leak represents the most common major complication of FESS (31). Direct communication between the intracranial compartment and the sinus cavity substantially increases the risk of intracranial spread of infection and may also lead to development of a pseudomeningocele or meningoencephalocele.

The Keros classification is used to document the maximum depth of the olfactory fossa and resultant length of the lateral lamella. Keros type I is defined as less than or equal to 3 mm in depth, Keros type II is defined as a depth of 4–7 mm, and Keros type III is defined as greater than 7 mm in depth (Fig 9). Type II is most common, followed by type I. Type III is the least common variant and portends the greatest risk of skull base injury during FESS. Asymmetry in the depths of the olfactory fossa is also important to identify, as surgical planning will need to be tailored to the appropriate depth on either side (32,33). With asymmetry, the more inferiorly positioned lateral lamella is at greater risk of injury during FESS (Fig 9).

Figure 8



a. b. c.

Figure 8: Keros classification. Coronal reformatted CT images demonstrate the anatomy of the cribriform plate/anterior skull base and varying depths of the olfactory fossae. The olfactory fossa is delineated by the horizontal lamina cribrosa inferiorly, horizontal fovea ethmoidalis superiorly, vertical lateral lamella laterally, and vertical crista galli centrally/medially. Its depth is categorized according to the Keros classification (arrows). **(a)** Keros type I defined as less than or equal to 3 mm in depth, **(b)** Keros type II defined as a depth of 4–7 mm, and **(c)** Keros type III defined as greater than 7 mm in depth.

Lamina Papyracea

The lamina papyracea is a thin layer of the ethmoid bone that comprises the medial orbital wall. It is best evaluated in the coronal and axial planes. When dehiscent from a prior injury, the bony margin of the lamina papyracea is displaced medially into the ethmoid sinus, along with intraorbital fat and occasionally portions of the medial rectus muscle (Fig 10). Deviation into the ethmoid sinus places the lamina papyracea and orbital structures at risk for intraoperative penetration, as the lamina papyracea can be mistaken for an ethmoid sinus septation during ethmoidectomy.

The lamina papyracea may also be at risk for injury–even when intact–during uncinectomy in the setting of an underpneumatized or atelectatic maxillary sinus, with lateral deviation and apposition of the uncinate process with the medial orbital wall (Fig 11) (34). Excessive or aggressive manipulation of the uncinate process may result in disruption of the medial orbital wall. Manipulation or resection of a Haller cell may also cause inadvertent disruption of the lamina papyracea due to its location along the orbital wall. Although not specifically evaluated on the preoperative CT examination, manipulation of the basal lamella of the middle turbinate, which represents the demarcation

Figure 9

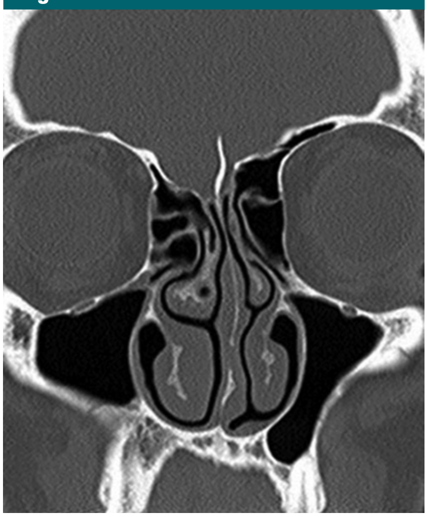


Figure 9: Coronal reformatted CT image shows asymmetry in the depths of the olfactory fossae, with the right measuring approximately 2 mm (Keros type I) and the left measuring approximately 8 mm (Keros type III). The more inferiorly positioned lateral lamella (right in this case) is at greater risk of injury during FESS.

Figure 10

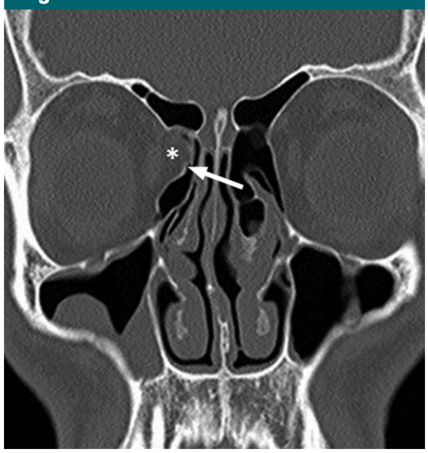


Figure 10: Lamina papyracea dehiscence. Coronal reformatted CT image shows a remote right medial orbital wall/lamina papyracea fracture with deviation of the bony wall (arrow) and intraorbital fat (*) into the ethmoid sinus. Lobulated mucosal thickening is noted within the right maxillary sinus.

of the anterior and posterior ethmoid air cells, may cause inadvertent breach of the lamina papyracea.

The most worrisome complication of orbital violation is an intraorbital hematoma. Hematomas cause increased intraorbital pressures and may result in temporary or permanent visual loss, depending on the size of the hematoma and rate of expansion. When substantial, immediate ophthalmologic intervention may be necessary (35). Direct injury to intraorbital structures, particularly the medial rectus musculature, is less common but disastrous due to its irreparability. Rectus muscle injuries range from intramuscular hematomas with focal muscle enlargement to complete transection, which is fortunately rare. In addition, penetration of the lamina papyracea establishes a direct communication between the orbit and a potentially infected sinus, which may lead to development of orbital emphysema and cellulitis.

Figure 11

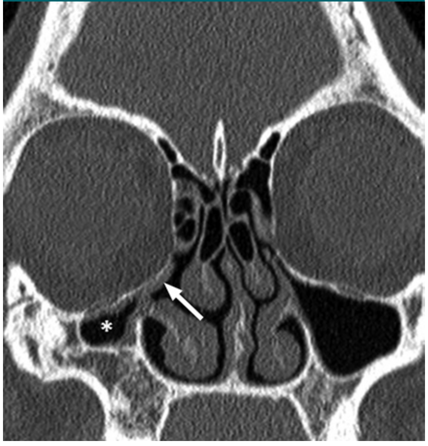


Figure 11: Lamina papyracea-uncinate apposition. Coronal reformatted CT image demonstrates a hypoplastic right maxillary sinus (*) with lateral deviation of the uncinate process, which contacts the lamina papyracea (arrow). Bilateral concha bullosa of the middle turbinates are also noted.

Figure 12

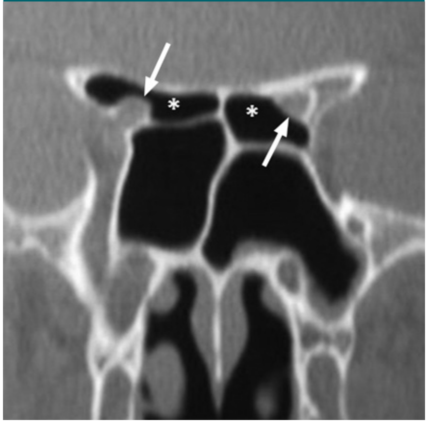


Figure 12: Coronal reformatted CT image demonstrates bilateral posterior ethmoid air cells that extend along the superior margin of the sphenoid sinuses, consistent with Onodi cells (*). The optic nerves course through the Onodi cells with a thin bony margin separating them from the sphenoethmoidal air cells (arrows).

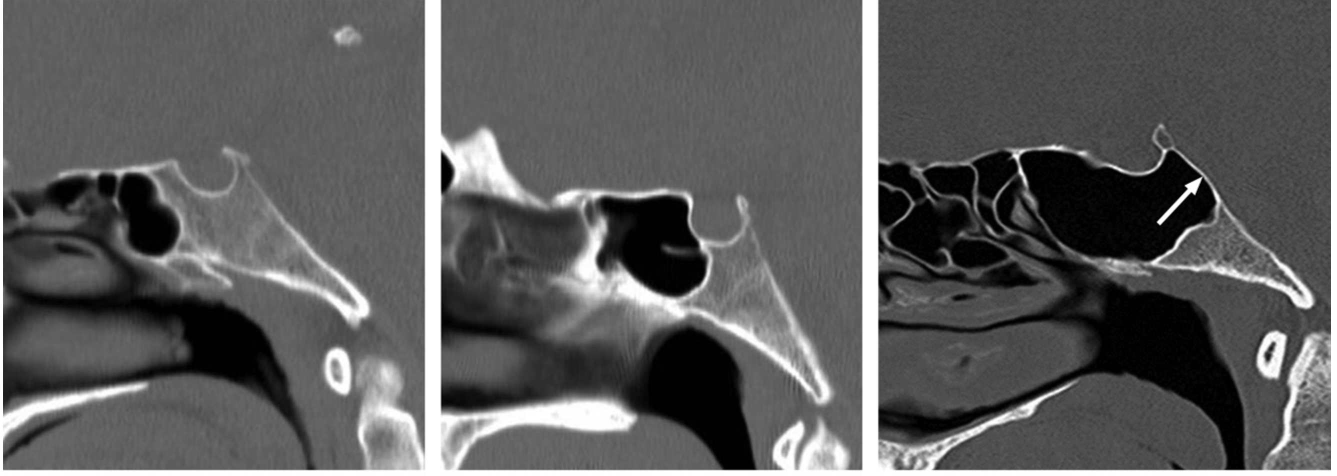
Onodi Cell

The Onodi cell, or sphenoethmoidal air cell, is a variant posterior ethmoid air cell that extends posteriorly along the superior and lateral aspect of the sphenoid sinus. It is best evaluated in the coronal plane. Onodi cell is an important variant to identify, as the optic nerve commonly courses through the Onodi cell, with a thin margin of bone separating the optic nerve from the underlying air cell (Fig 12). This greatly increases the risk of optic nerve injury during posterior ethmoidectomy, especially when surgeons are unaware that they are in a sphenoethmoidal air cell. An Onodi cell is best visualized on coronal sequences by first locating an air cell above the sphenoid sinus and identifying its continuity with a posterior ethmoid air cell.

Sphenoid Sinus

It is important to evaluate the sphenoid sinus for the pattern of pneumatization, as well as dehiscence of the overlying bony plate of the carotid artery and

Figure 13



a. b. c.

Figure 13: Sagittal reformatted CT images show **(a)** conchal, **(b)** presellar, and **(c)** sellar variants of sphenoid sinus pneumatization. The sellar variant results in a thin posterior bony margin of the clivus, which is more susceptible to intraoperative injury (arrow).

Figure 14

Figure 14: Axial CT image shows excessive posterior pneumatization of the sphenoid sinus, with dehiscence of the right cavernous carotid artery canal along the posterior margin of the sinus (arrow). A thin bony margin is noted overlying the left carotid artery (arrowhead).

Figure 15

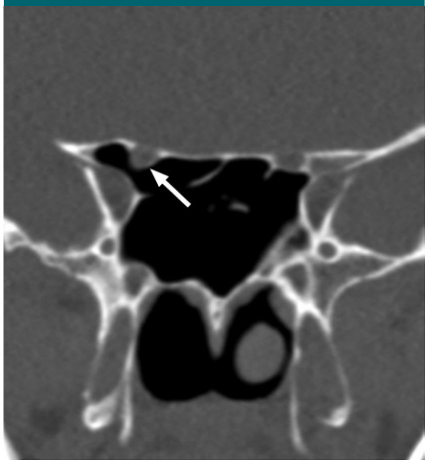


Figure 15: Coronal reformatted CT image demonstrates sphenoid sinus pneumatization extending into the anterior clinoid with resultant exposure of the right optic nerve canal (arrow) within the sphenoid sinus.

Figure 16

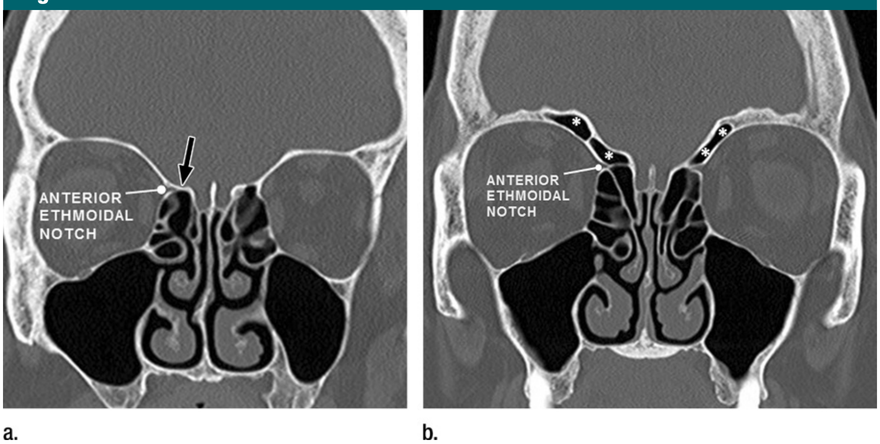


Figure 16: Coronal reformatted CT images demonstrate the anterior ethmoidal notch along the superolateral margin of the anterior ethmoid sinus. **(a)** When the ethmoidal notch abuts the fovea ethmoidalis (arrow) or lateral lamella, it is considered protected. **(b)** With supraorbital pneumatization of the ethmoid sinus above the ethmoid notch (*), the anterior ethmoidal artery is at risk for intraoperative injury.

optic nerve. Sphenoid sinus pneumatization with respect to the clivus and sella may be characterized as conchal, presellar, or sellar and is best evaluated in the sagittal plane (Fig 13). The conchal variant refers to underpneumatization, with a thick bony margin between the sphenoid sinus anteriorly and the sella posteriorly. The presellar variant refers to pneumatization extending posteriorly to the anterior margin of the sella. The sellar variant is most common and refers to pneumatization that extends inferior and posterior to the sella, resulting is a thin posterior bony margin of the clivus (36). The sellar variant is important to identify preoperatively, since it places the thin posterior clival margin at risk for inadvertent perforation due to supine positioning of the patient, with the force of gravity directed posteriorly.

Excessive pneumatization of the sphenoid sinus into the skull base and anterior clinoid processes may result in dehiscence of the bony margins of the carotid and optic nerve canals, rendering them susceptible to injury during FESS (Figs 14, 15). This is best evaluated in both the coronal and axial planes. It is also important to identify a sphenoid septation attachment along a thin bony margin of the carotid canal, as resection of the septation may expose or damage the underlying carotid artery (35,37–40). Fortunately, injuries to the carotid artery are rare; however, when present, they may be catastrophic, depending on the degree of injury and ability to control the hemorrhage (35). Emergent treatment–either surgical or endovascular–to obtain hemostasis is essential. Optic nerve dehiscence may occur in the setting of excessive pneumatization of the sphenoid sinuses into the anterior clinoids or in the presence of an Onodi (sphenoethmoidal) cell.

(Anterior) Ethmoidal Artery

The anterior ethmoidal artery is a branch of the ophthalmic artery that supplies portions of the paranasal sinuses and nasal cavity to include the ethmoid and frontal sinuses, anterior portion of the nasal septum, and portions of the lateral nasal wall (41–48). The artery can be located on coronal CT images by identifying the anterior ethmoidal notch along the medial orbital wall at the level of the anterior ethmoid sinus (49,50). Prior studies have demonstrated that the anterior ethmoidal notch can be reliably identified on coronal CT images bilaterally in approximately 95%–100% of cases and unilaterally in the remaining cases (46,49,50). If the notch abuts the fovea ethmoidalis or lateral lamella, then the artery is considered relatively protected during FESS (Fig 16a). The presence of supraorbital pneumatization of ethmoid air cells above the anterior ethmoidal notch, however, places the artery at increased risk of injury during FESS, since the artery travels freely within the ethmoid sinus

(Fig 16b) (49,51,52). Supraorbital pneumatization is a common and often overlooked critical variant, occurring in approximately 26%–35% of patients (49,53). Inadvertent injury of the anterior ethmoidal artery can result in a rapidly enlarging retro-orbital hematoma due to retraction of the transected vessel into the orbit. A severed anterior ethmoidal artery should be prophylactically cauterized when this complication occurs to prevent further complications.

Impact of Report Standardization

The aforementioned structured report with inclusion of the "CLOSE" mnemonic has been implemented at the authors' practices at two academic medical centers and has been well received by both referring surgeons and radiologists. In particular, radiologists have embraced the use of the "CLOSE" mnemonic, since it highlights critical areas that they often overlook when interpreting preoperative sinus CT scans. Prior to use of the "CLOSE" mnemonic, our institutional experience mirrored that described in the otolaryngology literature, with few preoperative imaging reports documenting the anatomic configuration of the skull base/cribriform plate, presence or absence of an Onodi cell, pneumatization pattern of the sphenoid sinus and its impact on the carotid artery and optic nerve, or location and pneumatization pattern associated with the anterior ethmoidal artery. Since its implementation, otolaryngologists have a newfound confidence in utilizing our preoperative imaging reports for surgical planning.

Conclusion

Although FESS is an effective means of treating patients with recurrent and refractory sinusitis, the procedure is not without risk of complications, which can be serious. The routine utilization of preoperative CT affords the opportunity to prospectively identify important anatomic variants that predispose patients to surgical complications; however, there is substantial variability in terms of evaluating for and documenting the presence of these important variants on imaging reports. The "CLOSE" mnemonic provides a simple means of recalling critical variants that can easily be incorporated into the preoperative imaging report. This will prove beneficial to referring otolaryngologists, and—more important—help reduce the risk of surgical complications.

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