

## Imaging of Sinonasal Inflammatory Disease<sup>1</sup>

Changes in imaging sinonasal inflammatory disease have paralleled changes in the treatment of chronic sinusitis. As functional endoscopic sinus surgery has become a more widespread technique, coronal computed tomography (CT) has become the primary imaging modality, replacing plain radiography. Knowledge of the plethora of sinonasal anatomic variations and the inherent surgical implications is critical to the interpretation of the CT scans and to the safe performance of endoscopic surgery. Currently, the role of magnetic resonance imaging is restricted to the evaluation of complicated sinusitis, intraorbital and intracranial manifestations of aggressive sinusitis, and sinonasal neoplasms.

**Index terms:** Nose, diseases, 26.24 • Paranasal sinuses, diseases, 23.25 • Sinusitis, 23.25 • State-of-art reviews

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**S**INONASAL imaging has progressed methodically as each new generation of imaging modality has encroached on the domain of the former generation. While plain radiography was once the study ordered most commonly to evaluate the sinonasal cavity, computed tomography (CT) has now supplanted plain radiography because the endoscopic sinus surgeon has required greater anatomic precision. The 1970s and 1980s saw the introduction of the Messerklinger technique—subsequently coined functional endoscopic sinus surgery (FESS)—replace the more traditional Caldwell-Luc and maxillary antrostomy procedures for treating chronic sinusitis. At the same time, coronal CT has become the study of choice for chronic sinusitis, since it simulates the endoscopist's view of the sinonasal cavity and provides a road map of bone for surgery. Finally, previously unresectable sinonasal malignancies invading the skull base can now be treated by a team of otorhinolaryngologists and neurosurgeons performing aggressive craniofacial surgery even into the cavernous sinus. The need for optimal mapping of such tumors has led to the ascendancy of magnetic resonance (MR) imaging for sinonasal neoplasms.

This article will review the pertinent anatomy of the sinonasal cavity, discuss imaging of uncomplicated and complicated sinusitis, and analyze the current role of each imaging modality.

### BASIC ANATOMY

To understand the pathogenesis of sinusitis, one must understand the normal pathway of mucociliary clearance in the paranasal sinuses. The cilia within the maxillary sinus propel the mucus stream in a starlike pattern from the floor of the maxillary sinus toward the *ostium* situated superomedially. In approximately 30% of pa-

tients there is a second accessory ostium to the maxillary sinus inferior to the major opening (1). From the maxillary sinus ostium, mucus from the maxillary antrum gets swept superiorly through the *infundibulum*, which is located lateral to the uncinate process and medial to the inferomedial border of the orbit (Fig 1). The *uncinate process*, a sickle-shaped bone extension of the lateral nasal wall extending from anterosuperiorly to posteroinferiorly, is rarely (less than 2.5% of patients) pneumatized (1). Occasionally the uncinate process attaches to the lamina papyracea (the medial wall of the orbit). If it does so, the infundibulum will not have a superior opening creating a blind pouch, the *recessus terminalis*. Posterior to the uncinate process, at the termination of the infundibulum, mucus is propelled to the *hiatus semilunaris*, an air-filled space just anterior and inferior to the largest anteroinferior ethmoid air cell, the *ethmoidal bulla*. The mucus is then passed posteromedially via the *middle meatus*, a channel passing medial and superior to the uncinate process, into the back of the nasal cavity to the nasopharynx, where it is subsequently swallowed.

The OMC refers to the maxillary sinus ostium, the infundibulum, and the middle meatus, the common drainage pathway of the frontal, maxillary, and anterior ethmoid air cells.

The frontal sinuses drain inferomedially via the nasofrontal duct. The term nasofrontal duct has been replaced with the term *frontoethmoidal recess*, since a true circular duct is usually not present and since frontoethmoidal recess connotes the common drainage of the frontal sinus and the anterior ethmoidal sinuses (Fig 2). The frontoethmoidal recess is the

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**Abbreviations:** FESS = functional endoscopic sinus surgery, OMC = ostiomeatal complex.

space between the inferomedial frontal sinus and the anterior middle meatus. The frontal sinus and the anterior ethmoidal sinuses usually drain through the recess directly into the middle meatus via the frontoethmoidal recess or, less commonly, into the superior ethmoidal infundibulum before passing to the middle meatus.

The anteriormost ethmoid air cells, located in front of the attachment of the middle turbinate to the cribriform plate, are termed *agger nasi cells*. *Agger nasi cells* lie anterior, lateral, and inferior to the frontoethmoidal recess. They are present in over 90% of patients (1,2) and lie deep to the lacrimal bone (the anteromedial margin of the orbit). Another set of anterior ethmoidal air cells, which are variably present in patients, are supraorbital ethmoid air cells. These are important to identify, as these air cells are difficult to access through the endoscope because of their superolateral location and proximity to the orbit.

As stated earlier, *ethmoidal bulla* is the term used for the ethmoid air cell directly above and posterior to the infundibulum and hiatus semilunaris. A very large ethmoidal bulla can obstruct the infundibulum and hiatus semilunaris, leading to obstruction of the drainage of the maxillary and anterior ethmoid sinuses. When anterior ethmoid air cells are located inferolateral to the bulla, along the inferior margin of the orbit protruding into the maxillary sinus, they are termed *Haller cells* or maxilloethmoidal cells. *Haller cells* have been reported to be present in 10%–45% of patients undergoing sinus CT (1–3). When greatly enlarged, these *Haller cells* may narrow the infundibulum or maxillary sinus ostium.

Between the ethmoidal bulla and the basal lamella (the lateral attachment of the middle turbinate to the lamina papyracea of the orbit) is the *sinus lateralis*. The *sinus lateralis* may open into the frontoethmoidal recess or into a space posterior to the bulla, the hiatus semilunaris posterioris. The *sinus lateralis* is important to identify as a potential area for residual sinusitis after ethmoidectomy, shielded as it is by the bulla. The bulla, *Haller cells*, and *sinus lateralis* are all part of the anterior ethmoid complex, anterior to the basal lamella.

The posterior ethmoid air cells are located behind the basal (or ground) lamella of the middle turbinate and drain via the superior meatus, the supreme meatus, or other tiny ostia just under the superior turbinate. Ultimately, these ostia drain into the

sphenoethmoidal recess of the nasal cavity, from which the secretions pass to the nasopharynx. In some patients, the most posterior ethmoid air cell may pneumatize into the sphenoid bone, superior and lateral to the sinus. This is termed an "Onodi cell."

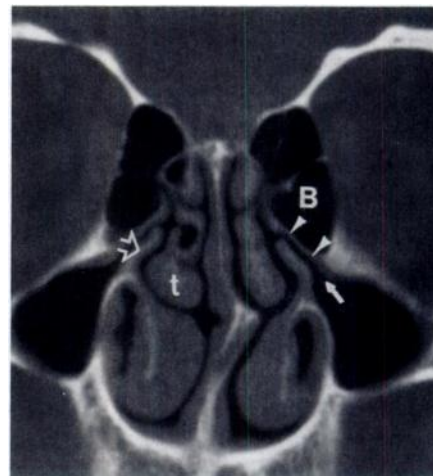
The sphenoid sinus drains anteriorly into the nasal cavity through its ostium into the sphenoethmoidal recess, just medial to the superior turbinate of the nose. This ostium is best seen in the axial plane, since it passes posterior to anterior (Fig 3). The sphenoid sinuses may have aerated extensions into the pterygoid plates (44% of patients) or into the clinoid processes (13% of patients) (4,5).

The nasal cavity typically has three sets of turbinates—the superior, middle, and inferior turbinates—divided by the midline nasal septum. Occasionally, one may identify a fourth superiormost turbinate, the supreme turbinate. An aerated middle turbinate, which usually communicates with the anterior ethmoid air cells, is termed a *concha bullosa* and is seen in approximately 34%–53% of patients (1–3). The vertical attachment of the middle turbinate is pneumatized more commonly than its inferior bulbous portion, and an air cell in this area is termed an "intralamellar cell." Pneumatization of the inferior or superior turbinates is much less common (less than 5% of patients) (1).

Paradoxical middle turbinates are ones that are concave medially rather than laterally. In our experience this occurs in less than 10% of the population (3), but another study has found this variation in 26% of cases (1). Large paradoxical turbinates have been implicated as a possible cause of middle meatus obstruction.

The nasal septum is composed of three parts. There is a cartilaginous anteroinferior portion, a bony posteroinferior portion known as the vomer, and a superoposterior bony portion, the perpendicular plate of the ethmoid bone. The nasal septum is only rarely aerated. Nasal septal deviation, however, is quite common, and bone spurs often develop at the apex of the deviation, usually at the junction of the perpendicular plate, cartilaginous septum, and vomer. Spurs may cause the sensation of nasal obstruction.

The nasolacrimal duct courses downward from the lacrimal sac along the medial canthus, where it is in proximity with *agger nasi* air cells. Inflammation of *agger nasi* cells may be associated with epiphora because of this close relationship (6). The duct



**Figure 1.** Ostiomeatal complex (OMC) on coronal CT scan. A 3-mm-thick CT section obtained with 120 kVp, 100 mA, and 2-second scanning in the coronal plane with a bone algorithm and filmed with window width of 3,000 and level of 300 demonstrates bone anatomy of the OMC well. The left maxillary sinus ostium (solid arrow) and infundibulum (arrowheads) are below the large ethmoidal bulla (B). Medial to the right uncinate process (open arrow) one identifies the middle meatus air channel, bounded medially by the middle turbinate (t). The insertion of the right middle turbinate into the lamina papyracea of the orbit can be seen. This patient has mild nasal septal deviation with a small spur on the left.

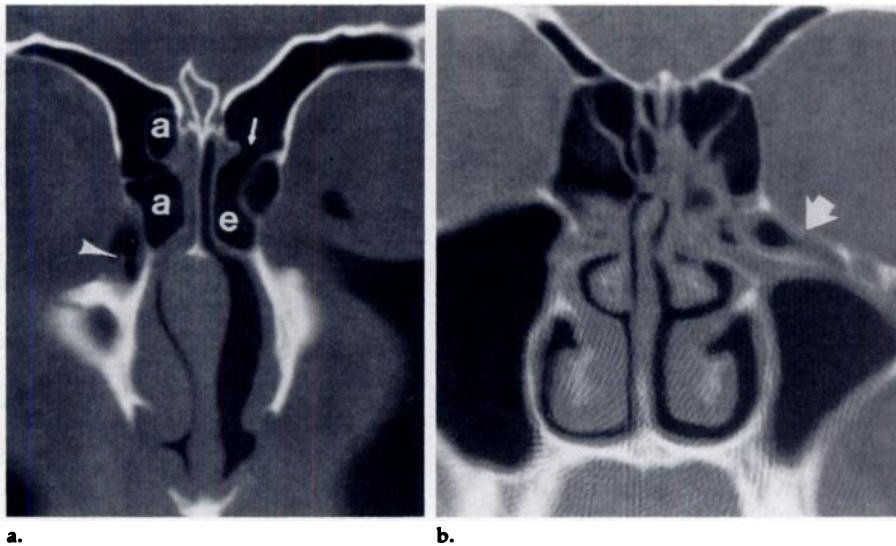
subsequently runs in the anterior portion of the lateral nasal wall. Its ending opens below the inferior turbinate at the inferior meatus.

## IMAGING MODALITIES

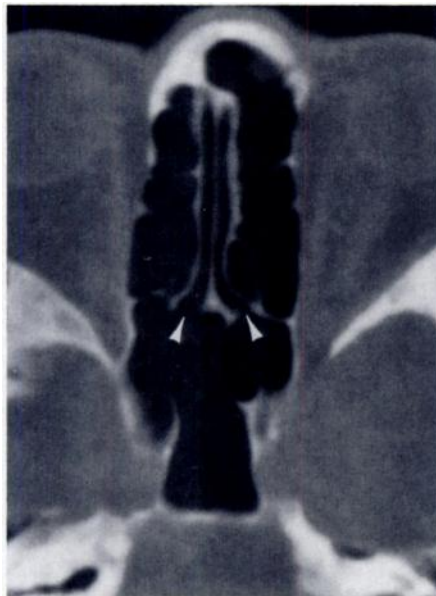
### Plain Radiography

The plain radiographic examination in sinonasal imaging consists of acquisition of Waters, Caldwell, lateral, and submental vertex views. While the utility of the plain radiographic series in evaluating sinonasal malignancies is relatively limited, it is still ordered frequently in the evaluation of routine sinusitis. For the identification of air-fluid levels suggestive of acute sinusitis in the maxillary antrum, plain radiography is still a relatively easy and sensitive examination. However, for the evaluation of chronic sinusitis where mucosal thickening alone may be present, the drawback of overlapping structures makes the evaluation of the OMC, anterior ethmoid sinus, middle meatus, and sphenoid sinus somewhat limited.

If one is searching for a localized cause of sinusitis or if surgical intervention is contemplated, a more exact look at the anatomy is required. This is typically obtained with CT scans.



**Figure 2.** Frontoethmoidal recess, agger nasi cell, and Haller cell on coronal CT scans. (a) A wide frontoethmoidal recess (arrow) is seen on the left side with communication to an anterior ethmoid air cell (e). As this section is anterior to the middle turbinate's cribriform plate attachment, the ethmoid air cells seen are agger nasi cells (a on right). Note their proximity to the nasolacrimal fossa (arrowhead). (b) A Haller cell (arrow) is seen below the left orbit. This cell contributes to the narrowing of the left infundibulum. Associated OMC and superior maxillary sinus inflammatory change are present.



**Figure 3.** Sphenothmoidal recess on axial CT scan. The exits from the sphenoid sinus into the posterior nasal cavity are seen bilaterally (arrowheads). The ostia leading from posterior ethmoid air cells are usually not definable.

The decline in the role of plain radiography is exemplified by a recent study that showed the plain radiographs ordered by ophthalmologists were useless 98.5% of the time, led to unnecessary additional studies in 20% of "abnormal" plain radiographic studies, and were normal in 86% of studies ordered (7).

The advantages of plain radiography of the paranasal sinuses are its

low cost, small radiation dose, ease of performance, and capability for portable examination. At our institution, where an active FESS team is present, plain radiography is ordered infrequently. Sinonasal endoscopy has replaced plain radiography as a screening test in patients with chronic or recurrent sinusitis. Plain radiography is most often ordered at our hospital in the evaluation of a fever of unknown origin in patients in the intensive care units who are unable to be transported for CT. For the general practitioner suspicious of sinusitis in a patient with equivocal clinical findings, a positive plain radiographic examination may be a low-cost confirmatory test for sinusitis. However, a negative radiographic examination should not eliminate sinusitis from the differential diagnosis. Endoscopy, CT, or both must follow if suggestive symptoms persist.

### CT Scanning

The role of CT in providing a road map for the functional endoscopic sinus surgeon is well known. To understand the purpose of CT examination of the sinonasal cavity, one must understand the rationale for FESS.

The goal of FESS is to maintain the normal mucosa of the sinonasal cavity in order to preserve the normal pathway of mucociliary clearance. Therefore, rather than create an alternate egress of mucus from the maxillary sinus, as in an inferior meatal antros-

tomy (the Caldwell-Luc procedure), FESS enlarges the natural ostia and passageways of the paranasal sinuses. Whereas in the past maxillary and frontal sinusitis was thought to be a primary process in patients with chronic sinusitis, it is now believed that these sinuses are secondarily obstructed due to disease in the ostiomeatal complex. Disease at the ostium and inferior infundibulum obstructs the maxillary sinus, whereas disease in the middle meatus and anterior infundibulum obstructs the frontal and anterior ethmoid sinuses. Therefore, surgery is directed toward removing potential obstacles to mucociliary clearance at the OMC. Persistence of chronic sinusitis after nasoantral windows (nasal antrostomies) is usually due to anterior ethmoid disease. Therefore, amputation of the uncinate process, enlargement of the infundibulum and maxillary sinus ostia, and creation of a common unobstructed channel for the anterior ethmoid air cells are common practices at FESS. Usually FESS also includes complete or partial ethmoidectomy. In a similar vein, FESS does not attempt to strip the mucosa clean, as in a Caldwell-Luc procedure. Mucociliary motility is preserved.

The surgery is done by means of an intranasal endoscope rather than with an external approach, so knowledge of the bone landmarks is essential to planning surgery. Posterior ethmoid and sphenoid sinus access can also be obtained with the nasal endoscope but requires greater expertise. Posterior ethmoidectomy and sphenoidotomy are not performed routinely except by very experienced FESS practitioners. The surgeon must know where he or she is at all times in order to prevent complications such as orbital or intracranial entry, particularly when operating posteriorly in the sinonasal cavity.

For the FESS surgeon, coronal CT scans are ideal, as they simulate the appearance of the sinonasal cavity from the point of view of the endoscope. Because the otorhinolaryngologists have used CT more frequently as their screening and mapping study of the sinonasal cavity, an impetus for reducing the cost of the study and limiting the radiation dose has led to proposals for new protocols for performing sinus CT (8,9).

At our institution, CT scanning performed for cases of uncomplicated sinusitis referred by an otorhinolaryngologist consists of acquisition of 5-mm-thick contiguous coronal sections through the anterior frontal



sinuses, 3-mm-thick contiguous sections through the OMC, and 5-mm-thick sections through the sphenoid sinus. These scans are obtained at a plane perpendicular to the hard palate with 120 kVp, 100 mA, and 2-second scanning. Because the bone anatomy is most critical to the endoscopic-sinus surgeon, we perform the study by using a bone algorithm technique with very wide window widths (3,000–4,000), and high window levels (300–400). This technique does allow evaluation of the subtle mucosal thickening while preventing obscuration of thin bony septa. The same parameters have been embraced by Babel et al (8). It is insufficient to study the orbit or brain, however.

For the evaluation of sinusitis by non-otorhinolaryngologists or for the evaluation of complicated sinusitis, we obtain axial 5-mm contiguous sections parallel to the hard palate through the maxillary sinuses to the top of the frontal sinuses. These scans are followed by the coronal protocol listed above. The axial scans, however, are obtained with a standard soft-tissue algorithm and filmed both with bone windows and soft-tissue windows. These scans are reviewed by a neuroradiologist to decide whether intravenous contrast material is required for further evaluation. If complications of sinusitis—such as epidural abscess, meningitis, periorbital abscess, subperiosteal abscess, or cavernous sinus extension—are suspected, iodinated contrast agents should be given.

As a low-cost alternative, some radiology departments offer a limited coronal scanning protocol through the paranasal sinuses. This includes acquisition of one or two sections through each of the four pairs of sinuses (8,9). With an eight-section technique, throughput can be increased, the cost lowered, and the radiation dose limited. Because ethmoid air cells may be small and because even limited disease can produce obstructive symptoms, we do not advocate these protocols at our institution. Others have experimented with low milliamperes-second techniques to reduce the radiation exposure (9). With 30–60 mA and 2-second scanning, Duvoisin et al showed that good-quality scans can be obtained rapidly, but there is definite mild deterioration of signal-to-noise ratio and of anatomic depiction with an increased susceptibility to streak artifacts (9). We believe that a scan obtained with 100 mA over 2 seconds is a good compromise between

decreased radiation dose and optimal image quality.

To eliminate the effects of reversible sinus congestion, patients undergoing CT for evaluation of chronic sinus disease are best scanned 4–6 weeks after medical therapy and not during an acute infection. Some radiology departments also administer nasal spray decongestants or antihistamines to reduce reversible mucosal edema prior to placing the patient in the scanner. This aids in assessing the nonreversible sinus disease.

CT scans of the sinuses are not without potential problems. In a study by Bingham et al (10), some pitfalls of CT examinations of the sinuses were identified (10). These included (a) inability to assume hyperextended neck position for coronal scanning (5%), (b) claustrophobia (3%), (c) polypoid obstructing views of the OMC, (d) incorrect windows for identifying intraorbital or intracranial disease, (e) inability to distinguish scarring or granulation tissue from inflammatory disease, and (f) poor visualization of the frontoethmoidal recess. How can one correct these failures? By using meticulous technique and filming at appropriate windows. Coronal scans can be obtained with the patient in a prone or supine (head lowered below the table) position; reconstructed coronal views from thin-section (1–2-mm) axial scans may suffice in some instances. If thin sections are taken through the intricate frontoethmoidal anatomy, identification of the OMC and frontoethmoidal recess should be achieved. Granulation tissue may enhance in a solid fashion, whereas most inflammatory thickening shows only peripheral enhancement. If the scar tissue is thin, then it, inflammatory tissue, and normal thickened mucosa will all look alike. Mature scar tissue may not enhance or may enhance only minimally.

### MR Imaging

The MR examination of the sinonasal cavity can be performed in a standard head coil or, if more precise anatomic resolution is needed, with a surface coil placed over the anterior portion of the face. A 5-inch (12.5-cm) round general-purpose coil usually will cover the region of the OMC and frontoethmoidal sinuses, although the sphenoid sinus may be insufficiently examined because of the lack of deep penetration with this coil. Coronal images, again, are the mainstay of sinonasal imaging even with MR. Axial images are also obtained to best eval-

uate the sphenoid sinus and the relationship of sinonasal disease to the orbit, cavernous sinus, carotid arteries, and optic nerves. T1-weighted and T2-weighted images are both required because of the variability of signal intensity of sinonasal secretions because of protein concentration. The fast-spin-echo techniques (rapid acquisition with relaxation enhancement, RARE) for T2-weighted imaging may be of extra benefit in the sinonasal cavity because of their reduced sensitivity to susceptibility artifacts at bone-air-soft-tissue interfaces (11–13). However, fat tends to be high in signal intensity on fast-spin-echo images owing to reduced J-coupling dephasing effects brought about by the repetitive 180° pulses (14,15). Therefore, fat-suppression techniques should be employed with fast imaging so that the fatty borders of the sinuses are dark, to highlight high-intensity inflammation or intermediate-intensity tumor. Gadolinium-enhanced T1-weighted images are employed for the evaluation of complicated sinusitis or for suspected neoplastic disease. Differentiating tumors from infections of the sinonasal cavity may be best achieved with contrast material-enhanced MR: The inflamed mucosa around infected secretions enhances in a peripheral fashion, whereas tumors usually enhance solidly and centrally. The borders of the tumor with inflamed mucosa may be obscured because both will enhance. Fat-suppressed gadolinium-enhanced T1-weighted images are required when evaluating the fat-filled orbits and the skull base.

### SINUSITIS

From the standpoint of a public health hazard, sinusitis ranks as one of the most common afflictions suffered by Americans. It is estimated that over 31,000,000 people in the United States are affected by sinus inflammatory disease each year, and 16,000,000 visits to primary care physicians annually are for sinusitis and its complications (16). Adults average two or three colds per year, and 0.5% of viral upper respiratory infections are complicated by sinusitis (17). Overall, Americans spend over \$150,000,000 per year for over-the-counter cold and sinusitis medicines, \$100,000,000 of which is for antihistamine medications (16).

Most cases of acute sinusitis are related to an antecedent viral upper respiratory tract infection. With mucosal congestion as a result of the viral

infection, apposition of mucosal surfaces occurs in the paranasal sinuses. Once this occurs, obstruction of the normal flow of mucus results in a retention of secretions, creating a favorable environment for bacterial superinfection. The ethmoid sinuses are most commonly involved in sinusitis, possibly because of their position in the "line of fire" as inspired particles impact and irritate the fragile ethmoid sinus lining. The bacterial pathogens responsible for acute sinusitis include *Streptococcus pneumoniae*, *Haemophilus influenzae*, beta hemolytic streptococcus, and *Moraxella catarrhalis* (16,18). In the chronic phase, staphylococcus, streptococcus, corynebacteria, bacteroides, fusobacteria, and other anaerobes may be responsible. The fungi that may infect the sinuses include *Aspergillus* species, mucormycosis, *Candida* species, *drechslera*, *curvularia*, and *Candida* species (19,20).

The workup of a patient with sinusitis has changed over recent years because of the advent of experienced intranasal endoscopists. While acute bouts of sinusitis are typically treated medically and the diagnosis is usually made on a clinical basis, patients with recurrent or intractable sinusitis often are referred to the otorhinolaryngologist for evaluation. In a patient with recurrent or chronic symptoms (debilitating headache, facial pain, or congestion) or persistent symptoms after medical therapy, intranasal endoscopy is usually performed. On the basis of the endoscopic findings and the clinical symptoms, the patient may be treated with a second long-term course of antibiotics. If medical therapy fails again and the endoscopic findings suggest surgically correctable abnormalities, CT scanning is requested.

Why not order plain radiography instead? Besides its inability to show the relevant anatomy to guide the surgeon, plain radiography has limited accuracy. Using air-fluid levels and opacification as criteria of disease and antroscopy as the standard of reference, Kuhn found that the sensitivity of plain radiography was 54% and specificity was 92% (21). With the criterion of mucosal thickening, the numbers were nearly reversed: sensitivity was 99% and specificity was 46%. These maxillary sinus accuracy rates are higher than expected in the other sinuses, since soft-tissue overlap is less of a problem in the antra. With antral aspiration used as a standard, another study found plain radiography to be accurate in only 63%–82% of cases of maxillary sinus infection (17). This has led to wider use of CT.

When evaluating a CT scan in a preoperative patient before FESS, several issues must be addressed (22). Is the uncinate process apposed to the medial orbital wall (an atelectatic infundibulum)? If so, its vigorous removal may result in orbital penetration. Are there areas of dehiscence in the lamina papyracea or do the orbital contents protrude into the ethmoid sinus, both of which may lead to unintentional orbital entry from the ethmoid sinus? Defects in the lamina papyracea have been reported in 5%–10% of autopsy specimens (5,23). Because orbital hematomas are the most common orbital complication of FESS, it is important to identify any gaps in the lamina papyracea (24–26). CT obviously is the best means for identifying the thin medial bony wall of the orbit. However, orbital (and cribriform plate) perforations at the time of FESS often occur through areas of nondehiscence because of overly vigorous surgical technique.

Is the internal os of the frontal sinus occluded with bone? Bone disease of the frontal sinus typically precludes an endoscopic approach. Are there areas of dehiscence in the cribriform plate? Another uncommon but serious complication of FESS is the production of a dural tear leading to a cerebrospinal fluid leak. By identifying areas of dehiscence in the cribriform plate, reported in 8.5%–14% of patients at autopsy, the radiologist effectively warns the endoscopic sinus surgeon (5,23).

Are the bony walls between the sphenoid sinus and the optic nerve intact? It has been shown that in 4% of patients there is no bony border between the optic nerve and the sphenoid sinus and in 78%–88% of patients the bone is less than 0.5 mm thick (4,5). The posterior ethmoid air cells contact the optic canal in 48% and also may have a very thin bone border (4). There have been limited reports of optic nerve transection during sphenoethmoidectomy from an intranasal approach, and dehiscence of the sphenoid wall may be a predisposing factor. Additionally, the relationship of the posteriormost ethmoid air cell to the sphenoid sinus and to the optic nerve is important, since the sphenoid sinus is typically entered through this cell (5). If an Onodi cell extends far lateral to the lateral wall of the sphenoid sinus, the endoscopist must remain close to the midline as he or she perforates into the sphenoid sinus. Otherwise orbital entry may occur near the orbital apex, a site where the risk of injury to the extra-

ocular muscles or nerves is very high. By the same token, the angle at which the sphenoid sinus should be entered, based on the superior and inferior relationships of the Onodi cell and sphenoid sinus, may be determined on the basis of the preoperative CT scan (and best with a sagittal reconstruction).

In 8%–14% of autopsy cases, there is no bone between the internal carotid artery and the sphenoid sinus (23). An intersinus septum in the sphenoid sinus, which attaches to the carotid canal, is important to recognize preoperatively and is typically best identified in the axial view. Removal of such an intersinus septum during surgery may result in carotid laceration. Consideration should therefore be given to routine acquisition of axial CT scans when sphenoid sinus surgery is contemplated.

Preoperatively, the sinus surgeon examines the height of the ethmoid roof in relationship to the cribriform plate (5). Normally the cribriform plate is lower than the ethmoid roof, and therefore the surgeon can dissect more superiorly if he or she proceeds laterally along the ethmoid roof during ethmoidectomy. Variations in this anatomy should be cited in radiologic reports. The presence of middle turbinate pneumatization (concha bullosa) and/or opacification will be inapparent to the endoscopic sinus surgeon looking at the mucosal surface only. The radiologist can identify this normal variant and determine if it is compromising the middle meatus.

Because of all of these factors that the endoscopic sinus surgeon must evaluate prior to and during the surgery, good-quality CT scans are critical at the time of the operation. We provide "operating room copies" of the coronal sinus scans for all surgical cases. Teatini et al stated "few organs of the human body are liable to such remarkable intersubject and intrasubject variations as the paranasal sinuses" (5). This is certainly true and, unfortunately, creates considerable peril for the endoscopic surgeon. The radiologist and the operating room CT scan can be the navigators.

In addition to commenting in the CT report on the normal anatomic variations, the radiologist should identify areas of mucosal thickening and sinus passageway opacification. It has come to be accepted that the location of sinusitis is more important in producing a patient's symptoms than the extent of the sinusitis. Therefore, a subtle area of opacification in the infundibulum of the OMC may cause

more pain and discomfort than near complete opacification of the maxillary sinus with a mucous retention cyst and/or polyp. According to Kennedy et al, CT almost always causes underestimation of sinus mucosal thickening compared with what is seen at endoscopy, despite high-resolution imaging with appropriate windows and section thicknesses (27).

OMC opacification correlates well with the development of sinusitis (Fig 4). Yousem et al found that the positive predictive value of infundibular opacification for the presence of maxillary sinus inflammatory disease in 100 consecutive patients was 79% (3). When the middle meatus was opacified, the maxillary and ethmoid sinuses showed inflammatory change in 84% and 82% of patients, respectively (3). The specificity of middle meatus opacification for maxillary or ethmoid sinus disease was 93%. Another study found frontal or maxillary sinus disease in 84% of patients who had OMC opacification (1). Bolger et al demonstrated that when the infundibulum was clear, the ipsilateral maxillary and frontal sinuses were free of disease in 77% of cases (1). Anterior ethmoid disease was present in 84% of patients with chronic sinusitis and 19% without sinus symptoms (1). Zinreich et al found middle meatus opacification in 72% of patients with chronic sinusitis, and, of these patients, 65% had maxillary sinus mucoperiosteal thickening (28). Isolated OMC disease without frontal, maxillary, or ethmoid disease was uncommon (28). Of patients with frontal sinus inflammation reported in the study of Zinreich et al, all had opacification of the frontoethmoidal recess. These findings support the contention that obstruction of the narrow drainage pathways will lead to subsequent sinus inflammation.

After analyzing CT scans of 500 patients, Babbal et al categorized recurrent inflammatory sinonasal disease into five patterns: infundibular, ostiomeatal unit, sphenothmoidal recess, sinonasal polyposis, and sporadic or unclassifiable disease (29). The infundibular pattern was seen in 26% of patients and referred to isolated obstruction of the inferior infundibulum, just above the maxillary sinus ostium. Limited maxillary sinus disease often coexisted with this pattern, whereas the ostiomeatal unit pattern, seen in 25% of cases, often had concomitant frontal and ethmoidal disease (29). The ostiomeatal unit pattern was designated when middle meatus opacification was present. Sphenoth-

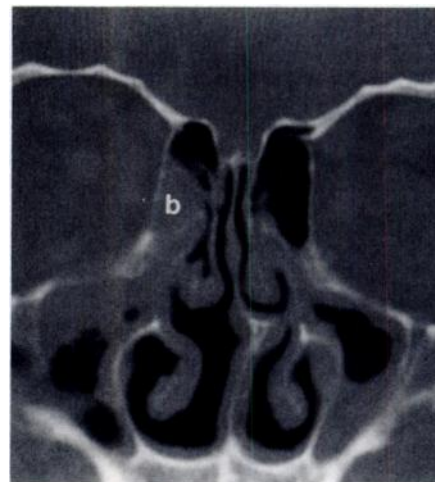
moidal recess obstruction occurred in 6% of cases and led to sphenoid or posterior ethmoid sinus inflammation. When the sinonasal polyposis pattern was present, enlargement of the ostia, thinning of adjacent bone, and air-fluid levels were often seen.

In the study of Yousem et al, the presence of a greater degree of nasal septal deviation and a horizontally oriented uncinate process correlated with an increased prevalence of sinus inflammation (3). The presence of a concha bullosa did not increase the risk of sinusitis. This work has been duplicated in another study in which the presence of a concha bullosa, paradoxical turbinates, Haller cells, and uncinate pneumatization were not shown to have a significantly higher rate in patients with chronic sinusitis than in patients without sinus symptoms (1). It appears that the size, not the presence, of these normal variations is the critical factor. Even when small, however, these variations are worth reporting, since they help guide endoscopy.

The presence of air-fluid levels on plain radiographs or CT scans of the sinuses are more typically associated with acute sinusitis than chronic inflammatory disease. Of course, acute sinusitis may be superimposed on chronic changes. The findings suggestive of chronic sinusitis include mucosal thickening, bone remodeling, polyposis, and bone thickening secondary to osteitis from adjacent chronic mucosal inflammation.

Hyperattenuating secretions on CT scans may be due to inspissated secretions, fungal sinusitis, or hemorrhage in the sinus. The hyperattenuating sinus may be the only clue to fungal sinusitis and is an important feature to note. However, chronic sinusitis infected with bacteria occasionally will be hyperattenuating at CT, particularly in patients who have very longstanding disease or cystic fibrosis. The hyperattenuating sinus often corresponds to the hypointense sinus on T2-weighted MR images.

What then is the role for MR imaging in the evaluation of a patient with chronic uncomplicated sinusitis? I believe that MR is more sensitive to mucosal thickening than CT (and the potential for improvement is there according to Dr Kennedy's assessment of CT). Sinus thickening is usually seen as high signal intensity on the T2-weighted image against the black background of air and/or cortical bone. On T1-weighted images the mucosal thickening is low in intensity.

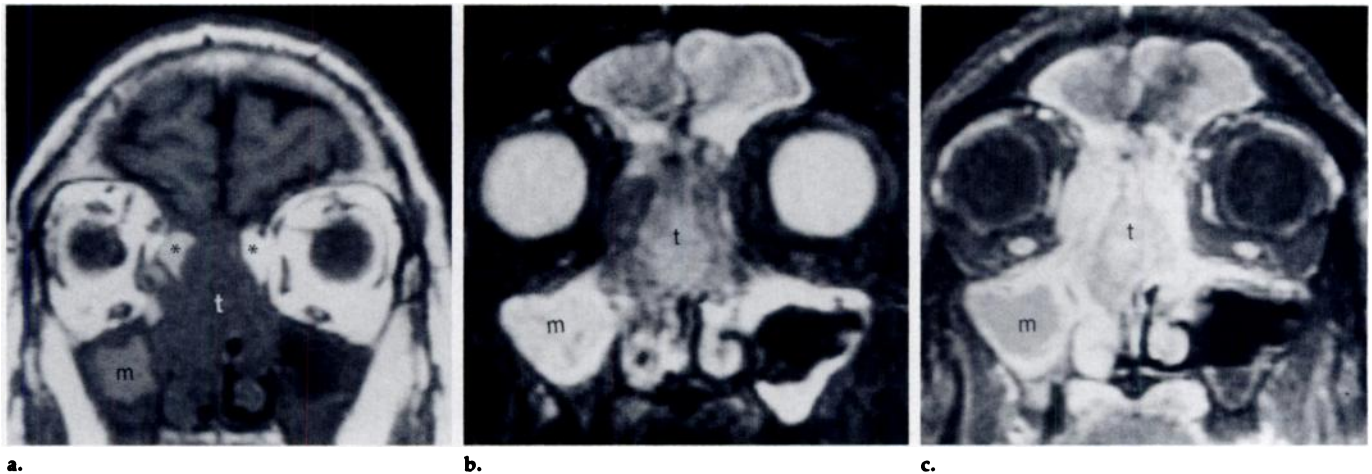


**Figure 4.** Bilateral OMC disease in a patient with chronic sinusitis. Bilateral opacification of the infundibula and maxillary sinus ostia can be seen in this patient with chronic sinus drainage. The left hiatus semilunaris and middle meatus are also opacified at the level of the middle turbinate (cf normal Fig 1a). This patient also has a nasal septal spur and deviation to the left. Maxillary sinus mucoperiosteal thickening is present bilaterally, and the right bulla (b) is obstructed.

The sensitivity of MR to mucosal thickening accounts for the visualization of the normal nasal cycle as described by Zinreich et al and Kennedy et al (30,31). There is cyclical passive congestion and decongestion of each side of the nasal turbinates, nasal septum, and ethmoid air cell mucosa over a 50-minute to 6-hour period in humans. Thus, 1–2 mm of ethmoid sinus mucosal thickening may not be due to inflammatory disease but may reflect the normal intermittent congestion of the nasal cycle. In a similar vein, asymmetry in the size and intensity of the nasal turbinates is normal. Because many radiologists are not aware of the presence of this nasal cycle (it is not readily apparent or described on routine CT scans), there has been a gross tendency to interpret increased signal intensity from the turbinates and ethmoid sinus as a pathologic finding on MR images. This accounts for some of the studies in the literature claiming that MR is an inaccurate study for the evaluation of sinusitis.

This overcalling of the normal nasal cycle as ethmoid sinusitis notwithstanding, there is a high incidence of sinus inflammatory mucosal disease in asymptomatic patients. The prevalence of incidental sinus mucosal thickening on CT scans of the paranasal sinuses in asymptomatic patients ranges from 39% to 43% (32,33). In the asymptomatic population the





**Figure 5.** Squamous cell carcinoma of the maxillary sinus with obstructed secretions. (a) Patient with squamous cell carcinoma demonstrates a variety of signal intensities in her sinonasal cavity on this T1-weighted (repetition time msec/echo time msec [600/17]), coronal image. One can see intermediate-intensity tumor (*t*) in the nasal cavities and along the midline septum. In the right maxillary sinus (*m*) there is central high signal intensity and peripheral low to intermediate signal intensity obstructed secretions and mucosa, respectively. In the left maxillary antrum the secretions are low in intensity centrally and intermediate peripherally. The lateral ethmoid sinuses bilaterally also show air cells with high intensity (\*). The intensity variations reflect different protein concentrations in the sinuses and tissue differences between secretions, tumor, and mucosa. (b) On this T2-weighted (3,000/90) image, one identifies intermediate-intensity tumor (*t*), high-intensity secretions centrally in the right maxillary antrum (*m*), and low-intensity secretions centrally with bright mucosa peripherally in the left maxillary antrum. (c) The gadolinium-enhanced fat-suppressed short repetition time image shows solid enhancement in the tumor (*t*) and peripheral enhancement in the maxillary antrum (*m*). The high-intensity secretions in the right maxillary antrum (*m*) simulate contrast material enhancement.

presence of ethmoid sinus disease (28.4%) predominates over maxillary sinus disease (24.8%), which is more common than sphenoid (7%–11%) and frontal sinus (4.8%) mucosal changes (32,34). Of all the sinuses, sphenoid sinus opacification is most likely to cause symptoms (34). Mucosal thickening is the most common finding, but polyps and/or mucous retention cysts may often be found in asymptomatic patients. In asymptomatic patients with a history of seasonal allergies, the prevalence of abnormal sinus CT scans is 54.4% (32). In children younger than 1 year old, 70% will have opacified sinuses, with the maxillary sinus more commonly affected than the ethmoid sinus (35). The significance of sinus opacification in children is limited, since redundant mucosa, congestion from crying, and tears can cause opacification.

When asymptomatic patients are evaluated with MR for sinus inflammatory changes, approximately 13%–63% of patients have abnormal sinuses (36–39). The predominant finding is mucoperiosteal thickening, just as at CT, followed by mucous retention cysts (38). Again, maxillary (27%–39%), ethmoid (6%–25%), or combined maxillary and ethmoid (43%) sinus inflammatory disease predominates (36,37). In the presence of an upper respiratory tract viral infection, the sinuses are abnormal on MR images in 65% of patients, whereas if there is no history of a cold, the MR image is abnormal in 34% of cases

(37). Even when ethmoid sinus thickening of 1–2 mm is eliminated from consideration (to account for the nasal cycle), over 35% of asymptomatic patients have changes of mucosal thickening (39). Polyps are seen in a smaller percentage, and, in approximately 3%–5% of asymptomatic patients, air-fluid levels or total sinus opacification may be found within the paranasal sinuses (37–39). Sphenoid sinus disease can be seen in 6%–8% of patients undergoing MR or CT of the brain; of these, approximately 25% have symptoms including visual problems and meningitis (34).

Why is MR not employed in the routine evaluation of patients suspected of having sinusitis? Why not spare the patient ionizing radiation? Again, this harks back to the primary goal of imaging prior to FESS: to map the bony anatomy for preoperative planning. Because bone and air are seen as signal voids on MR images, MR has less utility for surgical planning. A surgical map is not possible.

Another drawback of MR is the problem of signal intensity and sinus secretions. Sinonasal secretions are not simply bright on T2-weighted images and dark on T1-weighted images. Som et al described the changes in signal intensity of sinonasal secretions on the basis of protein concentration and mobile water protons (40). The changes are probably due to the increased cross-linking of glycoproteins in hyperproteinaceous secretions, which leads to fewer free water

protons available and more bound protons (bound to glycoproteins). Som et al found that as protein concentration increased, the signal intensity on T1-weighted images of sinus secretions changed from hypointense to hyperintense to hypointense again. These changes paralleled changes in viscosity. On the T2-weighted images, hypoproteinaceous watery secretions were initially bright, but as the protein concentration and viscosity increased, the signal intensity on T2-weighted images decreased. Therefore, the authors were able to describe four combinations of intensity patterns for sinus secretions: (a) hypointense on T1-weighted images and hyperintense on T2-weighted images in the most liquid form (total protein concentration less than 9%); (b) hyperintense on T1-weighted images and hyperintense on T2-weighted images in the mildly to moderately proteinaceous form (total protein concentration, 20%–25%); (c) hyperintense on T1-weighted images and hypointense on T2-weighted images in a highly proteinaceous form (total protein concentration, 25%–28%); and (d) hypointense on T1-weighted images and hypointense on T2-weighted images when the secretions are in a near solid form (total protein concentration greater than 28%) (Fig 5) (40). Because of the last combination of signal intensities, there is the potential for misdiagnosing completely opacified sinuses at MR, since the concretions of very hyperproteinaceous secretions

may show a signal void simulating aeration on both T1-weighted and T2-weighted images (41,42). This is also a potential pitfall when evaluating a patient with a hyperproteinaceous mucocele (41,43,44).

Other potential pitfalls in which a signal void may be encountered on both T1-weighted and T2-weighted images include osteomas, odontogenic lesions, osteochondromas, fibrosis, and fungal sinusitis mycetomas (42). The hypointensity of fungal sinusitis is thought to be secondary to the paramagnetic effects of either iron or manganese produced by the fungi (Fig 6) (19,20). Fungi are also a cause of a hyperattenuating sinus on CT scans (19).

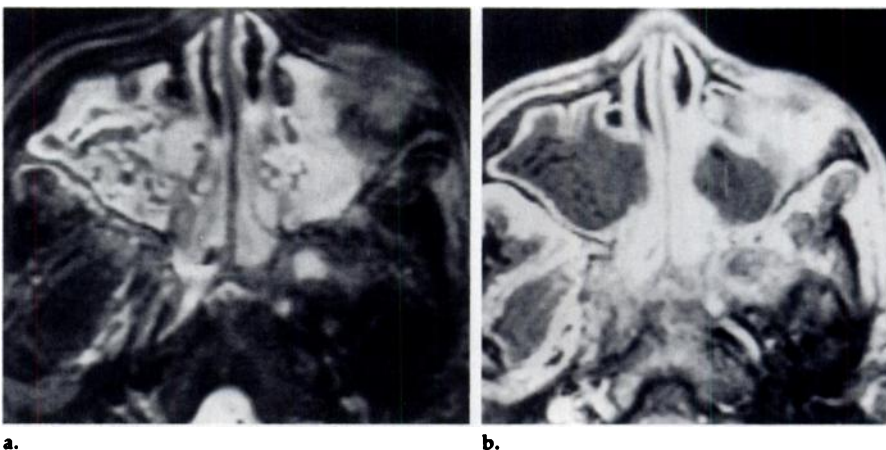
Since chronically obstructed sinus secretions may have any combination of signal intensities, it may be difficult to distinguish inflammation from neoplasm solely on the basis of intensity patterns. For this reason, the presence of rim gadolinium enhancement is a reassuring finding that suggests inflammation rather than neoplasm (which enhances centrally).

Postoperatively, neither CT nor MR is highly accurate in distinguishing fibrosis from inflammation. Both will enhance and appear as mucosal thickening. The absence of disease on a postoperative study is reliable, but false-positive studies occur frequently (45).

### COMPLICATED SINUSITIS

While MR has a limited role in the evaluation of uncomplicated sinusitis, MR has great potential for evaluating intracranial and intraorbital complications of sinusitis. The complications of sinusitis, including meningitis, thrombophlebitis, subdural empyemas, intracranial abscesses, and perineural or perivascular spread of infection, are well depicted with MR.

MR has been shown to be superior to CT in the evaluation of the meninges in many other settings. For detection of meningitis, gadolinium is required in order to identify contrast-enhancing abnormal meninges (Fig 7). A subdural or epidural collection associated with infection will be seen without gadolinium but may also imitate contrast material and is generally much thicker than pachymeningitis. Epidural or subdural abscesses may be drained surgically; meningitis is treated medically, so this distinction may be significant. Occasionally one will identify pial enhancement deep into the sulci of the brain. While this finding is relatively uncommon, it is



**Figure 6.** Hypointense secretions of fungal sinusitis on MR images. (a) T2-weighted image of a patient with documented aspergillus infection shows low-intensity areas amidst the high-intensity secretions of the right maxillary antrum. This probably represents saprophytic growth of the fungus in the sinus. (b) Gadolinium-enhanced T1-weighted image demonstrates a peripheral pattern of enhancement in the infected sinus and low-intensity secretions.

fairly specific for meningeal irritation (46).

Thrombophlebitis may occur due to adjacent sinusitis, but it is more commonly seen with mastoiditis. Sigmoid sinus venous thrombosis and venous infarction may complicate mastoiditis and petrous apicitis. In the paranasal sinuses, the most common venous channel involved is the cavernous sinus, and thrombosis is usually associated with sphenoid sinus inflammation (47). A less common cause of sinus thrombosis is frontal sinusitis. On the other hand, frontal sinusitis may lead to superficial vein thrombosis and or meningeal spread of the sinus infection. MR is superior to CT for the diagnosis of sinus thrombosis and its complication, venous infarction.

There are advantages and disadvantages to both CT and MR in the evaluation of the orbital complications of sinusitis. Because of the low-density fat in the orbit, orbital cellulitis is usually well seen with CT. MR, with its high-intensity fat on T1-weighted images, is competitive with CT for the evaluation of orbital cellulitis. While CT is superior for identifying defects in the lamina papyracea and or breaches of the bony walls of the ethmoid sinus by inflammation, it is not as useful in the evaluation of the orbital apex. When CT and surgical findings were compared in 19 cases of orbital complications of sinusitis, surgery corroborated CT findings in 16 abscesses (84%), but there were two false-positive and one false-negative cases (48).

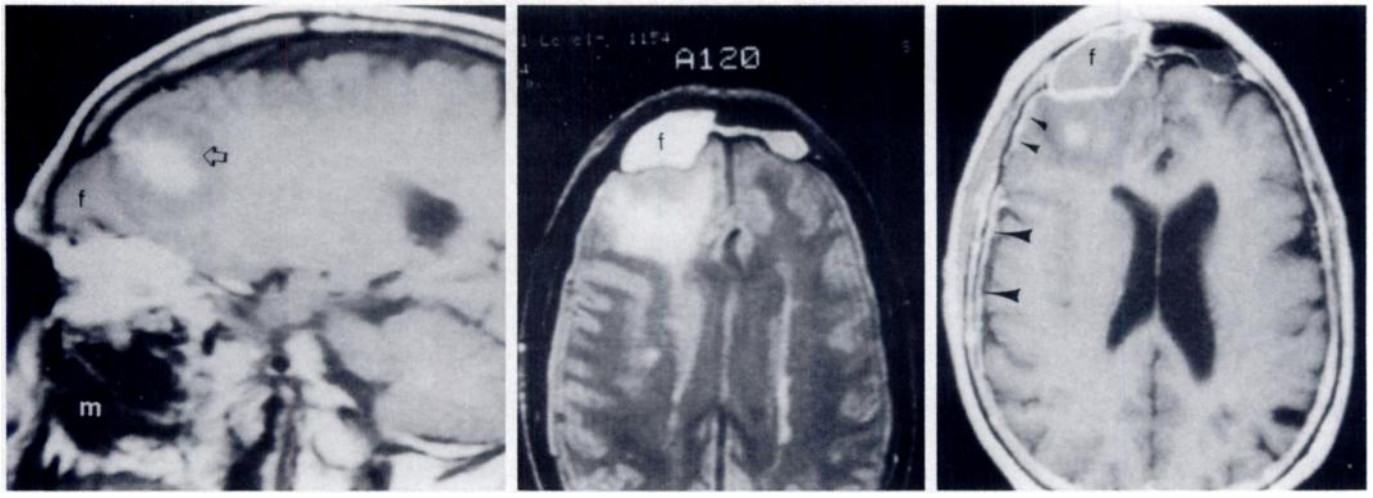
Because of the lack of signal intensity from bone at the orbital apex, inflammation in the orbit is well evaluated with MR. If an inflammatory

process extends from the orbital apex into the cavernous sinus, MR also has the advantage, since bone creates CT artifacts there. Both T1-weighted images, which demonstrate bright orbital fat and dark inflammation, and fat-suppressed T2-weighted images, which demonstrate dark fat and bright inflammation, may depict orbital and cavernous sinus complications of sinusitis. Additionally, the superior ophthalmic vein may be evaluated noninvasively with MR through the use of vascular flow gradient-echo imaging. Differentiation of optic nerve from optic nerve sheath abnormalities are also best seen with T2-weighted MR images. Typically, CT does not allow the sheath to be distinguished from the nerve.

These advantages of MR are of particular value in a patient who has an aggressive fulminant fungal sinus infection, such as mucormycosis or aspergillosis (19,20,47). These fungal infections have a propensity for invasion of the orbit, the cavernous sinus, and the neurovascular structures. Numerous case reports have described the ability of MR to demonstrate fungal spread of sinusitis into the intracranial cavity, resulting in vascular abnormalities including thromboses or parenchymal infarcts. Mucormycosis in particular appears to spread intracranially along the vessels. This fungus grows in the internal elastic membrane of blood vessels; its hyphae may penetrate the lumen of the vessel to occlude it. Prompt detection of this complication can lead to life- or orbit-saving therapy.

With regard to fungal sinus infections, one must understand that there are different levels of aggressiveness





**Figure 7.** Sinusitis, mucocele formation, meningitis, and venous thrombosis demonstrated at MR. (Courtesy of Nazareth Hospital, Rhode Island.) (a) Sagittal T1-weighted image through the right side of the brain demonstrates relatively hyperintense secretions in the right frontal sinus (*f*) compared with the secretions in the maxillary antrum (*m*). There is an area of intracranial hemorrhage with surrounding edema (arrow). (b) Axial long repetition time image shows extensive edema in the right frontal lobe, the right frontal mucocele (*f*), and an air-fluid level in the left frontal sinus. (c) Gadolinium-enhanced image shows peripheral enhancement of the mucocele (*f*), as well as meningeal enhancement along the right side (arrowheads). The high signal intensity in the right frontal lobe was due to hemorrhage. At surgery, the lesion in the right frontal lobe was not infected and represented a benign intracranial hematoma, presumed to be due to cortical venous thrombosis from the mucocele and associated meningitis.

to mycotic infections. Sinonasal mycotic infection is similar in this regard to pulmonary fungal disease. Extramucosal fungal infection may manifest as *polypoid lesions* (due to saprophytic growth on retained secretions in patients with atopy) or as *fungus balls*. These are benign conditions usually caused by aspergillus. Steroid therapy and local excision are sufficient treatment for extramucosal fungal infections. *Infiltrating fungal sinusitis* occurs in an immune-competent host but is not as aggressive as the *fulminant* infection seen in the immune-compromised individual. The fulminant disease is the lethal form of infection and may be caused by mucormycosis or aspergillus. Wide local excision and intravenous administration of amphotericin B are required for extirpation of the invasive mycotic infections. Orbital exenteration and radical surgical therapy often are necessary for fulminant cases, and, even then, the prognosis is grim.

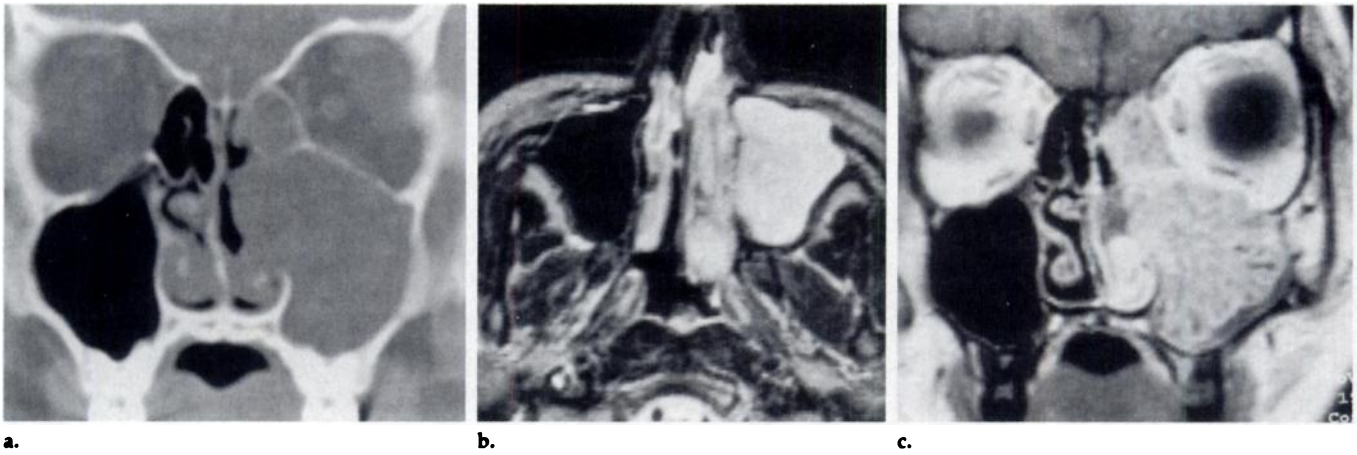
Another complication of sinusitis is a mucocele. While CT best demonstrates the bone distortion associated with mucocele formation, as well as remodeling of the osseous structures suggesting chronicity, MR can best depict its interface with intracranial or intraorbital structures (Fig 7). The signal intensity of mucoceles may vary considerably because of protein content (40,43,44). Mucoceles are most common in the frontal and ethmoid sinuses; sphenoid sinus mucoceles are the least common. Lanzieri et al have

described a peripheral enhancement pattern seen with mucoceles on MR images (43). This pattern is useful for distinguishing mucoceles and obstructed secretions from neoplasms such as inverted papillomas or malignancies, which may also remodel bone but show solid gadolinium enhancement (Figs 5, 7). The sensitivity of enhanced MR for distinguishing mucoceles from neoplasms or both together was 83%–93% in the report of Lanzieri et al; the specificity was 86%–95% (43). Simultaneous carcinoma and mucocele remains a difficult diagnosis to make. As stated earlier, signal intensities on MR images may not be as helpful as enhancement patterns in distinguishing the two. Some neoplasms may be hypointense on T1-weighted images and hyperintense on T2-weighted images, just like nonviscous secretions (Fig 8) (49). However, the tumor will enhance in a solid fashion.

Encephaloceles are better distinguished from sinonasal inflammation with MR than with CT (50). Encephaloceles may occur from congenital defects or may arise in the postoperative setting when the cribriform plate has been violated (24). Particularly if brain herniates downward within the defect, the distinction between inflammation and encephaloceles may be difficult to make with CT. MR usually is very accurate, since brain-tissue signal intensity and sinusitis signal intensity do not overlap. Often, rhinorrhea is the manifestation that elic-

its the imaging study, but this may occur as late as 18 months after surgery (24). Is it due to a dural tear or an encephalocele in the postethmoidectomy patient? MR seems to be the best study.

One of the manifestations of allergic sinusitis is sinonasal polyposis. Polyps may also occur in the absence of allergies and are due to nonneoplastic hyperplasia of inflamed mucous membranes. Nasal polyps occur in approximately 25% of patients with allergic rhinitis and 15% of patients with asthma (50). From an imaging standpoint, this entity is somewhat problematic because the lesion, though benign, may demonstrate fairly aggressive bone distortion. At CT, the findings suggestive of polyposis include enlargement of sinus ostia, rounded masses within the nasal cavity, expanded sinuses or portions of the nasal cavity, thinning of bony trabeculae, and, less commonly, erosive bone changes at the anterior skull base (29,51–53). Because the aggressive skull base erosion might suggest a malignancy, it would be useful if there were specific findings at MR or CT to distinguish polyposis from cancer. Unfortunately, this is not always possible. While the signal intensity of most sinonasal polyps on T2-weighted MR images is high, this overlaps with some of the neoplasms seen in the paranasal sinuses including sarcomas, adenoid cystic carcinomas, and other less common minor salivary gland neoplasms (54–58). Pol-



**Figure 8.** Adenoid cystic carcinoma simulating sinusitis by signal intensities. (Courtesy of Greg Weinstein, MD, Hospital of the University of Pennsylvania, Philadelphia.) (a) Coronal CT scan demonstrates an enlarged opacified maxillary sinus with soft tissue widening the ostium. The differential diagnosis included polyps, a mucocele, and a slow-growing neoplasm. (b) Axial T2-weighted MR image shows high signal intensity in the expanded left maxillary antrum. This was presumed to be due to inflammatory disease, thus favoring the diagnosis of a mucocele or polyp. (c) On gadolinium-enhanced coronal MR image, the lesion shows a solid enhancement pattern, which would be highly atypical for inflammation. At surgery an adenoid cystic carcinoma was found filling the maxillary antrum and anterior ethmoid air cells.

yps usually enhance peripherally, since they represent hypertrophied mucosa, but occasionally they may enhance solidly, as do neoplasms.

Antrochoanal polyps arise in the maxillary sinus but may protrude into the nasal cavity or the nasopharyngeal airway. They are smooth masses that often remodel bone and enlarge the maxillary sinus ostium on CT scans. On T2-weighted MR images they are bright and have a variable amount of contrast enhancement.

Mucous retention cysts develop due to obstruction of small seromucinous glands, usually in the maxillary sinus. In most cases it is impossible to distinguish a polyp from a retention cyst. The distinction is of little clinical relevance. If the endoscopist is told that a patient has a mucous retention cyst, he or she will pay particular attention to that OMC for possible intermittent obstruction. The cyst itself may not be addressed unless obstructive in size.

### POSTOPERATIVE COMPLICATIONS AND OUTCOMES

CT is the study of choice in the acute setting of visual symptoms after FESS. To diagnose an orbital hematoma rapidly, assess for compromise of the optic nerve, and plan therapy to relieve the intraorbital pressure, CT is fast and reliable, and is readily performed in an emergency setting with less risk of eye-motion artifact. Often, however, if vision is deteriorating rapidly, this complication is treated on the basis of clinical findings. Acute

hematomas are usually hyperattenuating on CT scans; occasionally, diffuse orbital fat edema may be the most salient finding. Usually, orbital hematomas are due to transection of an ethmoidal artery at FESS. The artery then retracts into the orbit and continues to bleed. The intraorbital pressure rises with the expanding hematoma, leading to compromise of the flow of the retinal artery and ischemia of the optic nerve (26). Decompression is required rapidly (within hours), or irreversible nerve damage will occur.

Orbital cellulitis should also be considered if fatty infiltration alone is seen on MR or CT studies in the postoperative setting. Orbital cellulitis may simulate postoperative edema or diffuse retrobulbar hemorrhage. With regard to another orbital complication of surgery—extraocular muscular injury—both MR and CT should be reliable in diagnosis. The muscles appear thickened, edematous, and often irregular in shape.

Postoperative cerebrospinal fluid leaks that are caused by dural tears are best assessed with a combination of studies. Dural tears occur most commonly on a patient's right side because most surgeons are right-handed, making the left sinonasal cavity more easily accessed. Nuclear medicine studies in which indium diethylenetriaminepentaacetic acid is injected intrathecally are highly accurate for detecting leaks when active flow is present, even at a slow rate. Pledgets are placed in the nose, and counts are recorded from the right and left sides for comparison, as well as from superior and inferior quad-

rants. However, the anatomic definition afforded with CT makes a postcisternographic CT study more useful to the clinician (24). If there is rapid active cerebrospinal fluid leakage, the CT study may show the contrast dye in the sinonasal cavity at the site of intracranial opening. The endoscopic treatment of this complication can best be guided by the CT scan, since the bony dehiscence can usually be seen and the landmarks to the site delimited. If, however, there is a possibility of brain herniating through the dehiscent area, MR is of value. It may also distinguish postoperative scar tissue or inflammation from meninges, cerebrospinal fluid, and brain. Despite the relative contributions of imaging, direct endoscopic visualization of intrathecally instilled fluorescein leaking from the cribriform plate is the most reliable test when performed by a skilled endoscopist.

Very rarely, pseudoaneurysms may occur as a postoperative complication of FESS. These may occur in the cavernous carotid artery (when posterior ethmoid or sphenoid sinus surgery, or both, has been performed) or in the anterior cerebral artery branches as a result of anterior intracranial entry (24). Conventional arteriography is the standard and should be performed if subarachnoid hemorrhage is present; MR angiography may be useful as a screening study.

Are the benefits of FESS worth the risks of complications? The data from several reports suggest this is so. In children with chronic sinusitis, the surgical failure rate is 36% (59) for nasal antral windows but just 8% for FESS (60). Medical management is still

the mainstay of treatment for children with sinusitis; however, FESS can be performed safely and effectively with smaller endoscopes. In adults, the success of FESS is usually assessed by grading the patient's symptomatic improvement rather than residual mucosal disease. In one recent study, 97.5% of patients reported symptomatic improvement at a mean follow-up of 18 months (61). Eighty-five percent graded the improvement as marked and 12.5% as mild. Symptomatic improvement does not necessarily correlate with endoscopic or CT evidence of resolution of mucosal disease. In the 97.5% of symptomatically improved patients, endoscopic evidence of drainage, scarring, inflammation, or mucosal hypertrophy was present in 45% of sinus cavities. The patients with residual disease tended to be those who preoperatively had polyposis. Another FESS study was less successful: Good or moderate improvement in symptoms was present only in 73% of patients (62). By comparison, studies of the success of Caldwell-Luc surgery report favorable results in 70%–88% of cases (63–65), with complete resolution of symptoms in 53% (63). Intranasal nonendoscopic ethmoid surgery is associated with a success rate of approximately 69%, judged by subjective improvement in patients' symptoms (66). The success rate of surgery clearly depends on the level of experience of the surgeon. Nonetheless, the prevailing opinion in the otorhinolaryngology literature is that FESS is as successful, if not more so, than nonendoscopic surgery. The FESS complication rates of less than 1% (61) to 1.8% (62) compare favorably with those of nonendoscopic sinus surgery, 2.8% (67) to 19% (64). FESS has also gained acceptance because of the improved patient tolerance for the procedure and the shortened patient hospitalization.

Endoscopic repeat operation after previous sinus surgery is fraught with potential problems. The normal anatomic landmarks (turbinates, ethmoid septa, uncinate processes, bulla walls) may have been removed, and the bone contours may be thicker or thinner than expected depending on the degree of postoperative osteitis and intraoperative skeletonization of the bone. Scar tissue may obscure grooves and ostia that would normally direct the endoscopist. The radiologist who is able to identify anatomic signposts to direct the surgeon to occult residual disease is a valuable FESS team member.

## CONCLUSIONS

The advent of FESS has led to greater demand for coronal CT scanning of the paranasal sinuses and for radiologists familiar with the anatomic and surgical considerations in analyzing the images. Knowledge of normal anatomic variants and potential pitfalls at surgery will lead to more valuable reporting of these studies. While the role of MR is limited in uncomplicated sinusitis, MR is of benefit in diagnosing intracranial, meningeal, vascular, and intraorbital complications of sinusitis. ■

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