Chapter 51: Radiology of the Nasal Cavity and Paranasal Sinuses

S. James Zinreich, Kenneth D. Dolan

The radiologic examination is designed to give information that is complementary or supplementary to the clinical findings. By themselves radiographic changes are non-specific and require correlation with historical and physical examination findings to ensure the greatest diagnostic usefulness.

Three major forms of radiologic evaluation are available. Plain films serve as a survey evaluation of the transparency, size, and wall integrity of the sinuses. Customarily, the plain-film examination consists of Waters', Caldwell's, and lateral views of the paranasal sinuses, as well as a basal view. In special cases the posteroanterior and Towne projections are very useful supplementary views for obtaining specific information.

The overlapping structures and the limited resolution of the fine body outlines provided by plain films hamper this modality in the evaluation of the sphenoid and particularly in the evaluation of the ethmoid sinuses. Thin-section, pleural directional tomography, with its 1 mm planar displays, partially addresses this limitation by avoiding superimposition of structures and providing improved bone detail. However, the cost of tomography (two to three times the cost of plain films), the increased radiation dose, and the increased time required to perform the examination limit the use of this modality.

Computed x-ray tomography (CT), with its inherent capacity to simultaneously display bone, soft tissue, and air, enables the scanner to optimally evaluate the maxillofacial bone structures; nasal, orbital, and intracranial soft tissues; and minute nasal and paranasal sinus airways. Further, the originally obtained direct CT image data may be reconstructed to provide additional indirect orthogonal planes - multiplanar reconstruction - resulting in improved perception. This process is further optimized with three-dimensional reconstruction of the CT data, which will continue to facilitate surgical planning as well as the surgery itself.

Magnetic resonance imaging (MRI) is a radiologic examination technique that does not require ionizing radiation but rather depends on radiofrequency signals generated by nuclear protons in tissue or recovery times required after shift in position of the protons. Unfortunately, as of yet, this modality is limited in its display of bone. However, MRI is proving to be beneficial in the diagnosis of fungal sinusitis and in distinguishing squamous cell carcinoma from inflammatory disease.

Plain-Film Examination

The specific radiographic details of positioning and exposure are well described in standard manuals of radiographic methods (see Ballinger, 1982). This section will present analysis of each plain-film view to show the main sinus territory each view depicts. For illustrative purposes, Fig. 51-1 is the plain-film examination from a patient with extensive nasal polyposis and complete opacity of the sinuses on the left side.

Waters' view

Waters' view is a posteroanterior projection along a central plane in the occipitomental axis. This position places the maxillary sinus above the petrous bones and allows one to analyze the transparency of the maxillary sinuses. In Fig. 51-1, A, the left maxillary sinus is completely opaque while the right side is clear. The nasal fossa contains a large polyp on the left side. A large choanal polyp projects into the nasopharynx on the left and is evident through the open mouth. The anterior, orbital, and lateral walls of the maxillary sinus are intact. Table 51-1 lists supplementary structures visualized.

Caldwell's view

Caldwell's view uses an occipitofrontal beam. Consequently, the frontal sinus and nose are in contact with the film holder so that magnification is minimal, and the view can be used to obtain a frontal sinus template for surgical purposes. In Fig. 51-1, B, the left frontal sinus is opaque to such a degree that the sinus lamina dura is barely definable. Opacity of the left ethmoid sinus is present in comparison to the right. The left orbital floor cortex and lateral maxillary wall are thicker, indicating slight blastic osteitis.

Lateral view

In the lateral view projection the central x-ray beam should pass through the anatomic center of the sinuses. Transparency of the frontal, ethmoid, and maxillary sinuses is difficult to judge because of overlap. Opacity of the sphenoid sinus may be evident, as in Fig. 51-1, C. The large choanal polyp is evident.

Basal view

In the basal view the patient is in a submental vertex position with the mandible and frontal sinus area superimposed. Two representations of bone details are possible with this projection. If underexposed, it demonstrates the zygomatic arches. If normally exposed, the ethmoid sinus walls and septum, sphenoid sinus walls, and lateral maxillary, lateral orbital, and greater wing of sphenoid margins are evident.

Fig. 51-1, D, demonstrates opacity of the left ethmoid and sphenoid sinuses. Overlying teeth and a cap on the left second mandibular molar obscure the left maxillary sinus opacity.

Supplemental Plain Films

Towne's view

The Towne or Chamberlain-Towne projection is an anteroposterior projection in which the central x-ray beam is directed downward 40 degrees in relation to the cantho-meatal baseline. Used as a routine part of the skull examination for the posterior fossa and foramen magnum, the view also defines the upper surface of the maxillary sinus alongside the inferior orbital fissure, and the auricular and subauricular parts of the mandible.

Posteroanterior view

The posteroanterior view makes use of an occipitofrontal central x-ray beam aligned with the canthomeatal baseline. There the petrous ridges overlap the orbital roof on both sides. The value of this projection lies in defining the ethmoid and sphenoid sinus roofs.

Conventional Tomographic Examination

Tomography using conventional radiographic techniques makes use of the blurring effect produced when the x-ray tube and film are shifted in opposite directions during an exposure. In the plane of the locus of rotation no blurring occurs so that this layer is sharply defined while everything overlying and underlying that plane is blurred and not defined on the film. The thickness of the sharp layer is inversely related to the length of tube and film excursion. Therefore the tomographic layer produced by a linear tube-film shift is relatively thick, about 5 mm minimum, when compared with complex (hypocycloidal) motion that produces "cuts" of about 1 mm thickness. Complex motion also produces sharper edges in the tomographic plane and the most complete blurring of overlapping structures.

Generally, tomography is used to better visualize change within the sinus cavity or in the sinus wall when change cannot be thoroughly evaluated by plain-film examination.

Frontal tomograms are made in the anteroposterior position. Because of blurring of petrous bone, this area does not interfere with the image of the sinus being evaluated. In coronal tomograms one may visualize the cephalic, medial, lateral, and caudal margins of the sinus as well as any soft tissue-air or fluid-air interface lying perpendicular to the tomographic plane. Structures that lie parallel to the tomographic plane are not well visualized; therefore a second set of tomographic views is required to visualize the anterior or posterior edges of the sinus wall or any intrasinus abnormality. In some cases tomography of the suspicious area in an axial plane may be helpful.

Fig. 51-2, A, is a representative coronal section from the tomographic examination of a patient with biopsy-proven Wegener's granulomatosis. Plain films revealed opacity of the right maxillary sinus, ethmoid sinus, and nasal fossa. Bone erosion was suspected and demonstrated on this view, in which the right medial maxillary wall, maxillary-ethmoidal septum, and medial ethmoidal wall are missing. A soft tissue mass nearly fills the nasal fossa. Since visualizing the right lamina papyracea is difficult in this projection, an axial tomographic examination was also done (Fig. 51-2, B). The tomogram shows destruction of ethmoidal secondary septae but not of the lamina papyracea.

Even though the larger maxillofacial bone structures are better defined by tomography than plain films, the blurring (phantom artifact) that superimposes the ethmoid air channels precludes accurate definition. Moreover, the blurring artifact can be mistaken for mucoperiosteal disease, resulting in an overestimation of inflammatory disease.

Computed Tomography

CT differs from conventional radiographic study in several ways. First, the x-ray tube is aligned with a detector crystal or banks of detectors rather than an x-ray film. A highly collimated (very thin) x-ray beam is projected through the part being examined so that only a thin layer of the patient is exposed for each slice, in contrast to conventional tomography, in which the entire volume being studied is exposed even though only a small layer of the volume is in focus on each section. Therefore exposure of the patient to x-rays is much smaller in a CT examination than for conventional tomography. For example, if a 5 rad exposure is used for each conventional tomogram and 10 slices are obtained, the patient receives a total exposure of 50 rad. If 5 rad were used for a similar 10-slice CT examination of the same area, exposure through the entire volume would amount to only 5 rad (a slight additive effect may occur if adjacent CT slices overlap). Currently, CT scanning parameters are being adjusted to further decrease the radiation exposure. By reducing the milliamperage (Ma) and time of scanning, the radiation exposure can be reduced to 1 or 2 rads.

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 is the preferred plane for direct scanning. Each patient is positioned prone with the head hyperextended on the scanner bed (Fig. 51-3). For optimal visualization of the ostiomeatal channels, the field of view should be focused on the paranasal sinuses (on the Siemens Somatom DR 3) scanner we used a zoom of 4 or 5). Scanner computation algorithms are selected to favor the demonstration of soft tissue. Window widths are usually at 2000, and the window is centered to -200. These parameters are optimal for display of the regional anatomy and for the evaluation of patients with chronic inflammatory disease. For the demonstration of adjacent pathologic conditions (in the face) a narrower window range is necessary. Scanner "raw" data are transiently saved so that high-resolution bone-enhancing reconstructions can be applied when bone erosion was either visualized or suspected.

When patients are unable to assume the prone position, axial scans from the palate through the frontal sinus are obtained and indirect coronal reconstructions are then generated from them. For special attention to the anterior ethmoid region, coronal indirect reconstructions are performed to complement the initial scanning plane. In our experience, even in patients with extensive metallic dental fillings, the direct coronal plane proved superior to indirect reconstructions, and therefore the coronal plane remains the plane of choice.

Anatomy

Ethmoidal labyrinth

As seen on the coronal view, air cells collectively form the ethmoidal labyrinth. They appear as a near vertically oriented, thinly septated bony honeycomb lined by mucosa. These vertically situated air cells are narrower anteriorly and wider posteriorly. The boundaries of this labyrinthine structure are the lamina papyracea laterally, the orbital plate of the frontal bone superiorly, the perpendicular plate medially, and the middle turbinate inferiorly.

Ostiomeatal unit

Maxillary sinus ostium and infundibulum

The maxillary sinus ostium and the infundibulum serve as the predominant channel linking the maxillary sinus with the nasal cavity. They are best visualized in the coronal plane. The infundibulum is bounded laterally by the inferomedial orbit, superiorly by the hiatus semilunaris and ethmoidal bulla, medially by the uncinate process, and inferiorly by the maxillary sinus as the sinus funnels into it. 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 infundibulum represents the superomedial extension 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 (Fig. 51-4).

Hiatus semilunaris

This complex space gains its name from its arched appearance in the sagittal plane. The hiatus semilunaris is bounded superiorly by the ethmoidal 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 infundibulum. The hiatus semilunaris is best identified on parasagittal sections and runs obliquely in a posteroinferior direction between the uncinate process and the ethmoidal bulla. A posterosuperior extension of the hiatus semilunaris (hiatus semilunaris superioris) passes between the ethmoidal bulla and basal lamella and communicates with the sinus lateralis, affording drainage for this space.

Middle turbinate

The middle turbinate lies inferomedial to the anterior ethmoid air cells. Its most consistent bony attachments are vertical to the cribriform plate superiorly and to the lamina papyracea laterally via a bony strut termed the *basal (ground) lamella.* The basal lamella is oriented anteromedially to posterolaterally to become situated behind the ethmoidal bulla. The compartment between the posterior wall of the ethmoidal bulla and the basal lamella is the sinus lateralis. Quite often the body of the middle turbinate contains an air-filled cavity, the concha bullosa, which communicates variably with the superior medial meatus, the frontal recess, or the sinus lateralis.

Ethmoidal bulla

The ethmoidal bulla usually consists of an air cell of variable size and shape. It is bordered inferomedially by the infundibulum and hiatus semilunaris, laterally by the lamina papyracea, and superoposteriorly by the sinus lateralis. It communicates with the nasal cavity via an ostium, the site of which appears to be variable. According to Zuckerkandel (1893) the ostium is most often posterior, but according to Messerklinger (1967) a superoanterior opening is more frequent. We have also noted it medially.

Frontal recess

The frontal recess affords mucociliary drainage of the frontal sinus. Drainage may occur directly into the middle meatus medial to the uncinate process, into the ethmoidal infundibulum more laterally, or more posteriorly above the ethmoidal bulla. This communication between the frontal sinus and the nasal cavity is not strictly a duct but an internal aperture of hourglass configuration positioned between the sinus and the anterior middle meatus.

Nasolacrimal duct

The nasolacrimal duct is a straight-coursing tube that extends upward from the lacrimal fossa to a site adjacent to the attachment of the inferior turbinate. In the coronal view the duct is nearly superoinferiorly oriented, with its inferior portion lying about 3 to 5 degrees medial to its superior portion. In the sagittal view its posterior incline may be larger, varying from 5 to 30 degrees.

Sphenoidal sinus, sphenoid ostium, and sphenoethmoid recess

This continuum is best evaluated on either axial or sagittal scans. The ostium is located at the anterosuperior portion of the sphenoid sinus. The sphenoid ostium and the posterior ethmoidal air cells drain into the sphenoethmoidal recess.

Magnetic Resonance Imaging

Fig. 51-5 is an example of a magnetic resonance image made in the coronal plane that passes through the ethmoid and maxillary sinuses. Since no radio frequency signal is generated in the sinus areas, they appear black. The inferior and middle turbinates, which are larger on the left, produce a fairly intense signal. A very strong signal arises from the retrobulbar fat, in the center of which is a round black area representing the optic nerves. Medial to this is a vertical black line representing the medial rectus muscle. No signal arises from the maxilla, mandible, or teeth. A weak signal arises from the tongue muscles.

The nasal cycle is optimally demonstrated by MRI. The edematous soft tissue that occurs cyclically in the nasal cavity assumes a high signal intensity and should not be confused with a pathologic process. We have found that the mucosa of the nasal cavity, as well as the mucosa of the ethmoid sinus, takes part in this cyclic event. This cycle can vary from 20 minutes to 6 hours in individual patients. The mucosa in the maxillary, frontal, and sphenoid sinuses does not cycle. Thus the effects of the cyclic process can easily interfere with the estimation of inflammatory disease in the nasal cavity and ethmoid sinus. On the other hand, the presence of any increased signal within the maxillary, frontal, and sphenoid sinuses may be considered a pathologic process (Fig. 51-6).

MRI has proven very beneficial in its ability to distinguish between fungal and bacterial infection. Bacterial and viral infections assume a high signal intensity on T2-weighted images, whereas fungal concretions have virtually no signal, similar to the signal intensity of air. Similarly, MRI is very helpful in distinguishing between neoplastic and inflammatory pathologic conditions. Squamous cell carcinomas (90% of tumors in this area) have an intermediate rise in signal intensity on T2-weighted images compared to the very strong increase in signal intensity manifested by bacterial and viral infections.

Basic Abnormalities

Size

Sinus size depends on developmental factors and may also be influenced by acquired extrinsic mass lesions. Variations in sinus size may affect sinus transparency if compressive change is great. Transparency of a sinus also depends on the content of a sinus space and the integrity of the sinus wall.

Considerable variation in sinus size occurs from patient to patient. A tendency toward abnormality seems to exist in those sinuses that are smaller than normal. This tendency is especially evident in respect to the maxillary sinus; in our experience the symptomatic sinus is often the smaller one.

Size governs sinus transparency on transillumination and conventional radiographic studies. In general, a small sinus is less transparent than a normal one. Fig. 51-7, A, is Waters' view of a patient with right maxillary sinus hypoplasia. The diminutive transverse and perpendicular lengths of the right maxillary sinus differ sharply from the dimensions of the average-sized left sinus. The right maxillary sinus extends just past the right infraorbital canal, which is the usual size of the maxillary sinus in a 5-year-old child. The normal left sinus has a zygomatic recess and a small alveolar recess inferiorly.

The basal view of this patient is shown in Fig. 51-7, B. The dental structures obscure the right maxillary sinus, but the perimeters of the left side are easily visualized. In hypoplasia of the maxillary sinus the medial sinus surface is farther from the bony septum, resulting in enlargement of the nasal fossa transverse dimension. This fossal enlargement is evident in both views of Fig. 51-7. The normal left maxillary sinus is much more transparent than the small right cell. The lamina dura of the small right sinus is well defined and sharp, even though the thickness of the right lateral maxillary wall is greater than the left. The patient was asymptomatic in respect to the sinuses and was being evaluated for nasal injury.

Extreme variation in frontal sinus size may be found, as shown in Fig. 51-8. The patient in Fig. 51-8, A, has absence (aplasia) of the frontal sinuses. The anterior ethmoid cells produce the small, rounded air cells in the lower frontal area. By way of contrast, the air cells in Fig. 51-8, B, are hyperplastic and serpiginous. One portion of the left sinus extends into the orbital process of the frontal bone. Another frontal sinus variation is seen in Fig. 51-8, C, in which two nasal ridge cells overlie the lower frontal sinus. These cells lie within the sinus and occasionally may be large enough to obstruct the nasofrontal ducts, but usually they are just a variation and should not be confused with a pathologic process.

Ethmoid sinuses are rarely small; more commonly, they are enlarged and extend throughout the orbital roof as in Fig. 51-9, in which essentially all of the orbital roof is pneumatized on both sides. Orbital roof pneumatization may be unilateral.

Perhaps the most variation in size is found in the sphenoid sinus. Small cells that extend only into the presphenoidal area or just under the sella may be found. More commonly hyperplasia is present with recesses of the sphenoid sinus into the anterior and posterior clinoid process, lesser wings, and greater sphenoid wings. Fig. 51-10 illustrates sphenoid sinus hyperplasia: lesser sphenoid wing recesses are shown in Fig. 51-10, A; large sphenoidal recesses extending into the greater wing are demonstrated in Fig. 51-10, B; and anterior and posterior clinoid process recesses are shown in Fig. 51-10, C. In Fig. 51-10, D, a large sphenoidal air cell recess is shown extending far laterally into the orbital process of the greater wing and could suggest a pathologic process.

In general, no relation to the variations in size among the sinuses, seems to exist. Hypoplasia of all sinuses occurs rarely. Sinus size is related to surrounding structures. For example, after removal of an injured eye in a child, significant increase in ethmoid sinus size occurs unless a replacement ocular prosthesis is used. Similar increase in size of the frontal sinus may be found in the patient with unilateral cerebral atrophy. Conversely, compressive decrease in sinus size may occur as a result of expansion by a nearby mass. Fig. 51-11, A, shows a normal left frontal sinus. The right frontal bone has a hyperlucent area that resembles a large frontal sinus, but no definite sinus lamina dura is present. The lateral view (Fig. 51-11, B) illustrates marked thinning of the right frontal bone. Similar thinning was present on a basal view. CT studies in Fig. 51-11, C and D, confirm the thin right frontal bone and show an underlying arachnoid cyst as the cause of thinning.

Compressive change in sinus size may result from many causes. A giant carotid aneurysm may compress a sphenoid sinus cell. Lesions along the floor of the anterior fossa may compress the ethmoidal cells. Neurofibromas along the mandibular nerve may be large enough to compress the lateral maxillary sinus wall, and slow-growing masses arising within the pterygomaxillary area may compress the posterior maxilla. This led Potter (1969) to use a slightly rotated lateral view to separate the pterygomaxillary spaces on the two sides, thus uncovering unilateral enlargement that is a sign of juvenile nasal angiofibroma.

Air-fluid level

The prone Waters' view in Fig. 51-12, A, shows opacity of the right maxillary sinus. The same patient was examined in the upright position (Fig. 51-12, B), which revealed an air-fluid level on the right. Distribution of the fluid along the anterior sinus surface in A produced the appearance of complete opacity.

The lateral view may also reveal a maxillary air-fluid level, but the air-soft tissue interface of the nasal turbinate may resemble an air-fluid level. A maxillary air-fluid level is evident in Fig. 51-12, C. CT examination defines the maxillary air-fluid level particularly well, as seen in Fig. 51-12, D. Air-fluid levels are not evident in conventional radiographic examinations of the ethmoid sinuses but may occasionally be seen as intracellular change on CT studies.

Frontal sinus and sphenoid sinus air-fluid levels are present in Fig. 51-13. If the amount of fluid present in a sinus space is very small, the overlying structures or a sinus margin may obscure it. The presence of fluid in the sinuses is usually secondary to an acute inflammatory process, the result of hemorrhage from trauma, or of iatrogenic origin.

Domed sinus mass

The air-fluid level typically has a straight or slight meniscus-shaped interface. Domed lesions have a convex interface with the air contained in the sinus. Most commonly these lesions represent mucus or serous mucus-retention cysts. Blood clots and subperiosteal blood accumulations may occasionally be rounded. Benign or malignant tumors may have a dome shape. Dentigerous lesions, particularly cysts, will have a dome shape if the lesion projects into a maxillary sinus. Fascenelli (1969) has shown that domed lesions are very common and can be found in 10% of a population group.

Mucus-retention cysts may have quite a variable appearance in the maxillary sinus, as demonstrated in Fig. 51-14. In Fig. 51-14, A, a large cyst causes almost complete opacification of the left maxillary sinus. A cyst may arise on any surface of the maxillary sinus. The cyst illustrated in Fig. 51-14, B, arises from the anterior sinus surface. Cysts may be multiple or bilateral as demonstrated in Fig. 51-14, C.

The evaluation of the adjacent bony architecture is critical when attempting to assess the etiology of soft tissue pathologic findings. When dealing with a chronic inflammatory process, the adjacent bony architecture remains intact. If such an inflammatory process is chronic, an adjacent osteitis may ensure that can produce marked bony thickening (Fig. 51-15). In the presence of a neoplastic process, adjacent bony erosion is usually present. The bony erosion of neoplasia is usually aggressive compared to the erosion secondary to an expansile mass (usually caused by mucoceles).

Mucosal thickening

Allergic or inflammatory insult may result in thickening of the mucous membrane around the margin of a sinus wall to produce on radiographs a halo of increased density surrounding a central air collection. Variable thickness characterizes mucosal changes, as demonstrated in Fig. 51-16. The left maxillary sinus in Fig. 51-16, A, has thickening of the mucous membrane along the lateral and orbital surfaces. Diffuse bilateral mucosal thickening is present in both maxillary sinuses of the patient in Fig. 51-16, B. Only a very small central part of the sinus contains air. Tomography may indicate a lobular character to mucous membrane. The lateral tomogram in Fig. 51-16, C, shows lobular mucous membrane along the anterior, alveolar, and posterior maxillary surfaces. Similar lobular mucosal change in the sphenoid sinus is present on the coronal tomogram in Fig. 51-16, D.

Thickening of the mucous membrane is not often evident in the frontal sinus on plain films, probably because of the small volume of the frontal sinus. Mucosal thickening usually results in complete opacity of the ethmoid sinus. The extent of mucosal thickening is best demonstrated by the CT examination (Fig. 51-17). The ability to show the adjacent bony architecture and its relationship to the normal and pathologic mucosa continues to make CT the optimal modality.

Borders

After evaluating sinus content, the examiner should turn to evaluation of the sinus wall. Several forms of change may be defined and represent a deviation from the normal thin lamina dura representation of the normal osseous border.

Osteitis

Bone response may occur in relationship to an acute, high-grade infection that extends through the haversian system of the sinus wall and produces lytic osteitis, in which bone surrounding the infection seems to dissolve.

A well-defined region of bone absence resulting from lytic osteitis may be evident on radiographs, or infection of adjacent soft tissue surrounding the sinus wall may occur without specific radiographic evidence of bone absence. In the latter case the area of bone lysis may be too small to separate from uninvolved bone overlying it.

In response to low-grade, repeated infections, thickening of bone in the sinus wall may result in a buttressing increase of bone known as *osteoblastic osteitis.* Presumably osteoblastic osteitis is an effort of the sinus wall to isolate an intrasinus infection. Usually osteoblastic osteitis is quite evident on plain films as an area of bone wall thickening and increased density. Osteoblastic osteitis may occur in the wall of any sinus space. Lytic osteitis may not be evident on special examination with tomography or high-resolution CT.

In Fig. 51-18, A, the right frontal sinus is opaque. The peripheral lamina dura in the lateral sinus border is missing, and the inferomedial (orbital) border is also absent. Lytic osteitis is present in these areas as well as in the area of the upper right ethmoidal lamina papyracea. Considerable soft tissue swelling of the periorbital soft tissue and lids reflects orbital cellulitis on the right accompanying the lytic osteitis. The right maxillary sinus is also opaque, but no osteitis is present in this sinus wall.

The patient depicted by the CT scan in Fig. 51-18, B, had significant swelling of the right cheek. The right maxillary sinus is opaque, and an area of lytic osteitis is present along the anterior and zygomatic surfaces of the sinus wall.

Osteoblastic thickening of the right frontal sinus accompanies sinus opacity in Fig. 15-19, A. Similar osteoblastic thickening is present along the right lateral maxillary wall. The CT examination in Fig. 51-19, B, shows osteoblastic osteitis of the left maxillary sinus wall accompanying thickening of the mucous membrane.

The coronal and lateral frontal sinus tomograms in Fig. 51-19, C and D, show right sinus opacity accompanied by distinct osteoblastic osteitis. No evidence of lytic change is present. At operation, hyperplastic mucous membrane filled sinus space, and microscopic examination revealed chronic inflammatory cells throughout the mucosa.

From the foregoing cases one can appreciate that plain films and tomograms may well illustrate osteoblastic osteitis, but the sinus is opaque because of the overlying bone thickening. One cannot visualize the mucous membrane on plain radiographic studies when osteoblastic change is present. However, the mucous membrane is well visualized in CT examination (Fig. 51-19, B). Osteoblastic osteitis may also occur as a postoperative sinus change as described in a later section on surgical changes.

Bone proliferation

Proliferative bone thickening and overgrowth as found in fibrous dysplasia should not be confused with osteoblastic osteitis. Not only does the sinus wall become markedly thickened, but also the overall size of the sinus wall increases with proliferation. Commonly the alveolar portion of the maxilla is also enlarged and increased in density with the proliferative change of fibrous dysplasia.

The patient whose Caldwell's view is shown in Fig. 51-20, A, had a prominent right cheek and malar eminence. Also the right maxillary buccal surface was enlarged, and the teeth in this area did not articulate well with the mandibular dental structures. Significant thickening of the orbital and lateral maxillary walls existed, and the sinus air space was diminutive. A coronal tomogram of this patient (Fig. 51-20, B) showed the overall increase in size of the right maxilla as well as encroachment of the sinus. The appearance of bone in fibrous dysplasia has been described as "ground glass", which certainly accurately describes the bone in this case.

Fibrous dysplasia producing blastic thickening in one portion of a sinus may be associated with expansile change in another part of the sinus. The expanded sinus wall is seen in association with an enlarging ossifying fibroma contained within the sinus cavity. This expansile change of the sinus wall should not be confused with the expansile changes produced by a mucocele.

The bone proliferation of fibrous dysplasia should not be confused with an osteoma, in which the margin of the dense bone mass is usually much more sharply defined.

Osteoma

Local areas of bone proliferation can occur anywhere in the skeleton. Histologically these masses are composed of an abnormal amount of dense cortical bone, although the cellular composition of the bone is normal. The frontal sinus is the most commonly involved paranasal sinus. The large left frontal osteoma in Fig. 51-21, A, obliterates and arises from the left sinus margin. Expansion of the mass has produced slight depression in position of the subadjacent orbital roof. The lobular rounded border of the lesion helps differentiate an osteoma from fibrous dysplasia.

Osteomas are uncommon in the maxillary sinus. The osteoma illustrated in Fig. 51-21, B, is accompanied by osteoblastic change in the lateral sinus wall, which at least suggests an association with infection. Multiple sinus osteomas should suggest the possibility of Gardner's syndrome. Fig. 51-21, C, shows right frontal and ethmoidal sinus osteoma. The ethmoid sinus osteoma is more clearly defined on the coronal tomogram in Fig. 51-21, D. This patient also had the precancerous adenomatous polyps of the colon associated with Gardner's syndrome.

Expansion of sinus wall

An aerocele produces progressive enlargement of the involved sinus, which contains air. The sinus walls become very thin in association with such enlargement. An aerocele results from one-way ingress of air into the sinus as a result of a "trap-door" change in the sinus wall and is usually the result of trauma (Zizmor and Noyek, 1978). This condition is very rare.

A much more common cause of expansile change is a mucocele. This cystic abnormality is produced as a complication of inflammatory disease or by any other obstructing lesion such as an osteoma. Posttraumatic mucoceles may occur if injury obstructs the sinus ostium. Typically, the mucoceles gradually enlarge, producing thinning of the sinus wall and obliteration of the normal sinus shape. Usually the sinus is opaque because of the contents of the cystic lesion.

In Fig. 51-22, A, the right frontal sinus is opaque in comparison to the small left cell. Secondary septae around the sinus margin are absent and the central septum is displaced to the left. The right medial orbital border is depressed and is so thin adjacent to the anterior ethmoidal cells that it seems to disappear. Fig. 51-22, B, is a lateral view of A. Expansile thinning of the right frontal anterior and posterior walls is more evident. Least well visualized is the expansile change of the involved anterior ethmoid sinus.

Ethmoid and sphenoid sinus involvement by a mucocele may require special examination. Tomographic study was necessary to demonstrate the left ethmoidal mucocele in Fig. 51-22, C. Plain radiographs of this patient demonstrated only ethmoidal opacity. The tomogram showed expansile change of the left anterior ethmoidal cells and lamina papyracea, opacity of the supraorbital cell, and thinning of the adjacent orbital roof.

Plain-film examination of the patient illustrated by Fig. 51-22, D, demonstrated only sphenoid sinus opacity. The CT examination revealed expansile displacement of the sphenoid septum along with sinus opacity.

Expansile change has also been described in association with primary fibrous tumors and neurofibromas that affect sinus walls (Bergeron et al, 1984). Expansile change may also occur around the margins of a malignant sinus tumor, but the more specific change in sinus malignant tumor is erosion of bone.

Erosion of sinus wall

As tumor extends through the haversian system of the sinus bony wall, erosion results. The destructive change that tumor extension produces results in local or widespread absence of the sinus lamina dura. This change may be similar in appearance to that produced by osteoblastic osteitis in infections.

Waters' view was obtained to evaluate nasal obstruction in the patient depicted by Fig. 51-23, A. In this study a small soft tissue mass is present along the lower right lateral maxillary wall that has an intact lamina dura. Sinus pain prompted a repeat examination of this patient 3 years later. The second Waters' view (Fig. 51-23, B) revealed enlargement of the soft tissue mass with erosion of the overlying sinus wall. At surgery an adenoid cystic carcinoma was removed.

The more extensive undifferentiated right maxillary neoplasm demonstrated by the tomogram in Fig. 51-23, C, produced erosion of a large area of the nasal surface and pterygomaxillary surfaces. The ethmoidal, orbital, and anterior walls of the maxillary sinus are also vulnerable to neoplastic erosion.

The CT scan in Fig. 51-23, D, showed involvement of the pterygoid muscles by a maxillary neoplasm. On the right posterolateral and nasal sinus wall, erosion was present. The tumor invaded the right lateral pterygoid muscle and produced this mass.

CT best demonstrates the degrees of extension beyond the limits of a sinus primarily involved by a malignant tumor. Although plain-film examination, as shown in Fig. 51-24, A, effectively demonstrates the bony erosion along the orbital border of the ethmoid sinus affected by undifferentiated carcinoma, the CT scan in Fig. 51-24, B, better defines the extension of tumor into the trochlea and superior rectus muscle. The tumor present in the right ethmoid sinus in Fig. 51-24, C, has eroded through the posterior cell wall into the sphenoid sinus. Fig. 51-24, D, is a composite CT study of a left maxillary sinus neoplasm that has eroded through the floor of the orbit and into the right ethmoid sinus. Erosion through the lamina papyracea produces lateral displacement of the eye and medial rectus muscle.

Clinical Applications

Infection

Nasal endoscopic and CT findings confirm that the ostiomeatal complex is the most frequent site of inflammatory sinus disease and that disease may persist in this area after the secondary sinus disease has resolved. Nasal endoscopic examination consistently reveals significant but subtle evidence of disease that is not visible on anterior rhinoscopy, to the extent that the value of this diagnostic modality can no longer be seriously questioned. Further, the use of CT has allowed the incidence of concomitant anatomic variations and the extent of disease to be accurately recorded. In a study of 230 patients with chronic sinus complaints, we found that 78% had disease within the anterior ethmoid. The next most frequent site was the maxillary sinus (66%). The posterior ethmoid cells were involved in only 31%, a strong argument against the necessity for a routine ethmoid dissection that begins posteriorly. Similarly, the frontal sinus was only involved in 34% of patients and the sphenoid in 16%. At the time of the study, 16% of the patients had no evidence of inflammation. However, some of the patients had significant anatomic abnormalities that could possibly have been responsible for their prior recurrent disease. Therefore 93% of the patients with radiologic evidence of inflammation at the time of the study had disease within the anterior ethmoid. Evaluation of the same CT studies also revealed a wide variety of anatomic variations. The most common variation was concha bullosa, which occurred in 36%. The second most frequent finding was a septal deformity. Other variations occurred with differing frequencies.

Radiology and endoscopic surgery

The application of endoscopic and radiologic techniques for diagnosis and planning of endoscopic surgical therapy introduced a radical new approach to sinus surgery. To apply these techniques successfully, however, a clear understanding of the pathophysiologic changes responsible for the development of paranasal sinus inflammation is necessary.

Pathophysiology and mucociliary clearance

The middle turbinate area has been shown, by experiments using models, to be the primary route involved in inspiratory airflow through the nose. Although the highest velocity of airflow occurs through the area of the nasal valve, high velocity continues through the area of the anterior middle turbinate. This area then is exposed to a high velocity of unfiltered, poorly humidified air and bears the brunt of atmospheric pollutants, particulate matter, and bacteria in the environment. The knowledge that adenocarcinoma in woodworkers originates in this area and the results of experiments using tagged aerosol both support the concept of this being a key area for the deposit of particulate matter from inspired air.

The key to the majority of inflammatory sinus disease is the middle meatus and anterior ethmoid (ostiomeatal complex). The ostiomeatal complex is composed of narrow channels and is subject to wide normal anatomic variation. It contains the ostia not only for the drainage of the anterior ethmoid sinuses but also for the frontal and maxillary sinuses. These sinuses therefore depend on the integrity of the ostiomeatal complex for ventilation and mucociliary clearance. Therefore local inflammation or anatomic obstruction within the ostiomeatal complex may result in secondary disease within the maxillary and frontal sinuses.

The ability of mucosal disease in the major sinuses to resolve, when normal mucociliary drainage and ventilation are reestablished, is currently undergoing reevaluation. Clinical experience demonstrates that in many cases what had previously been considered irreversible disease may recover when obstruction and inflammation are removed from the ostiomeatal complex.

CT examination, usually performed after medical treatment of sinusitis, can reveal the extent of mucosal disease deep in the ostiomeatal complex. Resolution of secondary inflammatory changes affords a more accurate display of the regional anatomy and therefore provides a better "guide" for the surgical procedure.

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 our experience an exception to this guideline is the presence of erosion of the uncinate process, usually the result of chronic inflammation surrounding 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. It is fortunate that 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 using 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 paradoxic 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 during endoscopic sinus surgery an uncinectomy is usually performed, 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 the majority of patients, the ethmoid bulla is separated from the sinus lateralis by an intact posterior wall. When this is the case, there may be inflammatory disease in the sinus lateralis in the presence of a normal ethmoid bulla. This information, only available to the surgeon through CT, is critical if he or she intends to remove all the inflammatory pathologic process 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 surgical intervention should never be based on CT alone, because CT may demonstrate asymptomatic mucosal disease. Surgery is reserved for patients who fail medical management, and a decision to operate should be based on a combination of history, CT, and endoscopic findings.

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 confirms 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 with 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.

There is a need, however, 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 given the very small air passages, the fine mucosal lining, and very fine bony architecture (Fig. 51-25). 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-dimensional and three-dimensional reconstruction of CT and MRI data (ISG Technologies, Toronto), a high-resolution display screen, and a robotic mechanical sensor (FARO Medical, Florida) 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 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.

Summary

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 administration of a local vasoconstrictor (to diminish the effect of the nasal cycle). The milliamperage may be significantly lowered (as suggested by Babbel et al, 1991) 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.