

Imaging of chronic sinusitis in adults: X-ray, computed tomography, and magnetic resonance imaging

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Two decades ago, otolaryngologists became aware that greater attention should be given to the area of the anterior ethmoid sinus. Before then, the maxillary sinus was the primary focus of attention. This was the site at which most surgical procedures were performed on patients with chronic sinusitis (Caldwell-Luc, nasal antrostomy, and irrigation procedures).¹ A better understanding of the mucociliary clearance of the nasal cavity and paranasal sinuses underscores the shift in attention to the anterior ethmoid sinus.²⁻⁵

Proctor⁵ believed that the seat of infectious disease in the nasal cavity and paranasal sinuses resided in the anterior ethmoid sinus. He suggested that disease in the anterior ethmoid sinus area was the cause of secondary inflammatory disease in the frontal and maxillary sinus. Messerklinger^{2, 6} was the first to use endoscopes to demonstrate the mucociliary pattern in the nasal cavity and paranasal sinuses, thus confirming Proctor's beliefs. Messerklinger's use of telescopes led to the innovative surgical technique of functional endoscopic surgery.

The key to most inflammatory sinus disease is the air passage lateral to the middle turbinate, the middle meatus, and the communication with the adjacent sinuses through their respective ostia (ostioameatal complex) (Fig. 1).^{2, 4, 5} The role of mucociliary clearance as it relates to the ostioameatal complex is less well defined than the major functions of the nasal passages. However, a complete understanding of this area and the pattern of mucociliary clearance is crucial.

The ostioameatal complex is composed of narrow channels and is subject to wide normal anatomic variation (Fig. 2). It contains the ostia needed not only for the drainage of the anterior ethmoid sinuses but also for the frontal and maxillary sinuses. These sinuses are therefore dependent on the integrity of the

Abbreviations used

CT: Computed tomography

MRI: Magnetic resonance imaging

ostioameatal complex for ventilation and mucociliary clearance. Local inflammation or anatomic obstruction within the ostioameatal complex may result in secondary disease within the maxillary ethmoid and frontal sinuses. It is evident that if surgery is contemplated, primary consideration should be given to establishing the patency of the narrow passages of the ethmoid sinuses rather than focusing only on removal of disease from the maxillary sinuses.^{2, 4, 5}

Based on radiographic and surgical requirements, the importance of focal surgery to the minute passages of the nasal cavity and paranasal sinuses becomes clear. Surgery is specifically aimed at opening these tiny passages to reestablish normal ventilation and mucociliary clearance. Given the small field of view afforded by endoscopes and the small anatomic area in which the surgeon must operate, the need for detailed anatomic mapping is critical. To address this need, the surgeon relies on the radiologist to provide the best possible delineation of this anatomic area.

The major roles for imaging in this respect are to display the regional anatomy, with its numerous anatomic variations, and to display those structures that are inaccessible to direct view by the endoscope. Of the several radiographic modalities available, CT is the optimal choice to fulfill the radiologic and surgical requirements.

I will discuss the advantages and disadvantages of the available radiographic modalities in the demonstration of the regional anatomy of the nasal cavity and paranasal sinuses.

MUCOCILIARY CLEARANCE

Understanding the pattern of mucociliary clearance, as mentioned previously, is important for both the radiologist and the surgeon. The thin layer of mucus that covers the inner surface of sinuses receives the

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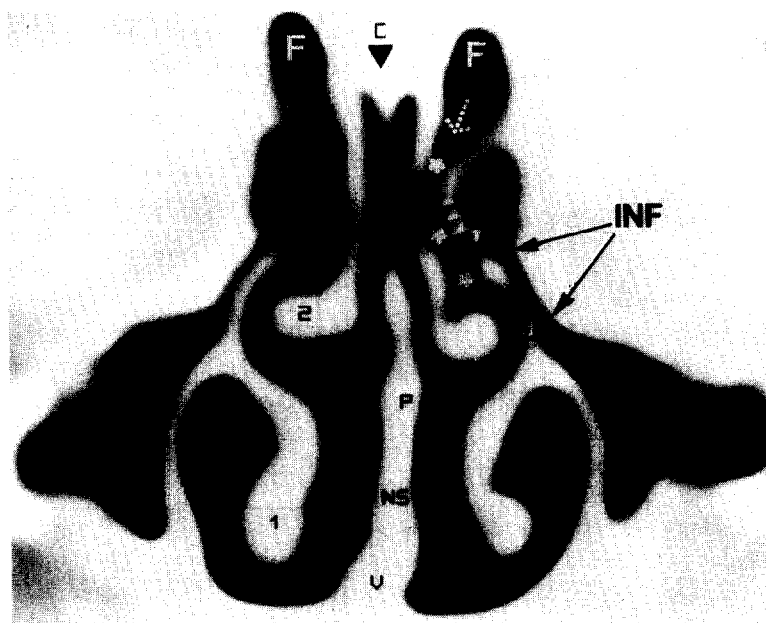


FIG. 1. The anterior ostiomeatal air channels. Coronal CT scan through the anterior ethmoid sinus reveals the intercommunication between the maxillary sinus (*M*), the infundibulum (*INF*), the middle meatus (*asterisks* and *arrowheads*), the frontal recess (*dotted arrow*) and frontal sinus (*F*), ethmoid bulla (*B*), maxillary sinus ostium (*O*), uncinete process (*U*), nasal septum (*NS*), perpendicular plate (*P*), vomer (*V*), inferior turbinate (*1*), middle turbinate (*2*), and crista galli (*C*).

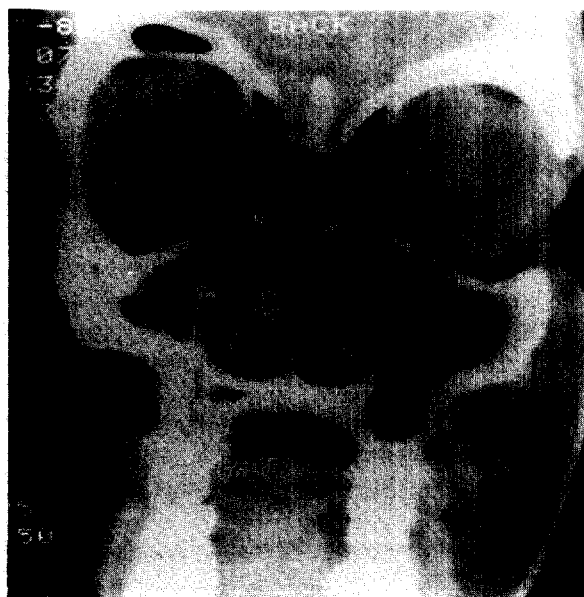


FIG. 2. Anatomic variations. Coronal CT scans reveal bilateral concha bullosa (*asterisks*). These anatomic variations may obstruct the ostiomeatal passages.

largest deposits of inhaled particulate matter. The cilia and the thin mucous layer here are in constant motion in predetermined pathways toward the various sinus ostia. If mucosal transport of bacteria, mucus, and

debris is obstructed, the sinus is susceptible to infection.

Mucociliary clearance in the frontal sinuses advances along the septal wall to the sinus roof and then moves laterally along the roof and medially along the floor toward the ostium. Backflow, which results from recirculation in the frontal recess, may be a cause of initial infection.⁶

In the maxillary sinus, mucociliary movement is toward the ostium. It starts at the sinus floor and radiates along the wall of the sinus superiorly. Even in the presence of nasal antral windows after inferior meatotomy, which is intended to clear mucus from the maxillary sinus, mucociliary movement persists in its upward movement toward the sinus ostium.

Unobstructed flow through the ostiomeatal complex and its narrow communicating passages within the sinus ostia is integral to mucociliary clearance and ventilation. It is of particular importance that the anterior and posterior ethmoid sinus channels be patent because the primary sites for mucociliary drainage include the anterior middle meatus and the posterior sphenoethmoid recess. With anatomic distortion or even minor swelling, two mucosal layers may become opposed and lead to stenosis or obstruction in the ostiomeatal complex. Reduced aeration or accumulated secretions in the major maxillary and frontal sinuses then appear to predispose again to infection.

On the basis of these observations, the guiding principle of management is to reverse the sinusitis cycle involving the ostiomeatal complex. Understanding how to do this has yielded research exploring new techniques that have dramatically changed standards in the care of patients with sinusitis.

MODALITIES

Standard radiography

Plain films, although commonly used to evaluate this area, provide very limited information about the anterior ethmoid sinus anatomy and have proved to be inaccurate in the display of soft tissue inflammatory disease.⁷ Plain films still provide noninvasive and fast evaluation of the lower third of the nasal cavity and maxillary, frontal, sphenoid, and posterior ethmoid sinuses. These observations are inadequate, however, for the evaluation of the anterior ethmoidal air cells, the upper two thirds of the nasal cavity, and the infundibular, middle meatus, frontal recess air passages.

CT

CT, because of its ability to simultaneously demonstrate the maxillofacial bony architecture, soft tissue, and air, is the modality of choice for the evaluation of the regional anatomy of the nasal cavity and the paranasal sinuses. CT excellently demonstrates the anterior ethmoid cells, the upper two thirds of the nasal cavity, and the frontal recess.⁸

In these areas CT can provide specific diagnosis and display the underlying causes of sinusitis in patients who have chronic or recurrent acute sinusitis; in the latter, CT examination is delayed until antibiotic therapy controls acute exacerbation. CT can clarify anatomic relationships and variations that may play a role in sinusitis; it may also guide endoscopic surgery.

To afford optimal demonstration of the anterior ethmoid sinuses and ostiomeatal structures, CT imaging is performed in the coronal planes. Sectional imaging of the maxillofacial area shows accurate soft tissue definition in the nasal cavity, paranasal sinuses, orbit, and intracranial compartment. Highly contrasting densities identify air within the bony sinuses, fat within the orbit, and soft tissues outlined by air in the nasal cavity. Thus CT enables the clinician to identify and evaluate systematically each frontal sinus, frontal recess, uncinate process, infundibulum, maxillary sinus, maxillary sinus ostia, ethmoid bulla, sinus lateralis, middle meatus, posterior ethmoid sinus cells, sphenoid sinus, and the sphenoid recess (Fig. 3).

CT examination, which is usually performed after medical treatment of sinusitis, can reveal the extent of mucosal disease deep in the ostiomeatal complex



FIG. 3. Coronal CT scans through the anterior ethmoid sinus reveal bilateral patent antrostomies (*open arrows*). There is extensive opacification of the ethmoid sinuses bilaterally with inflammatory disease obstructing the infundibulum. Also note obstruction of the maxillary sinus ostium (*asterisk*).

(Fig. 4).⁷ Resolution of secondary inflammatory changes afford a more accurate display of the regional anatomy and therefore provides a better “guide” for the surgical procedure.

In an attempt to decrease the radiation dose and the cost of the CT examination, “limited” CT examinations of the nasal cavity and paranasal sinuses are advocated. These examinations consist of coronal images performed with various gaps and thus provide a sampling of the extent of mucoperiosteal inflammation in these planes.

The information gained through such an examination might be achievable through diagnostic endoscopy because the area of clinical interest is the anterior ethmoid sinus. The limitation of this technique is the incomplete, segmented display of regional morphology, and therefore the available information should not be used to plan and guide surgery. Furthermore, the setup time required to achieve individual coronal planes precisely through the frontal recess and to show the sinus lateralis may be similar to the time required

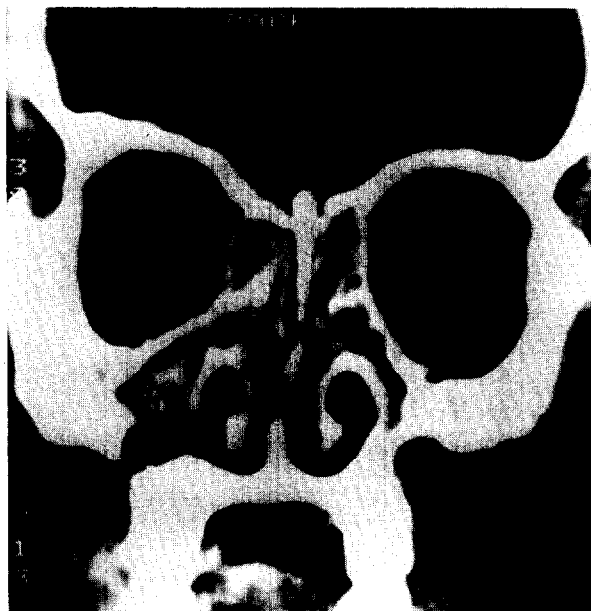


FIG. 4. CT of fungal sinusitis. Coronal CT image performed without administration of intravenous contrast material reveals a homogeneous density (*star*) in the maxillary sinus. Pathologic diagnosis was aspergilloma.

to scan the entire anterior ethmoid sinus after a single setup of the scanning parameters on the scout CT radiograph.

There is a need to decrease the radiation dose to this area, especially for patients who are repeatedly reevaluated for chronic inflammatory disease. However, this should be accomplished without sacrificing the complete display of regional anatomy. The use of a lower milliamperage and shorter scanning times addresses this issue. With a lower milliamperage, the anatomy can still be optimally displayed because the primary structures of interest are thin bone and surrounding soft tissue and interposed air passages. Application of this technique will prove cost effective without compromising the diagnostic and surgical planning value of the CT examination.⁹

The characteristics of chronic inflammatory disease on CT are mucoperiosteal thickening, soft tissue mass, and osteitis of the ethmoid bony architecture. It is unusual to observe bony erosion, because such erosion is most often associated with more invasive processes such as a mucocele or a neoplastic process. In my experience an exception to this guideline is the presence of erosion of the uncinate process, which is usually the result of chronic inflammation that surrounds the "free edge" of this structure. This process, however, could also be explained as a mucocele of the maxillary sinus. The posterior ethmoid and the sphenoid sinuses are hidden from the endoscopist's direct

view and access by the basal lamella. Fortunately, an infection is present in this location in only 20% to 30% of the population with chronic inflammatory disease. When these air-containing spaces are blocked by inflamed mucosa, mucosal removal and drainage become possible under endoscopic guidance. In these cases sagittally oriented reconstructions facilitate endoscopy and therapeutic instrumentation by affording a view of the plane assumed by the penetrating instruments. Distances and angulations with the anterior nasal spine as a point of reference can be used to guide the endoscopist in the posterior advancement of the endoscope.

The information gained from CT evaluation is critical for presurgical planning. A sequential evaluation of the sinuses, ostia, and interconnecting air passages, starting anteriorly and progressing posteriorly, should be made.

A systematic evaluation should include the frontal recess and adjacent Agger Nasi cell, the orientation of the middle meatus, and the infundibulum. The paradoxical shape of the middle turbinate should be addressed in relation to the middle meatus and infundibulum. Similarly, when Haller cells are present, their possible infringement on the infundibulum should be considered. Because an uncinectomy is usually performed during endoscopic sinus surgery, the position of the "free edge" of the uncinate process in relation to the orbit needs to be clearly perceived by the surgeon. In most instances the ethmoid bulla may be positioned between the uncinate process and orbit, but commonly this structure may directly adhere to the lamina papyracea. In the latter case care must be taken not to incise the medial orbital wall during this procedure.

In most patients, the ethmoid bulla is separated from the sinus lateralis by an intact posterior wall. When this is the case, inflammatory disease may occur in the sinus lateralis in the presence of a normal ethmoid bulla. This information, which is only available to the surgeon through CT, is critical if he or she intends to remove all the inflammatory disease in the anterior ethmoid sinuses.

The presence of inflammatory disease in the posterior ethmoid and sphenoid sinuses necessitates a display and understanding of the relationship between the width and height of aeration of the posterior ethmoid sinus with respect to the sphenoid sinus. This relationship strongly influences the surgeon's choice of a "working plane" related to the position of the nasal septum. Similarly, the extension of the carotid artery into the sphenoid sinus and its relationship to the septations within this sinus must be noted to prevent a surgical complication. The decision regarding

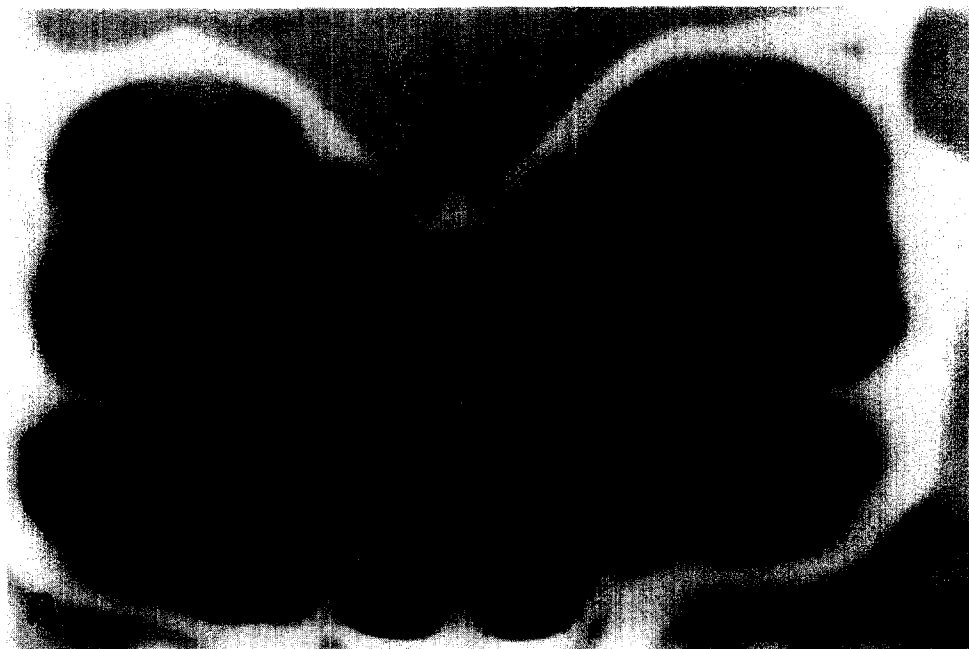


FIG. 5. Coronal CT scan through the anterior ethmoid sinus demonstrates mucoperiosteal thickening obstructing the left middle meatus (*large asterisk*) and infundibulum (*small asterisk*). There is ipsilateral mucoperiosteal thickening in the left maxillary antrum (*arrow*). Note inflammatory disease in the right middle meatus (*star*) and ethmoid bulla (*B*).

surgical intervention should never be based on CT alone, because CT may demonstrate asymptomatic mucosal disease. Surgery is reserved for patients who do not respond to medical management, and a decision to operate should be based on a combination of history, CT, and endoscopic findings. The functional endoscopic approach provides a reduction in morbidity over conventional techniques, and this, when combined with its aim of reestablishing the patency of the ostia, is its greatest benefit. The most frequent indications for surgical intervention are chronic and recurrent acute sinusitis, diffuse nasal polyposis, and mucocoeles. With the latter, careful diagnostic evaluation frequently reveals an underlying cause within the ostiomeatal complex that can be treated by an endoscopic approach. Some of the long-term diagnostic problems associated with external frontoethmoidectomy are also avoided with this approach.

MRI

Although early reports were enthusiastic about the use of MRI in studying the paranasal sinuses, its use to diagnose sinusitis may have some limitations. Although MRI supersedes CT in resolving soft tissue structures and is superior in distinguishing between bacterial and fungal sinusitis as well as inflammation and neoplasia, its use for the evaluation of nasal anatomy, particularly for the ethmoid sinuses, is precluded

because of its poor resolution of bone (Figs. 5 and 6). The ability to directly perceive the orientation, thickness, and possible dehiscences within the fovea ethmoidales, the lamina papyracea, and the sphenoid sinus wall is critical for the surgeon and is clearly a problem with MRI. However, in patients with encephaloceles and neoplasms, this imaging technology is invaluable.

FUTURE DIRECTIONS

Improved imaging of the sinuses, especially the anterior ethmoid sinuses, is crucial for optimal diagnosis and treatment of diseases of the nasal cavity and paranasal sinuses. The increased use of endoscopy and CT confirm the importance of ostiomeatal disease and anatomic deformities of the middle meatus in the pathogenesis of sinusitis. Nasal endoscopy should supplement clinical evaluation in all patients who have chronic or recurrent acute sinusitis. CT should be used when endoscopy fails to explain symptoms of sinusitis. CT shows the extent of mucosal disease deep in the ostiomeatal complex and optimally displays the regional anatomy.

However, there is a need to improve the three-dimensional perception of the complex and varying anatomy of the nasal cavity and paranasal sinuses. Three-dimensional reconstruction of digitized CT data has been attempted but continues to be problematic

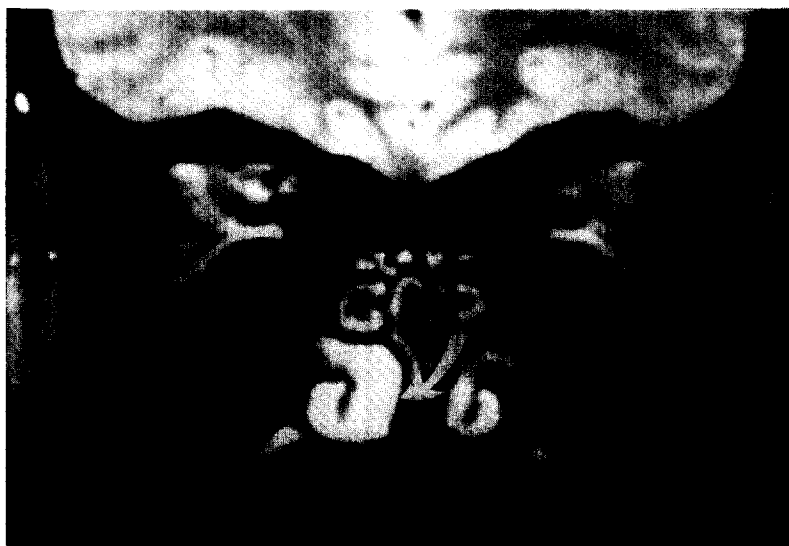


FIG. 6. MRI (T1-weighted coronal image) through the posterior ethmoid sinus reveals the bright signal over the mucosa of the nasal cavity and turbinates. Edematous state (*curved arrow*) of the right inferior turbinate reveals the nasal cycle. The high signal associated with this physiologic process is indistinguishable from bacterial or viral inflammation.

given the very small air passages, the fine mucosal lining, and very fine bony architecture. The available segmentation algorithms need considerable improvement to become adaptable for this clinical application. Nevertheless, the multiplanar two-dimensional reconstruction of the data, with a simultaneous display of axial, coronal, and sagittal images on which a particular anatomic landmark may be identified in real time, is available and may be very useful for surgical planning and even for guiding the surgical procedure.

The equipment needed to accomplish this task consists of a computer capable of two- and three-dimensional reconstruction of CT and MRI data (ISG Technologies, Toronto, Canada), a high-resolution display screen, and a robotic mechanical sensor (FARGO Medical, Clearwater, Fla.) connected to the computer. This system was tested on a plastic replica of a skull and several cadaver head specimens. Five markers taped to the surface of the test subject were used to register the subject position with the three-dimensional reconstruction on the computer's display screen. Subsequently, an interactive correlation between anatomy on the test subject and its three-dimensional display was accurate within 0.7 to 1.8 mm. This development promises to improve the endoscopist's perception of the anatomy in the operating field and improve the safety of this operative procedure. To date this development has been tested in two endonasal surgical procedures (ethmoid encephalocele and ethmoid tumor), and its accuracy proved to be similar to the accuracy determined in *in vitro* testing.

CONCLUSIONS

Nasal endoscopy and the clinical evaluation form the basis for diagnosis of chronic and recurrent sinusitis. Plain films offer no additional information in this setting. CT should be used when endoscopy fails to explain symptoms of sinusitis. It should be performed after adequate medical therapy, and if possible, after the administration of a local vasoconstrictor (to diminish the effect of the nasal cycle). The milliamperes may be significantly lowered, as suggested by Babbal et al., to decrease the radiation exposure. A CT examination (preferably in the coronal plane) should be available to the endoscopic surgeon for all surgical procedures. MRI facilitates the diagnosis of nasal and paranasal sinus neoplasms and fungal disease. Computers, when coupled with a robotic mechanical sensor, improve anatomic perception and surgical accuracy.

REFERENCES

1. Caldwell GW. The accessory sinuses of the nose: an improved method of treatment for suppuration of the maxillary antrum. *NY Med J* 1893;58:526.
2. Messerklinger W. *Endoscopy of the nose*. Baltimore: Urban and Schwarzenberg, 1978.
3. Stammberger H. Endoscopic endonasal surgery—concepts in treatment of recurring rhinosinusitis. Part I. Anatomic and pathophysiologic considerations. *Otolaryngol Head Neck Surg* 1986;94:143-7.
4. Kennedy DW, Zinreich SJ, Rosenbaum AE, Johns ME. Functional endoscopic surgery: theory and diagnostic evaluation. *Arch Otolaryngol* 1985;111:576-82.
5. Proctor DF. The nose, paranasal sinuses and pharynx. In: Wal-

- ters W, ed. Lewis-Walters practice of surgery. Hagerstown, Md.: WF Prior Co, 1966;4:1-37.
6. Messerklinger W. On the drainage of the normal frontal sinus of man. *Acta Otolaryngol* 1967;63:176-81.
 7. Zinreich SJ, Kennedy DW, Rosenbaum AE, Gayler BW, Kumar AJ, Stammberger H. Paranasal sinuses: CT imaging requirements for endoscopic surgery. *Radiology* 1987;163:769-75.
 8. Som PM. The paranasal sinuses. In: Bergeron RT, Osborn AG, Som PM, eds. *Head and neck imaging excluding the brain*. St. Louis: The CV Mosby Co, 1984:5-143.
 9. Babbel R, Harnsberger HR, Nelson B, Sonkens J, Hunt S. Optimization of techniques in screening CT of the sinuses. *AJR* 1991;157:1093-8.

DISCUSSION

Dr. Rachelefsky. I do not think that anybody would disagree with doing CT imaging studies on someone who is going to have surgery, but the problem that many of us face and maybe the message we are trying to get across is, when do we obtain a study other than in a presurgical patient?

Dr. Zinreich. I am surprised at how many CT scans we do on patients who are referred by specialists when they have normal findings or very minimal abnormality. I suspect that in many of those cases you have patients who are convinced that they have sinusitis. They have heard about a CT scan and nothing short of that will convince them that they do not have it. They had had plain films that were

perhaps normal. Besides, state-of-the-art does not mean that everybody must have the procedure. I think it is still a presurgical planning tool, or at least that is the way it should be thought of in most cases.

Dr. Shapiro. Let me add to that. What you said is very true, that sometimes one prescribes antibiotics repeatedly not knowing what in the world is going on, and so a negative CT scan is very helpful because the clinician knows to stop the antibiotics. The patient never had sinusitis or if he or she did, it is not there anymore. Thus a negative CT scan can be very valuable.

Dr. Lusk. I cannot tell the difference between acute inflammation and acute infection and chronic inflammation on a CT scan in the pediatric population. What do you do? You treat them all medically, with maximum medical management, and then you obtain the CT scan to see with what you are dealing. That is when it becomes useful.

Dr. Zinreich. That is the point. I think we have confused the clinicians by saying if someone has an abnormal CT scan, they should go to the surgeon.

Dr. Lusk. Right, and I preach it to all of my referring pediatricians that you do not obtain CT scans until they have received maximum medical management.

Dr. Lanza. If you find that you have started medical therapy and yet you have persistent symptoms, then the computed axial tomographic scan will help identify disease that is beyond the view of your scope, and that is an important aspect of using CT imaging.