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## Endoscopic Sinus Surgery: Role of the Radiologist

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Endoscopic sinus surgery has become an increasingly popular procedure since Messerklinger [1] and Wigand et al. [2] described the advantages of the intranasal endoscope and its surgical application. The concept of "functional endoscopic sinus surgery" [3] evolved from the work of Hilding [4, 5], Proctor [6, 7], and Messerklinger [8–10] on mucociliary clearance and air flow in the paranasal sinuses and on the importance of establishing drainage and preserving the mucosa of the sinuses. Functional endoscopic sinus surgery is based on the hypothesis that the ostiomeatal complex (maxillary sinus ostium, anterior and middle ethmoid ostia, frontal recess, infundibulum, and middle meatal complex) is the key area in the pathogenesis of chronic sinus diseases [3, 8–17]. Minor pathologic changes in the nasal mucosa in the vicinity of the ostiomeatal complex may interfere with mucociliary clearance or with the ventilation of the maxillary, ethmoidal, and frontal sinuses. The underlying principle of functional endoscopic sinus surgery is that the *sinus mucosa will return to normal if adequate drainage can be established* [13]. No attempt is made to remove the sinus mucosa; rather, it is allowed to return to normal and to resume its normal function.

In this issue of the *AJNR*, Babbel et al. [18] attempt to establish an optimal imaging protocol for preendoscopic screening CT of the sinuses, including preparation of the patient, CT technique, and data display (filming). I agree with the authors that pretreatment of patients with appropriate medical therapy and adequate preparation of patients enable the best CT assessment of mucosal disease of the nasal and paranasal sinuses. Coronal CT scanning with the patient in a prone position and the head hyperextended currently affords the best preoperative evaluation for endoscopic anterior eth-

moidectomy, frontal sinusotomy [14, 17], and for posterior endoscopic total sphenoidectomy [12]. The anterior and posterior walls of the frontal sinuses and the anatomic relationship between the posterior ethmoidal and sphenoidal sinuses are best evaluated in the axial plane [16]. In terms of filming, Babbel et al. recommend an intermediate (2500 H/250 H) window width/level technique. I prefer CT images filmed with extended window width-bone technique (4000 H/700–800 H). I also require that the technicians provide a set obtained by using a soft-tissue technique. The soft-tissue technique allows better evaluation of inspissated mucosal debris, microcalcifications, and incidental findings in the orbit and eyeball, as well as in the parts of the face and cranium included in the study.

I would like to discuss three issues related to the article by Babbel et al.: the concepts of functional endoscopic sinus surgery, the important role of the radiologist in preoperative assessment for endoscopic sinus surgery, and the increasing rate of significant and serious complications associated with endoscopic sinus surgery.

The paranasal sinuses, like other parts of the upper respiratory system, are lined with a pseudostratified columnar ciliated epithelium under which is a tunica propria, which contains mucous and serous glands [13, 14]. The secretions of these glands form surface films of mucus and fluid (mucus blanket) that cover the epithelium. Cilia of the upper respiratory mucosa beat with a wavelike, synchronous rhythm that continuously propels a surface coat of mucus, containing entrapped particles, toward the pharynx [20]. In the paranasal sinuses and nasal cavity, the ciliated epithelium and the mucus blanket form the so-called mucociliary system that protects

This article is a commentary on the preceding article by Babbel et al.

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the sinuses and nasal cavity [13, 14]. It is important to realize that the mucus blanket is moved by the cilia toward the natural ostium of the individual sinus. This occurs regardless of any other openings that may or may not be present in the sinus [14]. In the maxillary sinus, mucociliary movement originates from the floor and radiates along the walls of the sinus to propel the mucus blanket toward the ostium [16], which is located in the posterosuperior portion of the medial wall of the sinus. This mucociliary system captures 80% of inspired particles larger than 3–5  $\mu\text{m}$  and 60% of those larger than 2  $\mu\text{m}$  and exposes them to mast cells, polymorphonuclear leukocytes, eosinophils, lysozyme, immunoglobulin G, and interferon while sweeping them into the pharynx to be swallowed [13]. Each sinus has its own specific pattern of movement of its mucociliary blanket going toward, and ending at, the natural ostium. Placement of an ostium in another location is ineffective, as the cilia continue to move the mucus blanket toward the natural ostium [14, 16]. Chronic or chronically recurrent sinusitis therefore implies a breakdown in the function of the mucociliary system [14, 16]. Most frequently, this breakdown involves the anterior ethmoidal sinuses because they are ideally located to suffer chronic obstruction. The majority of inspired particles are deposited on the anterior ends of the middle and inferior turbinates and in the anterior middle meatus where their effect will be greatest on the anterior ethmoidal air cells.

Knowledge of the pathophysiologic mechanisms that cause the chronic changes in the ostiomeatal region is still incomplete. The etiologic factors include a variety of exogenous factors such as aeroallergens, microorganisms (fungi, viruses, bacteria), toxic inhalants, and endogenous factors such as immunologic disorders [11]. Proctor [6] and later on Messerklinger [10] introduced the principle that chronic or recurrent bacterial sinusitis is most often caused by unappreciated, untreated anterior ethmoidal disease [6, 10]. Inasmuch as they must drain through this drainage site of the anterior ethmoid, the maxillary and frontal sinuses are often secondarily infected and may produce the dominant signs and symptoms. A necessary conclusion is that relief of the obstruction caused by the anterior ethmoidal air cells will permit resolution of disease in the maxillary and frontal sinuses.

The anatomy of the ethmoid bone, nasal cavity, ostiomeatal complex, natural ostium of the maxillary sinus, and exact drainage system of the frontal sinus is of considerable importance in this operative technique. A successful outcome of endoscopic sinus surgery is based on a clearly defined diagnostic evaluation of the disease in the ostiomeatal complex in patients with chronic sinusitis [3, 14, 16, 17]. This evaluation includes a good medical history; careful physical examination, including intranasal endoscopy; and, after medical therapy, a CT scan to examine the ostiomeatal complex [3, 16, 17]. Familiarity with the anatomy of the paranasal sinuses, particularly the ethmoidal sinuses, is critical for interpreting imaging studies of the paranasal sinuses. In the endoscopic approach, the most important landmarks are the agger nasi cells, frontal recess, middle turbinate, middle meatus, uncinat process, ethmoid infundibulum, hiatus semilunaris, bulla ethmoidalis, natural ostium of the maxillary sinus, basal lamella, and sphenoidal recess (Figs. 1–3).

The ostiomeatal complex or unit has been referred to as the maxillary sinus ostium and infundibulum [16] and also as the normally aerated channels, providing airflow and mucociliary clearance for the maxillary, ethmoidal, frontal, and sphenoidal sinuses [21]. However, this term is often used to refer to the maxillary sinus ostium, anterior and middle ethmoidal air cells' ostia, frontonasal duct (frontal recess), infundibulum, and middle meatal complex. Also, in many otolaryngologic communications, the anterior and middle ethmoidal air cells are collectively referred to as anterior ethmoidal air cells. Recognition of the importance of the ostiomeatal complex has given the radiologist an important role in the examination of patients who are scheduled for functional endoscopic sinus surgery. Radiologists should be familiar with the principles of this operation, and make a careful evaluation of the paranasal sinuses, in particular, the ethmoid bone and the middle meatus region of the nasal cavity. The ethmoid bone is a delicate and complex structure. It articulates with 13 other bones: the frontal, sphenoid, nasals, maxillae, lacrimals, palatines, inferior nasal conchae, and vomer [22, 23]. The ethmoid bone consists of four parts: a horizontal lamina, called the cribriform plate; a perpendicular plate; and two lateral masses, called the labyrinths. Each ethmoidal labyrinth consists of thin-walled highly variable air cells, arranged in three groups: anterior, middle, and posterior clusters. These ethmoidal air cells are closed everywhere, except at their apertures or ostia of communication with the nasal cavity. (It is important to realize that the ostia of these ethmoidal air cells cannot be detected on CT images.) Some air cells are not entirely enclosed by the ethmoid bone (extramural cells); instead the ethmoid bone may be perforated so that the air-cell mucosa extends upward against the ethmoidal notch of the frontal bone, anteriorly against the lacrimal and maxillary bones and posteriorly against the sphenoid and palatine bones. The orbital plate of the ethmoid bone (lamina papyracea) covers the middle and posterior ethmoidal air cells. The anteriormost intramural ethmoidal air cells are the frontal recess cells, which extend toward the frontal bone anterosuperiorly. The frontal sinus arises from these cells, as do the supraorbital ethmoidal air cells [13]. The next most anterior group is the infundibular cells. From these arise the most anterior extramural cells, the agger nasi cells, which pneumatize the lacrimal bone and frontal process of the maxilla [13, 24]. The agger nasi cells are located on the lateral nasal wall immediately anterior to the anterior end of the middle turbinate [14]. These cells drain into the ethmoid infundibulum.

The medial surface of the labyrinth forms a part of the lateral wall of the corresponding half of the nasal cavity. Within the nasal cavity, scrolls of bone on the lateral walls, the conchae, project medially to divide the passageway into meatuses, or channels for air [22, 23]. The superior and middle conchae are parts of the ethmoid bone, but the inferior nasal conchae (a turbinate is a concha, meaning a soft-tissue complex) are a separate pair of bones. The superior, middle, and inferior meatuses (air channels), which are formed under the respective conchae, have increased contact with the nasal surfaces to permit more effective warming and moistening of inspired air [23].

The sphenoidal sinus ostium is located at the anterosuper-

Fig. 1.—A, Anatomy of lateral nasal wall. Middle turbinate in this dry skull has been removed, allowing visualization of left nasal wall. Note anteroinferior (*large arrows*) and posterosuperior (*open arrows*) borders of uncinate process. B = bulla ethmoidalis. Passage (*dashed line*) between posterosuperior border of uncinate process and anteroinferior border of bulla is semilunar hiatus (hiatus semilunaris). Hiatus courses around outer anteroinferoposterior border of bulla to reach middle meatus.

B, Direct parasagittal CT scan showing inferior turbinate (1), middle turbinate (2), bulla ethmoidalis (B), sinus lateralis (sl), and posterior ethmoidal air cells (p). Basal lamella is bony partition between bulla ethmoidalis and posterior ethmoidal air cells. Basal lamella is also between sinus lateralis and bulla ethmoidalis. A partial volume of the uncinate process (*white arrowheads*) is seen in this section. Note its anterior attachment (*long white arrow*) to ethmoidal process of inferior concha. Just superior and anterior to the uncinate process are the agger nasi cells. The infundibulum is a curved passage below bulla and above uncinate process (*short white arrow*). Area between posterosuperior border of uncinate process and anteroinferior border of bulla ethmoidalis is semilunar hiatus (*dashed line*), which courses around inferoposterior border of bulla to connect infundibulum with middle meatus. Note opacification of sphenoid sinus by a surgically proved mucous retention cyst. This image clearly explains why nasolacrimal duct (*black arrowhead*) or sac is injured during endoscopic anterior ethmoidectomy.

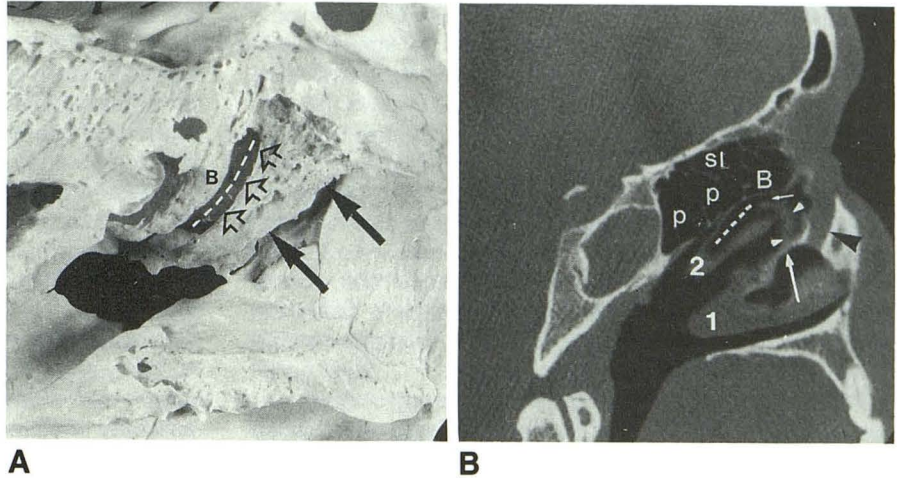
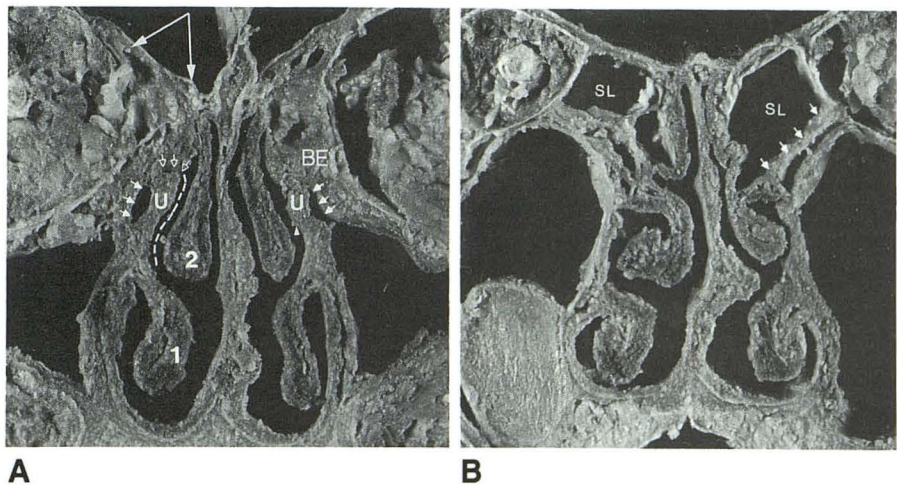


Fig. 2.—A, Coronal section through ostiomeatal complex of cadaveric head shows inferior turbinate (1), middle turbinate (2), uncinate process (U), and bulla ethmoidalis (BE). Note attachment of uncinate process (*arrowhead*) to the ethmoidal process of inferior concha. Infundibulum (*three solid arrows*) is passage between uncinate process and inferior border of bulla. Three open arrows indicate communication of middle meatus (*dashed line*) with infundibulum through semilunar hiatus. As seen, hiatus (*three open arrows*) is a passage between inferior aspect of bulla and superior aspect of uncinate process. Long arrows at top of photograph indicate fovea ethmoidalis (roof of the lateral masses of ethmoid bone). Note attachment of middle turbinate to junction of fovea ethmoidalis and cribriform plate.

B, Coronal section posterior to A and taken just posterior to bulla ethmoidalis. Note lateral attachment of middle turbinate, so-called basal or ground lamella (*arrows*). Basal lamella separates posterior ethmoidal air cells from bullar air cells. Sinus lateralis (SL) is posterior and superior to basal lamella. Note retention cyst along floor of right maxillary sinus.



ior portion of the sphenoidal sinus. The sphenoidal ostium and the posterior ethmoidal air cells drain into the superior meatus (sphenothmoidal recess). The middle meatus connects via various ostia with the anterior and middle ethmoidal air cells and the frontal and maxillary sinuses. The frontal sinuses communicate with the middle meatus of the corresponding half of the nasal cavity by means of a passage called the frontonasal canal. This communication between frontal sinus and nasal cavity is not strictly a duct [16], but an internal channel positioned between the sinus and the anterior middle meatus referred to as the frontal recess.

Just anterior to the superior attachment of the middle turbinate and anterior to the frontal recess is the agger (ridge) nasi [24]. This prominence on the lateral nasal wall represents the most anterior of the anterior ethmoidal cells. These cells (agger nasi cells) can invade the lacrimal bone or the ascending process of the maxilla. Because of their closeness to the frontal recess, they are excellent surgical landmarks. Opening these agger cells provides a good view of the nasofrontal duct.

Just posterior and inferior to the agger nasi cells lies the ethmoidal uncinate process (Fig. 1B), the starting point in an

anterior-to-posterior endoscopic procedure [13]. The uncinate process is a thin, curved bar of bone from the lateral side of the ethmoidal labyrinth that forms a portion of the lateral nasal wall (Figs. 1–3). It projects downward and backward and is subject to considerable variation in size. It ranges in height from 1 to 4 mm and is 14 to 22 mm long [14]. Anteriorly, it articulates with the lacrimal bone and ethmoidal process of the inferior nasal concha (Figs. 1B and 2). The superior edge of this process is free and forms the medial boundary of the hiatus semilunaris (Figs. 1 and 2) in the middle meatus of the nose [22]. As it progresses posteroinferiorly, it forms the inferior border of the semilunar hiatus (Fig. 1) and the medial wall of the infundibulum (Fig. 2).

The semilunar hiatus is a curvilinear opening of the lateral nasal wall that lies above the uncinate process and below the bulla ethmoidalis (Figs. 1 and 2A). This opening separates the uncinate process from the ethmoidal bulla and serves as a connection between the infundibulum and the middle meatus (Fig. 2A). The middle ethmoidal air cells produce a rounded swelling, called the bulla ethmoidalis, on the lateral wall of the middle meatus (Fig. 2A), whose lateral border forms a portion of the medial orbital wall. These cells open into the ethmoid

infundibulum or onto the medial wall of the bulla into the middle meatus.

The ethmoidal infundibulum is a trough-shaped cavity (deep curved passage) that is below the bulla and above and lateral to the uncinate process (Figs. 1–3). It potentially receives drainage from the anterior and middle ethmoidal air cells and the frontal and maxillary sinuses. In more than 50% of crania, the infundibulum is continued superiorly as the frontonasal duct into the frontal sinus [22]. Kasper [25] found that in 62% of cases the ethmoidal infundibulum and nasofrontal connections were discontinuous channels anatomically.

The exact drainage system of the frontal sinus depends on its embryologic development. The drainage usually occurs by way of rudimentary ethmoidal cells into the frontal recess [25] or directly into the frontal recess [13].

Medial to the bulla ethmoidalis and the uncinate process is the middle turbinate. Anteriorly, it attaches to the medial wall of the agger nasi and the superoanterior edge of the uncinate process [21]. Superiorly, it attaches to the cribriform plate. The attachment of the middle turbinate changes direction at its most posterior extent. Instead of running in an anteroposterior direction, it curves laterally, and the final lateral attach-

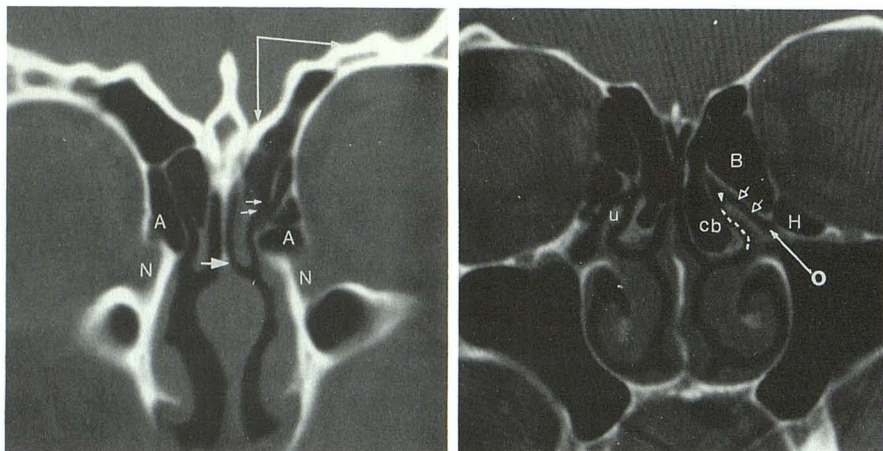


Fig. 3.—A, Coronal CT scan shows agger nasi cells (A), frontal recess (two small arrows), supraorbital anterior ethmoidal air cells, nasolacrimal canal (N), perpendicular plate of ethmoid bone (single short arrow), and fovea ethmoidalis (long arrows).

B, Coronal CT scan posterior to mid-portion of bulla ethmoidalis (B) shows uncinate process (u), bilateral concha bullosa (cb), orifice of maxillary sinus (O), and infraorbital ethmoidal air cells, the so-called Haller cells (H). Ethmoid infundibulum is the passage (two open arrows) between uncinate process and bulla. Arrowhead = hiatus semilunaris, which is the communication passage between middle meatus (dashed line) and infundibulum.

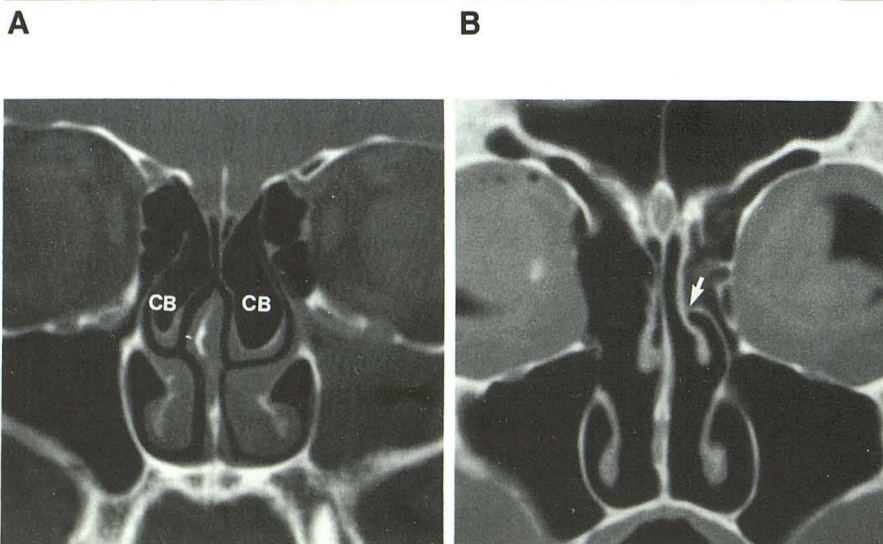


Fig. 4.—CT scan shows bilateral concha bullosa (CB). Note narrowing of left middle meatus and infundibulum and associated thickening of left maxillary mucosal lining.

Fig. 5.—CT scan of cadaveric head shows medial attachment (arrow) of left uncinate process to middle turbinate. Right uncinate process and anterior ethmoidal air cells have been removed, and natural ostium of right maxillary sinus has been widened.

ment of the middle turbinate is oriented in the frontal plane and is called the basal or ground lamella (Fig. 2B) [16, 21, 24].

The posterior ethmoidal air cells are between the basal lamella and the sphenoidal sinus. The basal lamella is an excellent landmark for separating the anterior and middle ethmoidal air cells from the posterior ethmoidal air cells [24]. An airspace is usually found between the ground lamella and the bulla ethmoidalis, which may extend superiorly to the bulla. This is called the sinus lateralis (Figs. 1B and 2B). This sinus lateralis, unlike the other posterior ethmoidal air cells that open into the superior meatus, may communicate with the frontal recess [21] or may open directly and independently into the middle meatus.

The natural ostium of the maxillary sinus is important in endoscopic sinus surgery. This ostium is located in the superior portion of the medial wall and drains into the posterior aspect of the ethmoid infundibulum as the sinus funnels into it, usually posterior to the midpoint of the bulla ethmoidalis (Fig. 3B) [13]. The posterior extent of the uncinat process points to the position of the ostium and is an excellent imaging and endoscopic landmark for its localization. Accessory ostia are present in 15–40% of cases, usually in the membranous medial sinus wall, the so-called fontanelles. The fontanelles are two areas along the medial aspect of the maxillary sinus where a double layer of mucosa with no intervening bone forms the nasoantral wall inferior to the uncinat process.

Certainly, individual structural differences in ethmoidal and ostiomeatal complexes and other paranasal sinuses are to be expected, and the reader ought not to be discouraged should certain illustrations in the literature fail to be identical with the images he or she will review for any individual patient. Certain anatomic variations are observed more commonly and should be included in the imaging report. These are as follows. (1) *Concha bullosa*, a pneumatized middle turbinate. The otolaryngologist is interested to know whether the concha bullosa has compromised the middle meatus or even the ethmoid infundibulum (Fig. 4). (2) *Low position of fovea ethmoidalis* (the roof of the ethmoid labyrinth). A low position of the cribriform plate and fovea ethmoidalis is a potentially dangerous anatomic variation, which can be penetrated easily unless the surgeon is aware of the finding. (3) *Bulging of the optic canal into the posterior ethmoidal complex*. In rare instances, the internal carotid artery may be exposed in the posterior ethmoidal sinus [26]. An important observation is extensive lateral pneumatization of the posterior ethmoidal air cells, which can increase the vulnerability of the optic nerve. In addition, identification of an asymmetric intersphenoid septum is important because the posterior extension of this partition usually marks the location of the internal carotid artery. (4) *Deviation of the uncinat process*. The superior edge of the uncinat process may deviate medially to obstruct the middle meatus (Fig. 5) or, more importantly, may deviate laterally to obstruct the infundibulum. Marked lateral deviation or even fusion of the uncinat process to the medial orbital wall may endanger the orbit and hence the optic nerve while the uncinectomy is performed during anterior endoscopic sinus surgery. (5) *Haller cells*. These are ethmoidal air cells extending along the medial floor of the orbit (infraorbital air cells) (Fig. 3B), which may cause narrowing of the infundibulum.

Other anatomic variations include deviation of the nasal septum, paradoxical middle turbinate, uncinat process bulla, and posttraumatic or congenital deformity of the medial wall or floor of the orbit.

In summary, CT scanning and endoscopy are complementary in the diagnosis and treatment of disorders of the nasal cavity and paranasal sinuses. Endoscopic nasal sinus surgery, like traditional sinus surgery, is associated with serious risks. Complications such as blindness, ocular motility dysfunction, orbital hematoma, CSF leak, anterior cranial fossa brain and/or vascular damage, brain abscess, pneumocephalus, carotid-cavernous sinus fistula, and death have been reported [27–31]. Buus et al. [30] reported bilateral blindness in a 39-year-old woman following endoscopic ethmoidectomies. Pathologic specimens from both sides revealed optic nerve tissues. As an entire generation of otolaryngologists learns these new techniques, complications will continue to evolve. Prevention begins with proper endoscopic and CT preoperative evaluation and surgical preparation [28]. The study of Babbel et al. [18] supplements the radiologic data reported by Zinreich et al. [16], Chow and Mafee [17], and others by pointing out some useful technical clues that are helpful in the presurgical diagnosis of sinonasal inflammatory disease and by providing essential information for functional endoscopic sinus surgery [3].

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