Recent advances in the understanding of mucociliary activity and the pathophysiology of the nasal cavity and paranasal sinuses have revolutionized the surgical management of chronic and/or recurrent sinusitis. Metliculous radiographic delineation of the small structures in this region, coupled with endoscopic evaluation, provides detailed preoperative information regarding morphology and pathology. This information has led to more focused endoscopic surgical procedures, which have dramatically reduced patient morbidity. As a consequence, there is now worldwide interest among otolaryngologists in the radiologic definition of paranasal regional anatomy. For effective interactions between radiologist and otolaryngologist, the former must be prepared to render interpretations that address these "micro-anatomic" locales. This communication is directed at familiarizing the radiologist with these observations and concepts, considering both normal and disturbed anatomy with their attendant pathophysiologic and therapeutic implications.

Index terms: Endoscopy • Paranasal sinuses, CT, 238.1211 • Paranasal sinuses, diseases, 238.25 • Paranasal sinuses, surgery, 238.1299 • Sinusitis, 238.25

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The clinical diagnosis of sinusitis is usually based on symptoms indicating maxillary or frontal sinus involvement. Clinically, maxillary and frontal sinusitis is seen more frequently than ethmoid sinusitis. Standard paranasal sinus radiographs can readily demonstrate such maxillary or frontal sinus disease but incompletely delineate ethmoid sinusitis (1-4). It is not surprising, therefore, that clinical as well as radiologic recognition of the interrelationships between ethmoid disease and disease of the adjoining maxillary and frontal sinuses has been largely unexplored.

The importance of the communications between the anterior ethmoid sinus and the frontal and maxillary sinuses (via the infundibulum, middle meatus, and frontal recess) in the pathogenesis and treatment of sinusitis was recognized earlier by otolaryngologists (5-12). Proctor in 1966 reported that "the ethmoid sinuses are usually the key to any problem involving infectious sinusitis. Infection begins there and persistent infection there is usually the reason for failure of therapy directed at any of the other paranasal sinuses" (8, 9). Subsequently, Messerklinger (10, 12) and Drettner (7) demonstrated that obstruction of the ostia is the usual precursor to sinusitis. They showed that apposition of abutting mucociliary surfaces within the paranasal sinuses forms an anatomic substrate for disrupting sinusonal drainage. The resulting retention of secretions leads to inflammation and infection. Messerklinger also showed that the infundibulum and the middle meatus are the channels most frequently affected by anatomic variations, which narrow them and juxtapose their mucosal surfaces, facilitating infection.

The development of new endoscopic instruments and associated techniques has fueled a new surgical approach for treating chronic sinusitis (10-15). This surgery is aimed at restoring normal physiology by reestablishing normal mucociliary drainage and ventilation of the sinuses. The surgery is primarily directed to removal of localized disease obstructing the ethmoid pathways. Furthermore, there is evidence that resolution of mucosal disease in the frontal and maxillary sinuses follows the restoration of normal mucociliary clearance and ventilation (10, 12, 14, 15).

Unfortunately, the convoluted anatomic framework of the ethmoid cells precludes the direct, noninvasive endoscopic evaluation of deeper

| Table 1 |
| Technique for CT of Paranasal Sinuses |
| --- | --- |
| Imaging Parameter | Imaging Plane |
| Patient position | Coronal |
| Gantry angulation | Axial |
| Extent of study | Prone |
| Section thickness (mm) | Perpendicular to IOML |
| Table incrementation (mm) | From anterior frontal sinus to posterior sphenoid sinus |
| kVp | 4 |
| mAs | 125 |
| Scan time (sec) | 450 |
| Note — Imaging was performed with use of the Siemens Somatom DR3 unit with version E software. IOML = infrasellar medial line. |

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Figure 1. Normal anatomy of ostiomeatal unit as seen on CT. (a) The infundibulum (INF) is delimited inferiorly by the maxillary sinus ostium (O), medially by the uncinate process (U), superiorly by the ethmoidal bulla (B), and laterally by the inferomedial orbit. The air space surrounding the ethmoidal bulla inferoposteriorly is the hiatus semilunaris (small arrows). (b) The middle turbinate (2) has dual attachments: a high vertical one to the cribiform plate (CP) and a horizontal one to the lamina papyracea, the basal lamella (BL). The air-containing space between the uncinate process (U) and the middle turbinate is the middle meatus (*). NS = nasal septum, P = perpendicular plate, V = vomer, M = maxillary sinus, 1 = inferior turbinate. (c) Mucociliary clearance from the maxillary sinus. The mucus film is propagated from the antral floor up along the walls of the sinus toward the main maxillary sinus ostium, through the infundibulum into the middle meatus (ostiomeatal unit).

c. ostiomeatal, posterior ethmoid, and sphenoid sinus disease. In such circumstances computed tomography (CT) proves indispensable for identifying the magnitude of disease. Moreover, in cases in which endoscopic surgery is likely to be helpful, CT should be used to guide the endoscopist to the site of disease to avoid complications.

In recurrent sinusitis when acute exacerbations supervene, CT should be delayed until medical treatment has controlled these acute manifestations (13). The diagnostic evaluation for surgery aimed at restoring normal sinus function thus becomes a combination of systematic nasal endoscopy and CT (13). The collaborative role between radiologist and otolaryngologist is reviewed in this communication.

TECHNIQUE

CT examination of the maxillofacial region was performed in patients with both chronic and recurrent acute sinusitis. All examinations were performed with a Siemens (Iselin, N.J.) Somatom DR-3 scanner equipped with version E software.

The coronal plane is the plane closest to the view of the endoscopist; it is also the imaging plane that best displays the ostiomeatal unit. Thus, it was the preferred plane for direct scanning. Each patient was positioned prone with the head hyperextended on the scanner bed. The
scanning parameters are outlined in Table 1. For optimal visualization of the osteo- 
meatal channels, imaging should be centered on the para nasal sinuses (on the 
Siemens Somatom DR 3 scanner we used a zoom of 4 or 5). Scanner computation 
algorithms were selected to favor the demon-
stration of soft tissue. Window widths 
were usually at 2,000, and the window 
was centered to −200. Scanner “raw” data 
were transiently saved so that high-reso-
lution bone-enhancing reconstructions 
could be applied when bone erosion was 
either visualized or suspected.

When patients were unable to assume the prone position, axial scans from the 
palate through the frontal sinuses were ob-
tained and indirect coronal reconstructions 
generated from them. For special atten-
tion to the anterior ethmoid region, 
coronal indirect reconstructions were 
performed to complement the initial 
scanning plane. Even in patients with ex-
tensive metallic dental fillings, the direct 
coronal plane proved superior to the indi-
rect reconstructions, and therefore the 
coronal plane remains the plane of choice 
even in this instance.

ANATOMY

Ethmoidal Labyrinth

As seen on the coronal view (Fig. 
1a, 1b), air cells collectively form the 
ethmoidal labyrinth. They appear as a 
near-vertically oriented, thinly sep-
tated bony honeycomb lined by mus-
cosa. These vertically situated air 
cells are narrower anteriorly and 
wider posteriorly. The boundaries of 
this labyrinthine structure are the 
lamina papryacea laterally, the orbit-
al plate of the frontal bone superior-
ly, the perpendicular plate medially, 
and the middle turbinate inferiorly 
(16–18).

Osteo meatal Unit

Maxillary sinus ostium and infundibu-
Ium.—The maxillary sinus ostium 
and the infundibulum serve as the 
predominant channel linking the 
maxillary sinus with the nasal cavity 
(Fig. 1). They are best visualized in 
the coronal plane. The infundibulum 
is bounded laterally by the infero-
medial orbit, superiorly by the hiatus 
semilunaris and ethmoidal bulla, medi-
ally by the uncinate process, and 
inferiorly by the maxillary sinus as 
the sinus funnels into it (9, 12). Less 
frequently, an accessory orifice of the 
maxillary sinuses is encountered. The 
accessory orifice most frequently 
opens into the anterior fontanel of 
the nasal cavity and is best seen on 
modified axial views, assuming a 
midposition between “true” axial 
and coronal planes. The infundibu-
Ium represents the superomedial ex-
tension of the ostium. The posterior 
extent of the uncinate process and 
the relative position of the ostium 
determine whether the ostium may 
be visualized on endoscopy.

Hiatus semilunaris.—This complex 
space gains its name from its arched 
appearance in the sagittal plane 
(Figs. 1a, 2a). The hiatus semilunaris 
is bounded superiorly by the ethmo-
dal bulla, laterally by the medial 
bony orbit, inferiorly by the uncinate 
process, and medially by the middle 
meatus. The hiatus semilunaris is the 
final segment for drainage from the 
maxillary sinus, being preceded by 
the maxillary ostium and infundibu-
um. The hiatus semilunaris is best 
identified on parasagittal sections 
and runs obliquely in a posteroinfe-
rior direction between the uncinate 
process and the ethmoidal bulla (Fig. 
2a). A posterosuperior extension of 
the hiatus semilunaris (hiatus semi-
1unaris superioris) passes between 
the ethmoidal bulla and basal lamella 
and communicates with the sinus la-
terals, affording drainage for this 
space (Fig. 2a).

Middle turbinate.—The middle tur-
binate lies inferomedial to the anterior 
ethmoid air cells (Figs. 1a, 1b, 2a). 
Its most consistent bony attachments 
are vertically to the cribiform plate 
superiorly, and to the lamina papry-
acea laterally via a bony strut termed 
the basal (ground) lamella (Figs. 1b, 
2b). The basal lamella is oriented 
from anteromedially to postero
craterially to become situated behind 
the ethmoidal bulla. The compart-
ment between the posterior wall of 
the ethmoidal bulla and the basal lamella 
is the sinus lateralis (Fig. 2a, 2b). 
Quite often the body of the middle 
turbinate contains an air-filled cavi-
ity, the concha bullosa, which com-
 municates variably with the superior 
medial meatus, the frontal recess, or 
the sinus lateralis (Fig. 3b).

Ethmoidal bulla.—The ethmoidal 
bulla usually consists of an air cell of 
variable size and shape. It is bordered 
inferomedially by the infundibulum 
(Fig. 1a) and hiatus semilunaris (Fig. 
3c), laterally by the lamina papry-
acea, and superoposteriorly by the si-
nus lateralis (Fig. 1a, 1b). It commu-
nicates with the nasal cavity via an 
ostium, the site of which appears to 
be variable. According to Zucker-
kandl (11) the ostium is most often 
posterior, but according to Messer-
klinger (12) a superoanterior opening 
is more frequent. We have also noted 
it medially.

Frontal recess.—The frontal recess 
(Figs. 1a, 2a, 2b) affords mucociliary 
drainage of the frontal sinus. Drain-
age may occur directly into the mid-
dle meatus medial to the uncinate 
process, into the ethmoidal infundib-
um more laterally, or more posterior-
ly above the ethmoidal bulla. This 
communication between the frontal 
sinus and the nasal cavity is not 
strictly a duct but an internal apert-
ture of hourglass configuration posi-
tioned between the sinus and the an-
terior middle meatus.

Nasolacrimal Duct

The nasolacrimal duct is a straight-
coursing tube that extends upward 
from the lacrimal fossa to a site adja-
cent to the attachment of the inferior 
turbinate. In the coronal view (not il-
lustrated) the duct is nearly supero-
inferiorly oriented, with its inferior 
portion lying about 3°–5° medial to 
its superior portion. In the sagittal 
view its posterior incline may be 
larger, varying from 5° to 30°.

Sphenoidal sinus, spheno id ostium, and 
spenoethmoidal recess.—This continu-
num is best evaluated on either axial 
or sagittal (Fig. 2c) scans. The ostium 
is located at the anterosuperior por-
tion of the sphenoid sinus (Fig. 2c). 
The sphenoid ostium and the pos-
terior ethmoidal air cells drain into 
the sphenoethmoidal recess (Fig. 2c, 
2d).

PATHOPHYSIOLOGY

Much of our present understanding 
of the mucociliary clearance of 
the paranasal sinuses is a result of the 
work performed by Hilding, Mes-
sklinger, and Proctor (5–12, 19, 20). 
The physiologic roles of the nasal 
passages are humidification, warm-
ing, and removal of particulate mat-
ter from inspired air. By far the larg-
est part of inhaled large particulate 
matter is deposited onto the mucocili-
ary blanket, transferred from the 
nasal passage through the nasophar-
ynx, and swallowed (16). The mucus 
blanket is transported by ciliary ac-
tion along formal pathways. Within 
the sinuses the mucus layer is ad-
vanced by cilia along defined pat-
terns toward the primary ostium (Fig. 
1c, 2d).

In the frontal sinus (5), mucociliary 
clearance proceeds along the septal 
wall to the roof of the sinus, then la-
terally along the roof and medially 
along the floor to reach the ostium. 
Messerklinger (10, 20) also identified 
some backflow into the sinus as a re-
Figure 2. Normal CT anatomy of nasal cavity and paranasal sinuses in the sagittal plane. A = anterior, P = posterior. (a) Sagittal reconstructed image through the middle of the ethmoidal bulla reveals the arcuate passageway of the hiatus semilunaris (dashed line). The hiatus semilunaris courses around the outer anteroinferoposterior border of the ethmoidal bulla (B). Posterosuperiorly, the sinus lateralis (SL) drains into the hiatus semilunaris; the sinus lateralis is delimited posteriorly by the basal lamella (BL). * = middle meatus, F = frontal sinus, S = sphenoid sinus, U = uncinate process, 1 = inferior turbinate, BP = bony palate, 2 = middle turbinate, SC = sagittal cursor. (b) Another patient. A slightly oblique parasagittal reconstruction (computer artifact disrupts cursor line, PSC) samples the middle of the ethmoid sinus to reveal the basal lamella (BL) and the air-filled space just anterior to it, the sinus lateralis (SL, open arrow). Solid arrows indicate posterior middle meatus; dotted arrow indicates frontal recess. F = frontal sinus, S = sphenoid sinus. (c) Paramidline sagittal reconstruction (SC on reference image) through sphenoid sinus ostium (curved arrow) shows the communication between the sphenethmoidal recess (*) and the superior meatus (dotted line) and their drainage into the nasopharynx (curved arrow). PE = posterior ethmoid cells, F = frontal sinus, 3 = superior turbinate, S = sphenoid sinus. (d) Diagram of lateral nasal wall demonstrating mucociliary flow in the nasal cavity toward the nasopharynx. Mucociliary clearance from the frontal sinus, anterior ethmoid sinus, and maxillary sinus occurs through the middle meatus and is then easily directed toward the nasopharynx. Mucociliary clearance from the sphenoid sinus and posterior ethmoid sinus takes place through the sphenethmoidal recess (SER), to the superior meatus (fine arrows), to the nasopharynx. Mucosal flow anterior to the middle meatus is forward (open arrow).

result of recirculation in the frontal recess, which suggests a potential mechanism for the introduction of infection. In the maxillary sinus, mucociliary movement originates from the floor of the sinus and radiates along the walls of the sinus superiorly to reach the ostium. When nasoan-
mucociliary movement maintains its upward movement toward the sinus ostium despite the more inferior nasoantral opening (12, 17) (Fig. 4a, 4b).

Mucociliary clearance and ventilation are dependent on unobstructed flow through the intricate and narrow passages of the ostiomeatal complex. However, in the presence of minor swelling, two mucosal layers may become apposed, leading to stenosis and obstruction, which in turn reduce aeration and predispose to the accumulation of secretions in the secondarily affected major sinus (maxillary, frontal), making the particular sinus prone to infection (5–15, 19, 20). Ostiomeatal passages already narrowed by anatomic variations, trauma, or tumor are prone to inflammation resulting in obstruction.

**EVALUATION OF ABNORMALITY**

**Nasal Endoscopy**

Routine anterior rhinoscopy performed with use of a headlight and nasal speculum allows only limited inspection of the anterior nasal cavity, whereas nasal endoscopy enables detailed visualization, including visualization of the crucial region of the middle meatus. Nasal endoscopy can be performed in the office setting at the time of initial consultation. Areas of inflammation or pathologic drainage are readily identified. In patients with a nasoantral window (inferior meatotomy), the telescope may also be introduced into the maxillary sinus and the entire sinus inspected without discomfort (Fig. 4b).

Within the middle meatus, anatomic abnormalities such as paradoxical curvature of the middle turbinate (Fig. 3e), expansion of the middle turbinate by a large concha bullosa...
(Fig. 3c), or a medially rotated uncinate process are easily recognized. The presence of local middle meatal inflammation, granulation, polypoid formation, or sinus discharge can also be identified (Fig. 5b). Limitations of nasal endoscopy include inability to discern the extent of disease within the ethmoidal sinus, difficulty in identifying disease in a constricted middle meatus, and the presence of hidden air spaces such as the ethmoidal bulla, posterior ethmoid sinus, and sphenoid sinus.

**CT Evaluation**

The CT examination of patients with chronic or recurrent acute sinusitis is performed to help identify underlying causes after a full course of antibiotic therapy has been administered and the acute exacerbation controlled.

Coronal CT sections are obtained of the maxillofacial area, and the following structures are identified and evaluated systematically: frontal sinus, frontal recess, uncinate process, infundibulum, maxillary sinus and ostium, ethmoid bulla, sinus lateralis, middle meatus, posterior ethmoid sinus cells, sphenoid recess, and the sphenoid sinus. Particular attention is focused on the middle meatus and the sphenoethmoid recess. The middle meatus is a narrow passage that receives mucus clearance from the frontal sinus, anterior ethmoid sinus (including all cells anterior to the basal lamella), and the maxillary sinus (Figs. 1a, 1b, 2a, 2d). The sphenoid recess and superior meatus receive and clear mucus from the posterior ethmoid sinus and the sphenoid sinus (Fig. 2c, 2d). Thus, each sinus is evaluated for the extent of mucoperiosteal thickening (inflammation), and then potency of its communication with either the middle meatus or the superior meatus (Figs. 4a, 5a).

Anatomic variations, trauma, and tumor represent structural variations that predispose to narrowing of the ostiomeatal complex and the sinus drainage channels. The anatomic variations encountered in the anterior or ethmoid sinus include a large ethmoid bulla (Fig. 3a), a large concha bullosa (Figs. 3b, 3c), a paradoxic middle turbinate (Figs. 3d, 3e) (the convexity is lateral instead of medial), an uncinate process bulla, and nasal septal deviation. The major consequence of these anatomic variations is narrowing of the middle meatus. Two other anatomic variations—Halle cells (ethmoid cells extending along the roof of the maxillary sinus) and lateral deviation of the uncinate process—can severely narrow the infundibulum.

Furthermore, reconstructed sagittal CT scans may be used to plan the approach to endoscopy and therapeutic instrumentation. CT can show the exact distance and angle from the piriform aperture to the frontal recess, the basal lamella, or the anterior rim of the sphenoid sinus (Fig. 6).

**OBSERVATIONS**

In the first 100 CT examinations of patients with chronic sinusitis (patients who had and had not undergone previous surgery), the region most commonly involved with inflammatory disease was the middle meatus (72%). Associated maxillary sinus mucoperiosteal disease was found in 65% (Fig. 5). Frontal sinus mucoperiosteal disease was found in 39 patients (39%), in all of whom the frontal recess was also occluded by an inflammatory mass extending from the middle meatus. Seven patients had ostiomeatal disease without maxillary sinus disease. This might be explained on the basis of incomplete occlusion of the infundibulum. The sphenoid sinus was affected in 29% and the posterior ethmoid sinus in 40%. In 7% no inflammatory pathosis was found (Table 2).

Our initial experience confirms the beliefs of Messerklinger and Proctor that ethmoid sinus disease influences the development of disease in other sinuses. Anterior ethmoid sinus infection was found in each patient with the major complaint of frontal or maxillary sinusitis. Moreover, middle meatal disease was found to extend to and occlude the frontal recess in each patient with frontal sinusitis and to extend to and occlude the infundibulum in all cases of maxillary mucoperiosteal disease (Fig. 4).

**DISCUSSION**

Although recognized earlier by otolaryngologists (5-12), the role of ethmoid sinus disease in the development of disease in other sinuses is often forgotten, perhaps because of poor visualization of the ethmoid sinus on standard radiographs. In 1966 Proctor stated that the ethmoid sinuses are the key to infectious sinusitis (8). When sinus ostia are obstructed, mucociliary clearance becomes ineffective and sinusitis ensues (5-15). Clinically the need to evaluate the ostiomeatal complex patients with chronic and recurrent sinusitis further highlights the need for a systematic radiologic evaluation of this area with a technique other than plain radiography.

The standard radiographic views (Caldwell, Waters, base, and lateral) allow quick, noninvasive evaluation of the nasal cavity and paranasal sinuses. With these views it is possible to evaluate the maxillary, frontal, sphenoid, and posterior ethmoid sinuses, as well as the lower third of the nasal cavity. However, the standard views are insufficient for adequate evaluation of the anterior ethmoidal air cells, upper two-thirds of the nasal cavity, and the frontal recess (2, 3). Because of problems with ideal positioning and overlapping structures, many studies are suboptimal.

![Figure 5](https://via.placeholder.com/150)

**Figure 5.** Inflammatory disease within the ostiomeatal channels with secondary effects in the maxillary sinus. (a) Coronal view reveals a soft-tissue mass occluding the right (R) infundibulum (solid arrow). Mucoperiosteal reaction (soft-tissue density) is present along the right antral floor (open arrow) and the right ethmoid bulla (+). The contralateral infundibulum is free of disease (dashed arrow). (b) Endoscopy performed after the patient was treated with decongestants revealed a scarred and closed inferior infundibulum (curved arrow) with mucus (arrowheads) bridging the occluded hiatus semilunaris (fine arrows) and the middle turbinate (MT). U = uncinate process, NS = nasal septum.
and preclude accurate evaluation of the extent of soft-tissue masses and bone destruction (2, 3).

Thin-section pluridirectional tomography was found to be more accurate than plain radiography in demonstrating the extent of soft-tissue pathosis and bone erosion (3). Even though the structures of the upper two-thirds of the nasal cavity are better visualized with tomography than with plain radiography, small structures are obscured by phantom artifacts. Phantom artifacts also tend to mask underlying small soft-tissue disease involving the osteo-
meatal unit, thus precluding their recognition.

CT, with its excellent capability for displaying bone and soft tissues, is the current diagnostic modality of choice for evaluating the osteomeatal complex (4). The technique described, which uses 20-25 CT scans, accurately depicts the presence and extent of paranasal sinus disease. Furthermore, CT is effective in demonstrating predisposing causes of chronic sinusitis (anatomic variations, trauma, tumor) and provides precise guidance for therapeutic endoscopic instrumentation.

In addition to the evaluation of osteomeatal disease in the patient that has not yet been operated on, CT is of particular value in the assessment of patients with persistent complaints after sinus surgery. Proctor has pointed out that the most common cause of failure in therapy directed at the major sinuses has been persistent ethmoid disease (8, 9), and disease in this area frequently persists after traditional therapeutic approaches to sinus disease have been carried out. In these patients CT is mandatory because inflammatory changes in the middle meatus are poorly seen on plain radiographs. In this setting CT can establish the extent of surgery, help the clinician determine if full patency of the narrow passages has been reestablished, and reveal the secondary consequences of osteomeatal inflammation.

The development of functional endoscopic sinus surgery and its ability to alleviate disease in the osteomeatal unit allows treatment to be undertaken with minimal injury to adjacent normal structures (10-15). When the cause of recurrent or chronic inflammation can be readily identified on endoscopy, CT provides additional information regarding regional anatomic detail, drainage impairment, and the magnitude of disease. CT and endoscopy are therefore complementary in the diagnosis and treatment of nasal cavity and paranasal sinus disease. Accurate knowledge of the extent of disease and the normal drainage pathways has proved crucial for the successful care of chronic sinusitis (13, 14). Recognition of the importance of the osteomeatal complex and the reversibility of secondary mucosal disease has led to the concept of functional endoscopic sinus surgery (13) in which the primary operation is performed within the ethmoid sinus-middle meatal complex.

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