Paparella IV: Section 2: Disciplines Closely Associated With Otolaryngology

Chapter 29: Diagnostic Imaging of the Head and Neck

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Effective treatment must be based on the most rational working diagnosis possible. That provisional diagnostic label must answer maximal questions concerning qualitative and quantitative aspects of the disease at hand. Clinical evaluation, even with the most modern of optical systems and other diagnostic modalities, may still fall short in effective pretreatment assessment of the patient. This shortfall can range from the understaging of cancer to a failure to recognize the biologic activity of osteomyelitis.

However, modern-day diagnostic imaging can contribute substantially to augmenting this clinical information base, and may answer specific, clinically directed questions (Table 1) that improve the formulation of the provisional diagnosis.

Table 1. Clinical Problems Directing Radiologic Examination

Qualitative diagnosis

1. Does disease exist?
2. Specific disease?
3. Group disorder?

Quantitative diagnosis

1. Extent in three dimensions?
2. Extension across major anatomic boundary?
3. Local-systemic disease relationship?
4. Specific anatomic abnormality?
5. Specific physiologic abnormality?

These questions concern both qualitative and quantitative diagnosis. In qualitative diagnosis the radiologist is not placed in a position of competition with the pathologist: rather, they are allied consultants on the same team. In quantitative diagnosis the radiologist provides, through conventional and sophisticated high-technology imaging, a perspective on the patient's anatomy and physiology in a manner not clinically recorded. The purpose of this chapter is to present imaging advances, especially those of the past decade, and to demonstrate their potentials for improved diagnosis and treatment of head and neck disorders. These modalities selectively augment conventional radiologic imaging, which has been with us since Wilhelm Roentgen's amazing discovery in 1895.

Not all clinical problems require a radiologic approach for their solution. Some require only a clinical methodology, others need the selective use of conventional x-rays, and still others require complex diagnostic protocols with the best available imaging technology. However, the imaging modalities often appear overwhelming in their technology and are often misunderstood in their application, even by those who have day-to-day access to these studies.

Clinicians cannot understand the details of the physics of diagnostic imaging, and do not need to; however, they should understand the basic principles of application. Similarly, imagers must understand elements of the critical problems faced by the clinicians in which imaging technology plays a key role in advancing the diagnostic process. This understanding of problematic perspective can be gained only through effective preimaging clinician-imager communication, mutual education, and mutual review of radiologic findings, and the scientific assessment of their role in the success or failure of patient management.

The material in this chapter is presented in a modality-oriented fashion that is representative, but not all-inclusive, of the spectrum of disease encountered by the otolaryngologist and head and neck surgeon. However, it is preceded by a small section outlining the role of diagnostic imaging in three major classic regions (the temporal bone; the paranasal sinuses, maxillofacial skeleton, and skull base; and the larynx). It is not possible to outline all conventional radiographic positions and technical details; this may be found by reference to appropriate texts. However, the routine radiographic studies are enumerated and their roles discussed, as well as key factors of potential and limitation. Further, high-technology imaging through computed tomography (CT), magnetic resonance imaging (MRI), angiography, ultrasonography, and radionuclide scans is similarly reviewed from a modern perspective.

An overview of imaging modalities and their broad applications to the specialty of otolaryngology and head and neck surgery is outlined in the Table, which serves only as a guide to the information that follows. It is not suggested that this constellation of modalities is a diagnostic panacea; however, the selective use of one or more of these by a responsible clinician-surgeon and radiologist may be critical to management decisions for patients with many simple or complex disorders.

Regional Perspective on Head and Neck Imaging

Although head and neck imaging has now expanded to include the possibility of studying all the soft tissue and bony (and cartilaginous) structures of the head and neck, the historical origin of the dependence of otolaryngology on radiologic consultation is centered about the concept that most otolaryngologic pathology lies within relatively inaccessible bony cavities (the temporal bone and the paranasal sinuses). Here the 16 shades of gray, capable of definition by the human eye, allow diagnostic contrast between bony confines and mucosa-air interfaces. From these early beginnings, a complex imaging process has evolved with unbelievable advances such as CT and now MRI. However, the basic principles have not altered, and we will look at the three major regions of x-ray development to understand those modalities that have disappeared, those that have survived, and those that are developing at this very moment. The other head and neck regions of the maxillofacial skeleton and mandible, the salivary glands, the soft tissues of the neck, and the thyroid and parathyroid glands, are placed in illustrative sequence only at this point.

Temporal Bone

Just after the turn of the century, a variety of conventional radiographic positions were espoused to answer critical questions related to the presence or absence of bone destruction within the temporal bone, and the mastoid process specifically. The stimulus was the search for coalescent mastoiditis, and this radiographic finding was often the basis for surgical intervention for life-threatening infection in the preantibiotic era. These conventional radiographs still survive in many parts of the world where such infective disease is still prevalent (such as the Middle East) and where high-technology imaging is as yet routinely unavailable. The conventional plain film projections for temporal bone examination, as well as the anatomic structure assessed, are indicated in Table 2.

Table 2. Overview of Temporal Bone Projections

Frontal	
Transorbital	Labyrinth, internal auditory canal, scutum, petrous apex
Guillen	Middle ear cavity, ossicles, lateral semicircular canal, facial canal (horizontal)
Chaussé III	Tympanic cavity, oval and round windows, scutum, external auditory canal
Towne	Petrous ridge, tegmen, mastoid antrum, aditus, internal auditory canal, petrous apex
Frontal oblique	
Stenvers'	Petrosa continuity (ridge and apex), labyrinth, mastoid tip
Chaussé II	Jugular bulb
Basal	Ossicles, labyrinth, internal auditory canal, tympanic cavity, external auditory canal, mastoid antrum and air cells, petrous apex, eustachian canal, basal foramina
Lateral	
Schüller's	Mastoid air cells, sigmoid sinus plate, tegmen
Law's	Sigmoid sinus plate, mastoid air cells, antrum
Mayer/Owens	Mastoid antrum, aditus, attic, ossicles.

The evolution of conventional plain films depended on the need to visualize the key attic-aditus-antral region, as well as the mastoid air-cell system. Thus, conventional imaging was utilized in the diagnosis of cholesteatoma and its extension as well as the definitive diagnosis of acute coalescent mastoiditis. Internal auditory canal imaging in acoustic neuroma and bone changes secondary to tumors in the cerebellopontine angle also were recognized on plain films, although the fact that these were "ear" rather than "brain" tumors was not realized from the early radiologic perspective of the 1920s. Multiplanar complex motion tomography studied the internal auditory canal intensively and was brought to North America from Europe in the 1950s by Valvassori. Temporal bone structures were well studied morphologically by 1-mm complex motion tomographic sections in frontal, lateral, and basal projections.

However, in many parts of the world, high-resolution, thin-section CT scans are the ultimate bone imaging modality and in turn have supplanted complex motion tomography, which itself advanced the anatomic display of conventional radiographs. These major modalities in temporal bone imaging are now selectively augmented, for example, by radionuclide scans (bone-gallium scan imaging in osteomyelitis) and angiographic studies in glomus tympanicum and glomus jugulare tumors, as well as arteriovenous malformations.

Paranasal Sinuses

Conventional radiographic examination of the paranasal sinuses represents approximately 50 per cent of all diagnostic imaging studies requested by the otolaryngologist. It is a commonplace, day-to-day procedure. For maximal information, the following minimal examination is required and should be carried out with the patient in the erect sitting position, in order that the presence of air-fluid levels may be detected. A complete series of sinus x-rays should include a Waters' posteroanterior view, a Caldwell posteroanterior view, a lateral view of the sinuses to include the nasopharynx, a submental vertex base view, and right and left oblique orbital views. If examination of the nasal bones is required, right and left lateral views (nonscreen films) and a superoinferior axial occlusal view (again with nonscreen film) should complement the Waters' posteroanterior view. Additional facial bone x-rays may be added as required; for example, the zygomatic arches may be profiled bilaterally by recording an underexposed submental vertex view. Dental-maxillary relationships may be best displayed by panoramic tomography.

These conventional views were augmented in the complex motion tomographic era by 0.5-cm screening examinations that gave excellent visualization of bone contrasted against air, in coronal and sagittal display; occasional basal tomography was initiated, but many patients could not tolerate neck extension for such studies. This axial (basal) dimension only became truly available with the advent of CT; in addition, the coronal plane could be studied by CT.

Although complex motion tomography expanded bone visualization, it fell short in delineating soft tissue extension of infection and tumor into the regionally important orbits and anterior and middle cranial fossae. CT added this important soft tissue display and gave increased information on bone so that tumor extension became truly quantifiable for the first time. Extension of tumor through the posterior wall of the maxillary sinus, for example, could be recorded by effective bone destruction imaging, as well as the soft tissue display of tumor extending into and outlined against the fat planes beyond the posterior wall of the maxillary sinus itself.

Now MRI has expanded multiplanar imaging of tumor and infection extension dramatically. Further, angiographic studies allow delineation of vascular tumors, such as angiofibroma, and assist an understanding of its compartmentalization and extrasinal and intracranial extension.

Radionuclide studies also contribute to better physiologic understanding of pathologic changes within the paranasal sinuses and skull base. Diagnostic ultrasonography contributes a single selective role in the detection of the fluid-filled opacified sinus, and differentiating this, in large measure, from other forms of sinus opacification. The entire problem of sinus opacification and the question of whether this is due to fluid, innocent soft tissue, or significant tumor is now fully appreciated for the first time by the display of CT and MRI.

The classic radiographic signs that can be demonstrated by conventional x-ray, complex motion tomography, and CT scan are itemized as follows:

1. Decreased aeration and luminal opacification.
2. Mucosal thickening.
3. Cyst formation.
4. Soft tissue mass.
5. Fluid level.
6. Emphysema.
7. Calcification.
8. Ossification.
9. One or more embryonic or adult teeth.
10. Foreign body(ies).
11. Alterations in bone walls.

    a. Decalcification.
    b. Osteolysis.
    c. Dehiscence.
    d. Fracture.
    e. Osteoblastosis and hyperostosis.
    f. Expansion or displacement of bone wall.
    g. Decreased luminal volume due to bony hyperplasia, lack of pneumatization, or hyperostotic encroachment of thickened bone walls.
    h. Sequestrum.

Larynx and Hypopharynx

Soft tissue radiography was first applied to the larynx in the search for foreign bodies in and about the upper aerodigestive tract. Subsequently the soft tissue lateral radiograph became a baseline evaluation for the supraglottis, subglottis, and trachea, by air-profiling the airway. This was used in the preliminary assessment of a variety of inflammatory, neoplastic, and other conditions. The barium swallow study became, and remains, the screening examination for the investigation of dysphagia and the detection of disorders affecting the adjacent hypopharynx and cervical esophagus.

Conventional techniques evolved, such as the high-kilovoltage selective filtration radiograph, as reported by Maguire and colleagues from McGill in 1965. The high-kilovoltage study gave information matching conventional coronal tomography, but conventional coronal tomography was the standard pretreatment staging examination, particularly for laryngeal cancer. However, this vertical overview examination demonstrated gross regional mucosal involvement, augmented by studies of vocal cord mobility and fixation; it gave no true depiction of soft tissue extension and often resulted in understaging.

Contrast mucosal radiography (laryngography, tracheography) became the primary modality for assessing mucosal extension. However, the laryngogram was dramatically and suddenly replaced by CT with its complete mucosal, deep soft tissue and cartilage display. The excitement of CT was not only in the extended display for soft tissue and cartilage, but in its plane of examination: the axial sections exactly match the surgical approaches to the neck and larynx.

MRI has extended the soft tissue display, and CT and MRI are now competing in the search for the most effective demonstration of extralaryngeal extension of cancer, as well as in the solution of other problems of laryngeal diagnosis. CT and MRI have improved not only T staging, but also the N staging in laryngeal cancer management. Other imaging modalities, such as high-resolution ultrasound, have also demonstrated selective usefulness.

Conventional Imaging

Plain films, tomography, contrast studies, fluoroscopy, and xeroradiography were the mainstays for the radiologic investigation of otolaryngic disorders until the advent of the many advanced techniques now available. The current role of these conventional techniques will be explored in this section. For some disorders, it is more logical to proceed directly to advanced radiologic techniques, bypassing completely the conventional examination. In the workup of other conditions, conventional techniques have a significant role to play in screening, arriving at a diagnosis, or assessing anatomic location and extent of disease. Notwithstanding the exciting advances in advanced imaging, the importance of conventional examinations cannot be overemphasized.

Plain Films

Roughly half of all plain film examinations requested by otolaryngologists relate to sinus disease. Plain films continue to provide day-to-day usefulness in this area. However, mandibular, temporal bone, and orbital assessment are often best carried out by other modalities. The soft tissue lateral radiograph of the larynx remains the baseline overview evaluation of the airway at this level and accounts for 25 per cent of conventional plain film x-rays. The use of plain films to detect disease in the mastoids, temporal bone, and internal auditory canals has been superseded for the most part by CT scanning and, selectively, by MRI.

The routine views for demonstration of the maxillary, frontal, ethmoid, and sphenoid sinuses, nasal cavities, nasopharynx and orbits are the Caldwell, Waters, lateral, basal, and right and left oblique orbital views.

The posteroanterior Caldwell view projects the petrous ridges in the lower third of the orbits. It is useful for visualizing the frontal and ethmoid sinuses, nasal cavities, and orbits.

The posteroanterior Waters view projects the petrous ridges caudad to the maxillary antra, and therefore clearly displays the maxillary sinuses. The orbits, infraorbital foramina, nasal cavities, and zygomatic arches are also well visualized. Abnormalities of the maxillary sinuses and orbital fractures are demonstrated on this view.

The lateral view images the overlapped anterior and posterior reaches of all the sinuses and the sella turcica, and profiles the nasopharynx and soft palate. Nasopharyngeal tumors, opaque foreign bodies, retropharyngeal abscesses, adenoid hypertrophy, and choanal polyps can be seen on the lateral radiograph.

The basal view shows the sphenoid sinuses, nasal cavities, posterior walls of the antra and lateral walls of the orbits, and foramina of the skull base. Masses in the sphenoid sinuses, nasopharynx, and nasal cavities can be seen surrounded by air, and bony changes related to adjacent pathology recognized.

Oblique orbital views display the superior ethmoid cells, frontal sinuses, and optic foramina. These views supplement the Waters and Caldwell views in the assessment of the ethmoid and frontal sinuses. It is preferable to perform sinus views with the patient in the erect sitting position to demonstrate air-fluid levels.

The routine radiographic views for the nasal bones are the right and left lateral views, the superoinferior axial occlusal view, and the posteroanterior Waters view. Fractures that are elevated or depressed are well characterized on the lateral views, and the superoinferior axial view shows medial or lateral displacement of nasal bone fractures. The nasal bony arch is defined on the Waters view.

The initial assessment of facial bone trauma is done by conventional radiographic views. The projections used are the Towne's view, Caldwell view, Waters view, lateral view with a horizontal beam in the brow-up position, and basal view. These views are useful to detect and delineate fractures of the zygoma, nasal bones, floor of the orbit, and sinuses. The assessment is selectively improved by the use of complex motion tomography and CT scanning.

Tomography

Tomography is a commonly employed conventional radiographic technique in the investigation of head and neck disorders, particularly to image bone anatomy in the paranasal sinuses, orbits, skull base, and temporal bone. Although there is a significant increase in the radiation dose to the patient, tomograms allow clearer visualization of structures at predetermined tissue depths. Structures situated above or below the plane of study are blurred, allowing a clearer depiction of structures in the plane of study. This blurring is achieved by the synchronous and opposite movement of x-ray tube and film, which are connected to each other by a rigid mechanism moving about a fulcrum. The level of the fulcrum is set at the plane of study; only at this level is there no blurring, enabling a clear view of all the structures in the plane of study. The level of the fulcrum can be adjusted precisely. Multiple tomographic slices or planes at contiguous levels, often 1.0 mm apart, are carried out to build up a serial display of the structure under investigation.

The simplest form of tomography involves a linear arc movement of the lever connecting x-ray tube to film. Greater arcs (40 degrees) yield a thinner plane of study than do lesser arcs (10 degrees). Complex motion tomographic units, which move the x-ray tube relative to the film in circular, elliptic, or hypocycloidal motion, give more complete blurring to the tissue levels above or below the plane of study and eliminate the streaking seen with linear tomography.

On occasion a panoramic tomogram is employed. This special device makes panoramic x-rays of a curved structure such as the upper and lower jaw, and projects it as though laid out in a flat layer. Because tomography employs long exposures, complete immobilization of the part under study is required. The anatomy of the facial skeleton, paranasal sinuses, and skull base contains many overlapping structures. For this reason, tomography is eminently suited to study this region, in spite of the increased radiation dosage to the patient.

In the delineation of the facial bones and paranasal sinuses, complex motion tomography is an important supplement to plain film radiography. Tomography is occasionally valuable in outlining the extension of certain inflammatory disorders; fractures of the facial bones, orbits, and paranasal sinuses; the extent of tumour invasion of bone; and congenital anomalies. Tomography improves detail in depicting the pterygoid processes and hard palate. CT scanning makes a more definitive contribution in all these areas.

The temporomandibular joint (TMJ) is another area that is well visualized by tomography. Plain films of this area do not adequately display this joint. The tomograms are carried out in anteroposterior and lateral projections using a complex motion unit, and both temporomandibular joints may be imaged for comparison.

It has been recognized that abnormalities of the temporomandibular joint meniscus are an important cause of pain and dysfunction of this joint, and an enigmatic clinical problem. A displaced or detached meniscus is increasingly being recognized as the cause of pain in this joint.

Temporomandibular joint arthrography combines tomography and an injection of contrast medium into the joint in order to assess internal derangements. This combination can assess the position of the meniscus, the extent of meniscal movement, and meniscal integrity. Abnormalities identified by arthrotomography are meniscal displacement with or without reduction, and perforation. In addition, arthrotomography is a valuable adjunct to ensure that intraoral splint therapy in cases of anteriorly displaced menisci is optimal. Loose bodies in the temporomandibular joint are recognized by arthrotomography.

Tomography allows multiplanar assessment. Tomography of the paranasal sinuses in the coronal plane yields valuable anatomic detail concerning orbital relationships. Sagittal tomography permits evaluation of the sphenoid sinuses, the sella, and adjacent basilar foramina, such as the foramen rotundum. Basal tomography is rarely used because axial CT gives better definition, with bone windows, to the basilar foramina (such as the foramen ovale) when viewed in face.

Multidirectional tomography has been an important investigative tool to detect changes in the internal auditory canals caused by bone erosive tumors, but this area is now best examined by CT or MRI.

Linear tomograms have been used to delineate tumors of larynx for 50 years. The technique provides good visualization of the subglottic space, true cords, laryngeal ventricles, and false cords. The long axis of these structures is perpendicular to the direction of the tomographic movement. However, structures parallel to the tomographic movements, such as the laryngeal vestibules and piriform sinuses, are not well seen. Multidirectional tomography permits better visualization of the laryngeal vestibule than does linear tomography. However, the combination of mirror laryngoscopy and/or telescopic evaluation and CT or MRI yields more accurate surface and deep tissue information, and has therefore almost completely replaced linear tomography for the assessment of tumors of the laryngeal region.

Contrast Studies and Videofluoroscopy

Contrast studies have been helpful in assessing a variety of structures in the head and neck. Angiography is dealt with elsewhere in this chapter. Temporomandibular joint arthrotomography is discussed above. Contrast laryngography, while it can show superficial detail in the supraglottic region, has been supplanted by CT and MRI for superficial and deep morphologic demonstration. The trachea (and subglottis) is well seen by endoscopy, complemented by contrast laryngotracheogram studies to investigate tracheal and subglottic stenosis and stricture.

Sialography involves the injection of contrast fluid, generally an iodinated oil-based liquid, into the duct of the parotid or submandibular glands. Oily contrast is safe to use but rarely may cause a foreign body granuloma if extravasated. Water-soluble contrast can be used; this is safer but does not give enough contrast for a satisfactory sialogram. Several films of the contrast-filled ductal system are obtained immediately after injection, and delayed films are taken to assess drainage. This technique may be combined with CT, using water-soluble contrast, to visualize the relationship of a mass to the ductal system of obstructions in the duct itself.

The major reasons to perform a sialography nowadays are to localize stones (of which 20 per cent are radiolucent), to demonstrate strictures, and to show salivary fistulas and chronic parotitis. The technique is contraindicated in the presence of infection. CT, MRI, ultrasonography, and radionuclide scanning are more appropriate in investigating tumors; sialography is best suited to assess diseases of the ductal system.

Contrast studies of the oropharynx, hypopharynx, and esophagus are widely used to assess a wide variety of functional and morphologic abnormalities. Imaging of these areas generally consists of fluoroscopy, rapid sequence spot filming, and videotaping of the real-time fluoroscopic image to yield a dynamic and detailed view.

The choice of contrast material depends on the clinical condition under investigation. When esophageal perforation or postoperative leak is suspected, a water-soluble contrast is used. However, this yields poor contrast examination, and after a leak has been ruled out barium is used for a more detailed study. Barium is a radiopaque element and various concentrations in suspension form are available.

If aspiration is suspected, barium is the preferred contrast fluid. Although it produces some irritation in the tracheobronchial tree, it is not as irritating as the water-soluble contrasts. Using gas-forming agents and a barium suspension with good mucosal adherence properties, a double-contrast effect is achieved that yields improved detail of superficial mucosal lesions. If a small foreign body such as a fish bone is suspected, a small piece of cotton soaked in barium may hang on the foreign body and make it more visible. A large marshmallow soaked in barium, and swallowed whole, may be used to detect the presence of a subtle stricture.

In the investigation of swallowing disorders, lateral videofluoroscopy using barium liquid, semisolid barium paste, and a cookie mixed with barium is employed to assess the sequence of swallowing. This examination yields useful information as to the exact nature of the dysfunction and the types of food (liquid, semisolid, or solid) that are best tolerated by the patient if no other therapy is available to correct the defect.

Xeroradiography

Xeroradiography was widely available and used in the past. Using a conventional x-ray tube, an exposure is made, not of an x-ray film, but of a latent image on a photoconductor (a positively charged selenium-coated aluminum plate). The positively charged plate is discharged in proportion to the amount of penetration of x-rays to each spot on the plate. A negatively charged powder is blow across the surface of the charged plate, and a visible image in shades of blue-white is produced. This technique has advantages over conventional x-rays by virtue of greater edge enhancement and wider latitude. However, the x-ray exposure to the patient is four times that needed for x-ray film exposure.

Xeroradiography is occasionally employed to enhance the findings seen on plain film examinations, and also in pediatric patients with laryngeal or tracheal stenosis to decrease the need for repeated endoscopic examinations.

Angiography

The technique of angiography involves injecting radiopaque contrast fluid into a blood vessel and recording the resultant image of the vascular compartments. Contrast agents are radiopaque by virtue of the element iodine in various organic molecular forms. Nonionic contrast is rapidly replacing the older ionic form because it is shown to cause a lower incidence of reactions and does not cause pain when injected intravascularly. The only drawback to its use is the approximately tenfold increase in cost of these agents compared with that of ionic contrast fluid.

Contrast injections may be made directly into the arterial system, usually by inserting a catheter retrogradely via the femoral artery or on occasion via the branchial artery. The catheter tip can be positioned in the aortic arch or common carotids, or even more selectively in the vertebral arteries or external or internal carotid systems, when using very fine, specifically designed catheters. For certain indications, a venous injection can be made by inserting a catheter retrogradely via the femoral or another vein.

A peripheral venous injection of contrast material is now a commonly used method of angiography owing to the development of a computerized technique of image recording called digital subtraction angiography. In this situation, a catheter is placed in the superior vena cava or right atrium. A bolus of contrast is injected, and subsequently the arterial phase of circulation is imaged and recorded.

Conventional angiography records images by rapid serial x-ray exposures while a film changer is quickly moving x-ray film into position to be exposed. Concealing bone shadows are removed by the photographic technique of subtracting a preinjection "mask" image from the postinjection images that have the vessels opacified by contrast. However, digital subtraction technique records the pre- and postinjection images in a digitized format using a powerful computer to store the data, and can therefore perform the subtraction rapidly and very accurately. Also, since the digitized image is stored in the computer memory, large amounts of film are not required. The image is immediately available for viewing on a monitor. Selected images may be displayed on the monitor and photographed from the monitor on film for hard-copy viewing.

The most significant advantage of computerized digital imaging is its ability to detect very slight amounts of contrast. Thus, even contrast material injected intravenously can be detected as it courses through the circulatory system until its appearance on the arterial side of the circulation. Vascular tumors of the head and neck, angiofibromas, chemodectomas, parathyroid tumors, aberrant vessels, or occlusive disease of the carotids may be safely and reliably screened on an outpatient basis.

The venous side of the circulation can be imaged in two ways. After an arterial injection, prolonged images can be made until the contrast appears in the venous phase. Alternatively, a direct venous injection can be made, as for example in retrograde jugulography, to assess the jugular bulb for intraluminal mass or obstruction. When more detailed viewing of the arterial system is necessary, selective arterial catheterization is employed using a film changer or digital subtraction.

In addition to its role in diagnosis, superselective angiography has important therapeutic applications. Intra-arterial embolization serves for an approach to arteriovenous malformations in inaccessible areas of the skull base. It may be used preoperatively to devascularize carotid body or glomus jugulare tumors. Facial arteriovenous malformations may be well treated by intra-arterial embolization, as may intractable epistaxis. These techniques may be used as a preoperative adjunctive procedure to devascularize highly vascular lesions, or may serve as the definitive therapy.

Arterial puncture and catheterization is not without risk. Sedation may be necessary, and occasionally general anesthesia is required. Cerebral complications result from embolization with clot, atheroma, or air, or from reflux of embolic agents into the internal carotid system. Happily, these complications are usually minor and transient, and rarely extreme or fatal. Puncture site complications include vessel injury, hematoma formation, and vascular compressive effects.

Ultrasonography

Otolaryngologic investigations employ two distinct ultrasound modalities at present. The first is high-resolution real-time imaging; the second is a technique utilizing the Doppler principle to assess flow characteristics in the major blood vessels of the neck.

In general terms, imaging by ultrasonography is accomplished by sending pulses of ultrasound into the patient, receiving the reflected and scattered echoes, and processing them through electronics to produce a tomographic image of the internal cross-sectional anatomy. The transducer or probe is a small, hand-held device that acts as the interface between the electronics and the patient. The transducer converts electrical energy emitted by the electronics into a pulse of ultrasonic energy. Ultrasound behaves in the same way as audible sound, only at a frequency far above the audible spectrum in the range of 5 to 10 MHz frequency. The conversion of electrical voltage into ultrasound is performed by a piezoelectric crystal in the transducer. As pulses of sound travel through tissue, they encounter interfaces with different acoustic impedance properties. As sound encounters these tissue interfaces it can be scattered, reflected, or transmitted. Those sound waves, reflected back to the transducer, are converted into an electrical voltage through the mechanism of the same piezoelectric crystal. These received electrical impulses are displayed on a monitor, after having been amplified and converted by the electronic component of the unit. Reflected echoes of differing intensity are displayed in various shades of gray (gray scale).

The real-time aspect of scanning is done by rapidly and repeatedly scanning the ultrasound beam into the patient. As many as 30 frames per second or more are integrated by the very fast electronics of the instrument to give the appearance of continuous motion, much as a movie film is displayed. This rapid scanning is performed either by mechanically moving a crystal or set of crystals within the transducer, or by electronic means in which an array of many transducers lined up in keyboard fashion are electrically stimulated in sequence or overlapping sequences. Mechanical real-time transducers have a sector scan format and the display is pie shaped. Electronic transducers have crystals lined up in a linear fashion and result in a rectangular display. A high-resolution ultrasound system is required for optimal imaging of superficial structures such as those regions of interest to the head and neck surgeon. The ability to resolve two reflectors located along the axis of the ultrasound beams called axial resolution and it typically 0.5 mm or less in modern equipment. Lateral resolution is the capability of resolving two points in a direction perpendicular to the ultrasound beam and is generally 1.0 mm or less. To achieve this degree of resolution, frequencies of 7.5 to 10 MHz are required; the higher the frequency of the system, the better is the resolution. The reason why even higher frequencies are not used is because tissue attenuation of the ultrasound beam increases at higher frequency. At higher frequencies of 10 MHz, tissue penetration is only to a depth of 4.0 cm.

Apart from high-resolution real-time imaging with ultrasonography, it can be used to measure the velocity of flowing blood based on the Doppler effect. The combination of high-resolution real-time scanning and Doppler signal analysis to examine the major blood vessels is referred to as Duplex scanning. Duplex scanning allows one to visualize arteriosclerotic plaques in the cervical portion of the carotids and determine their size and location, as well as to assess the hemodynamic significance of these lesions based on alteration of blood flow patterns. It is a simple, noninvasive screening procedure to assess the carotids (especially the bifurcation in cases of pulsatile tinnitus), detecting primary vascular tumors and extension of tumors into the carotid or jugular systems.

High-resolution real-time imaging used by itself gives excellent visualization of the thyroid gland in longitudinal and axial planes. Focal nodules are easily identified with regard to their number and size and their internal architecture, whether it be cystic or solid, hyperechoic or hypoechoic. The region and extent of gland involvement can also be assessed. Ultrasound distinguishes diffuse thyroid medical conditions such as thyroiditis from focal lesions. Although carcinomas and adenomas cannot be absolutely differentiated by the ultrasonographic appearance only, adenomas tend to have a well-defined peripheral halo of decreased echogenicity, and carcinomas generally are less well marginated than adenomas. Ultrasound is also an excellent system for guiding needle placement into a focal nodule for aspiration cytology. Because of its ability to resolve even very tiny structures, ultrasonography is the procedure of choice in the detection and biopsy of nonpalpable nodules; in patients being assessed years after neck irradiation; to detect occult malignancy; and for clinical follow-up in significant abnormalities. Up to 70 per cent of thyroid glands have some minor abnormality.

Parathyroid adenomas or carcinomas occurring in the neck can be identified and localized by ultrasonography. On the other hand, four-gland parathyroid hyperplasia is much more difficult to detect by ultrasound imaging, since the glandular enlargement is much less striking and impedance characteristics are similar to those of normal thyroid tissue. The sternum prohibits ultrasound assessment for possible mediastinal parathyroid adenoma.

Carotid body tumors are easily identified by ultrasonography in their characteristic location at the carotid bifurcation. No other abnormality arises in this site.

Any palpable lump in the neck, such as lymph node enlargement, branchial cleft cyst, or thyroglossal duct cyst can be assessed by ultrasonography and characterized by location and internal architecture. Similarly, the submandibular glands and parotid glands are well demonstrated and focal lesions visualized. Inflammatory conditions of the salivary glands may be seen as diffuse gland enlargement with decreased echogenicity. Dilated salivary gland ducts are visible. The development of focal abscesses in the glands may be monitored by ultrasonography.

The maxillary antra may be selectively assessed by ultrasonography to complement plain film findings of opacification. A fluid-filled sinus (maxillary or frontal) may be separated from an intrinsic soft tissue mass by characteristic through transmission of sound through a fluid medium. The thin anterior bony wall of the antrum and floor of the frontal sinus allow the passage of sufficient sound waves for imaging. However, the usefulness of ultrasonography in this regard has been somewhat overstated.

Radionuclide Scans

Three components are necessary in radionuclide imaging. The first is the patient with a specific organ, tissue, or pathologic process under investigation. The second is the appropriate radiopharmaceutical, which may have two parts: the radioactive component tracer and the pharmaceutical, which has a certain propensity to accumulate in the specific organ, system, or pathologic process under investigation (technetium Tc 99m methylene diphosphonate). Sometimes these two properties exist in one element (I-131). The third component is the imaging apparatus, which consists of a scanner sensitive to the gamma ray emissions of the radioactive pharmaceuticals plus a recording device, frequently computer assisted, to result in a visual display of the anatomy of physiology under investigation.

A simple illustration of nuclear medicine imaging is the investigation of lacrimal duct obstruction. The radioactive tracer is the radioisotope 99m technetium, a pure 140-keV gamma ray emitter with a half-life of 6 hours. The short half-life and the absence of beta and alpha emissions make this isotope a safe pharmaceutical label. A solution of this radioactive tracer is dropped directly into the conjunctival fornix. The scanner, or gamma camera, is then used to monitor the flow of tears containing the radioactive tracer as they traverse the lacrimal duct to empty in the nasal cavity. A functional flow map is created by serial imaging over time as the radioactive tracer moves downward from conjunctival fornix through lacrimal duct to nasal cavity. Blockage of this flow pattern is easily recognized on the serially recorded scanner images.

More complex organs, systems, or physiology may be assessed by injecting the radioactive pharmaceutical intravenously. In bone scanning the physiology is triphasic. In the first several seconds, the radiopharmaceutical is detected in the main vascular compartments and is termed a flow study. Within the first few minutes, equilibration of radioactive tracer occurs between the afferent vascular bed and the organ or system for which the pharmaceutical has affinity. The images at this stage represent the "blood pool" and hence may demonstrate hyperemia or enlarged vascular spaces. After some delay, generally measured in hours, a functional image of the organ or system is obtained in either a "snapshot" static fashion or in a serial "time-lapse" photography fashion. Static imaging is employed in bone scanning after the radiopharmaceutical (technetium 99m plus organic phosphate) is laid down on new osteoid in areas of osteoblastic activity.

Serial imaging is useful in salivary gland studies, since the salivary glands first incorporate and then excrete radioactive sodium pertechnetate in the saliva. Intense uptake is seen in Warthin's tumors of the parotids. A sialogogue enhances imaging in focal "hot" tumors and diffusely in ductal obstruction.

Thyroid scanning may be considered a prototype of all nuclear medicine studies. For the otolaryngologist and head and neck surgeon, a palpable nodule in the thyroid is the main indication for radionuclide scanning. Correlation of the physical examination is an integral part of scanning. It is necessary to mark the location of palpable nodules on the scan in order to assess correctly their functional status. If a nodule is clearly functioning ("hot"), it can generally be assumed to be benign. If it is cold ("cold, cool, warm isofunction"), many would advocate fine-needle biopsy guided either by palpation or by ultrasound to test for malignancy.

The physiology of iodide trapping, organification, storage, and release of thyroid hormone has been well documented. Technetium Tc 99m pertechnetate delivers the lowest radiation dose to the thyroid of all useful agents. Pertechnetate is trapped by the thyroid but, unlike iodine, is not organified. For this reason, thyroid scans using 99m TcO_{4-} may give discordant findings compared with iodine images. However, because of its low dose, this agent is the first line in radionuclide imaging. If scanning with 99m TcO_{4-} shows a nodule to be cold, it can be assumed to be a cold nodule. If the 99m TcO_{4-} shows a hot nodule, this does not exclude a carcinoma, since some cancers may trap the agent but not organify it. In these cases, a follow-up scan using I-123 is necessary to prove the nodule is truly hot (to rule out "false function"). As a rule, cancers will be cold on I-123 scanning. Cold nodules are investigated by fine-needle biopsy.

I-131, with a half-life of 8 days, emits gamma rays that create an image of thyroid structure and function, whereas its beta emissions, which cause local tissue damage, account for its therapeutic value in large doses. This radioisotope accumulates in functioning thyroid tissue and therefore can demonstrate ectopic thyroid tissue in the base of the tongue or in a retrosternal location. It also accumulates in functioning metastases of thyroid carcinoma. Most thyroid carcinomas are nonfunctioning and are seen as a photon-deficient area in the thyroid gland. I-131 is now used almost solely for its therapeutic effects.

Parathyroid imaging is a good example of the computerized subtraction technique in nuclear medicine. After an intravenous injection of thallous chloride TI 201, the thyroid gland and the parathyroid adenoma both take up the radioisotope, which has an energy of 80 keV. An image is made and stored in the computer. About 15 minutes later (the patient remaining in the same position during this period), an intravenous injection of 99m technetium pertechnetate is given, which is trapped by the normal thyroid but not the parathyroid adenoma; the resultant thyroid image is stored in the computer. The computer then subtracts the 99m technetium thyroid image from the thallium-201 thyroid plus parathyroid image, leaving only the parathyroid image, and hence potentially identifying and localizing the adenoma.

Some newer agents have a tumor-seeking propensity. The commonly used agent is gallium Ga-67 citrate, which is taken up by actively dividing cells and neoplastic reticuloendothelial cells in particular, and has application in the detection and staging of some lymphomas. However, this radioisotope does not readily differentiate between neoplastic and inflammatory cells.

The combination of radionuclide bone scanning and gallium scanning has been useful in the detection and follow-up treatment of osteomyelitis. In this clinical situation, gallium Ga-67 citrate is used for its propensity to accumulate in inflammatory tissue and determine the success or failure of antibiotic therapy. Osteomyelitis is a dreaded disorder in the head and neck and may erupt even after what appears clinically to be effective antibiotic therapy.

Plain film studies require 30 to 50 per cent of demineralized bone loss in order to demonstrate osteolysis of bone in acute osteomyelitis. This morphologic change may take 7 to 10 days. However, functional changes detectable by radionuclide scanning take a much shorter time, possibly only 24 hours. Thus, the triphasic bone scan is extremely sensitive in detecting the osteoblastic response to focal osteolytic disease. However, the increased activity demonstrated on the bone scan as seen in osteomyelitis is also seen in tumor, bone dysplasia, healing fractures, and other osteoblastic conditions. The scan is highly sensitive but nonspecific.

The gallium Ga-67 citrate scan images the infective focus of osteomyelitis because Ga-67 is bound to granulocytes. This is part of the nonspecific binding of gallium to actively dividing cells. Gallium imaging is highly sensitive although also nonspecific. When an infective process has been sterilized, the gallium scan should revert to normal. The effectiveness of therapy can thus be assessed and the infective process monitored through healing, continuation, or recurrence. It is also helpful in difficult assessment of cases of postsurgical infection.

Computed Tomography (CT)

The contemporary widespread availability of current-generation CT units, and the diagnostic confidence achieved between clinicians and imager, place CT in the dominant imaging role for virtually all major pretreatment staging. This modality will be discussed in relative detail for its varied head and neck applications.

Temporal Bone and Skull Base

Temporal bone radiology also encompasses, in a broad sense, evaluation of the adjacent skull base and the relationships to the middle and posterior cranial fossae. The anterior fossa skull base is considered in the section on paranasal sinus CT. The skull base is also studied critically for disease involving the basilar foramina, and for tumor extension from primary disease within the temporal bone and environs. Cerebrospinal fluid (CSF) otorrhea is also a diagnostic consideration in this region. Conventional pluridirectional tomography was previously used widely to assess the temporal bone. Its role has been superseded by high-resolution CT scanners, which can image both bone and soft tissue structures less than 1.0 mm in size. Thus, CT provides the clinician with almost all the information required for effective management of congenital anomalies, infections, fractures, and tumors of the temporal bone and the cerebellopontine angle.

Usually, series of approximately 12 contiguous 1.0-mm axial slices are obtained from the region of the hypotympanum to the superior semicircular canal. The examination should be carefully monitored with both bone and soft tissue settings, and tailored according to the clinical findings. The thickness of the scan slice must be smaller than the structure examined to produce high-quality detailed images. Intravenous contrast is given when assessing the cerebellopontine angle and when determining the intracranial extent of inflammatory and neoplastic processes. Very small acoustic neuromas, not evident on enhanced CT scans, can be shown on CT scans of the internal auditory meatus after introduction of several millimeters of air by lumbar puncture.

High-resolution CT is the optimal method of assessing congenital abnormalities of the temporal bone. Bony or soft tissue atresia of the external auditory canal may be readily evaluated, as may malformations of the ossicles, and fusion of the ossicles to the bony plate or to each other. The degree of atresia of the middle ear cavity may be measured and helps determine whether surgical correction of a conductive hearing loss is feasible.

An aberrant course of the facial nerve is frequent with congenital anomalies of the temporal bone. The entire course of this nerve must be shown on CT so that proper surgical approaches can be planned. Absence of the oval window may also be detected on CT, allowing for surgical correction of this defect.

When the carotid artery and jugular vein are in an anomalous position, they may be confused with vascular tumors of the middle ear. CT scanning with intravenous bolus technique can demonstrate the aberrant course of these vessels, and manipulation of bone window settings allows visualization of a laterally aberrant carotid artery at the skull base, or a high or intratympanic jugular bulb. Both arterial and venous abnormalities may effectively be visualized with intravenous digital subtraction angiography as a screening study.

Most infectious processes of the temporal bone are managed clinically, without an exhaustive radiologic workup, unless recurrent, refractory, or complicated disease is present. CT with bone window settings is currently the best detector of acute coalescent mastoiditis and other areas of specific bone lysis.

CT is an excellent means of studying the severity and extent of infectious changes produced by malignant external otitis in diabetic or immunocompromised patients. Early clouding of the middle ear cavity and mastoid air cells by fluid; destruction of the external auditory canal, middle ear cavity, temporomandibular joint, and skull base; and the presence of osteomyelitis of the skull base or sigmoid sinus thrombosis may be demonstrated by CT with bolus injection.

CT has excelled over complex motion tomography in its ability to demonstrate the soft tissue as well as the bony abnormalities produced by cholesteatoma, as it involves the key attic-aditus-antral region. Soft tissue masses as small as 3.0 mm in size can be depicted by CT. Minimal erosions of the attic wall, scutum, and ossicles not visible on complex motion tomograms are often demonstrable by thin-section CT scans. Cholesteatomas appear as soft tissue masses originating in the region of the attic and extending into the aditus and mastoid antrum, with associated bone expansion and destruction. Erosion of the facial canal, and erosion plus displacement of the ossicles medially by pars flaccida cholesteatomas and laterally by pars tensa cholesteatomas, may be seen. Destruction of the ossicles is seen, the long process of the incus being involved most frequently, followed by the body of the incus and the head of the malleus. Other complications may be demonstrated, such as erosions of the semicircular canals, intracranial epidural abscess, or lateral sinus thrombosis.

Acoustic neuromas (schwannoma of the eight nerve) are the most common neoplasms found in the cerebellopontine angle. Originating from the eight nerve within the internal auditory canal, they may cause inferior displacement or destruction of the falciform crest, enlargement of the internal auditory canal, or flared erosive widening of the internal auditory meatus. A difference of more than 2.0 mm in vertical height of the internal auditory meatus (IAM) signifies erosion by tumor. Contrast CT scans are routine mass screening studies for the cerebellopontine angle; they demonstrate pathology ordinarily down to 1.0-cm resolution. If these fail to show an acoustic neuroma but clinical suspicion remains high, gas cisternography, which can often be done on an outpatient basis, is very successful and images even the small intracanalicular neuroma. Acoustic neuromas appear as convex soft tissue masses within or protruding outside the canal. When large, they appear as enhancing masses in the cerebellopontine cistern, either obliterating or widening the cistern if they display the brain stem. A variety of cerebellopontine angle tumors (meningioma being the second most common) occur in the differential diagnosis.

Glomus tympanicum tumors are small vascular masses in the region of the cochlear promontory. Bone erosion is rare and, even when large and filling the middle ear, these tumors tend not to destroy the ossicles. Conventional multidirectional tomography is insensitive in detecting small glomus tympanicum tumors unassociated with bone destruction. High-resolution CT scanning is very accurate in demonstrating the presence of small glomus tympanicum tumors and any associated bone destruction. Differentiation from a carotid artery aneurysm, an aberrant carotid artery, or a high-lying jugular bulb may be made by dynamic scanning during a bolus injection of contrast. Selective angiography of the ascending pharyngeal artery is of diagnostic value and also, with embolization, a therapeutic measure.

Glomus jugular tumors erode the jugular fossa and break through the bony roof of the jugular fossa into the hypotympanum as they slowly enlarge to produce a soft tissue mass extending from the jugular fossa into the middle ear. Destruction of bone around the caroticojugular spine, jugular tubercle, and hypoglossal canal may be seen.

Schwannomas of the ninth, tenth, 11th, and 12th nerves may mimic glomus tumors but do not ordinarily enhance to the same degree as glomus tumors. Meningiomas in this region usually have a broad dural base, not infrequently calcify, and are often associated with bony hyperostosis. Metastases (chiefly from breast, lung, kidney, and prostate) may occur in the region of the mastoid air cells and tend to produce rapid bone destruction.

CT is the most sensitive way of detecting the presence, extent, and course of fractures of the temporal bone. Disruptions of the facial canal, with resultant facial paralysis and ossicular dislocation producing hearing loss, are also best shown by CT. Transverse fractures occur at right angles to the long axis of the petrous temporal bone, and coursing lateral to or through the labyrinth, and are all well displayed. Longitudinal fractures run along the long axis of the petrous temporal bone and may extend into the facial canal. Anterior longitudinal fractures occur in the parietotemporal region, and extend anteriorly through the petrous bone and tegmen tympani to the labyrinth and into the temporomandibular joint. Posterior longitudinal fractures involve the posterior aspect of the parietal bone and mastoid. Collections of blood in the mastoid air cells and middle ear can be well shown by CT. With ossicular dislocations, the malleus and incus, which normally are located centrally in the epitympanic recess, are displaced and may lie on the floor of the tympanic cavity, or in the external auditory canal if the tympanic membrane has been damaged. The usual displacement of the complex is medially away from the tympanic spur (scutum).

Traumatic CSF leaks may be demonstrated by intrathecally enhanced CT scans. After lumbar puncture the contrast (preferably a nonionic agent) is run up into the basal cisterns. Immediate scanning is performed with the patient in the position that usually promotes most flow. Patients with slow leaks are instructed to cough or perform the Valsalva maneuver to help demonstrate the leak. Leakage of contrast through a defect in bone or dura, or the appearance of contrast in a related middle ear cleft, nasopharynx, paranasal sinus, or nasal cavity or on a prepositioned cotton pledget, confirmed the presence of a CSF leak. In patients with very slow or clinically inapparent leaks, delayed scanning may show an increase in CT numbers in an opaque sinus owing to gradual leakage of contrast into the sinus. CT is superior to nuclear scanning in its ability to demonstrate both brisk and slow CSF leaks.

Paranasal Sinuses

The development of high-resolution CT scanners that can perform thin-body sections and fine-detail fast reconstruction images has made CT the best examination for evaluation of the paranasal sinuses. Plain film and conventional pluridirectional tomographic studies are still very useful for screening purposes when uncomplicated inflammatory processes of the paranasal sinuses are suspected, and in minor trauma cases. However, CT is now the major, most important, and most informative imaging modality used to investigate suspected neoplasms, to assess complicated aggressive infections of the nasal passages and paranasal sinuses, and in complex trauma cases. In these instances the role of pluridirectional tomography is rapidly becoming obsolete.

The ability of CT to delineate exquisitely not only bone but also the relationship of soft tissue structures relative to bone in this region accounts for its superiority over conventional tomography. For example, tomography may demonstrate destruction of the bony sinus wall, or tumor in the sinus, but it does not detect the presence and location of tumor extending outside the sinus, or the degree of invasion of contiguous soft tissue structures, which can be seen only by CT.

The indications for CT scans of the paranasal sinuses are as follows:

1. For diagnosis of suspected neoplasms.
2. For assessment of complicated inflammatory processes in the nasal cavity and paranasal sinuses, including mucocele.
3. For mapping of tumor margins to determine the surgical approach.
4. For mapping of tumor margins to determine the size of radiation portals.
5. To search for postoperative tumor recurrence.
6. To assess tumor response after radiation therapy.
7. For complex facial trauma.

Axial slices 5.0 mm thick at 5.0-mm intervals are obtained parallel to the intraorbitomeatal line from the level of the alveolar ridge of the maxilla cephalad to include the frontal sinuses. Coronal images are made at 90 degrees at Reid's baseline (or less optimally they may be reconstructed from axial images). If the patient is unable to extend the neck for coronal slices or has dental fillings that produce image-degrading artifact, a slightly different angle may be used, less than 90 degree to Reid's baseline. Contrast is given for almost all studies. Patients receive 300 mL of 30 per cent or 150 mL of 60 per cent Hypaque rapid drip infusion. Close monitoring at the CT console during the study is necessary, and each slice should be examined at both bone and soft tissue settings. Since fewer than 5 per cent of paranasal sinus tumors metastasize to cervical lymph nodes, this region is not routinely included in the CT scan.

CT is the preferred imaging procedure for complications of sinus inflammation such as suspected intraorbital or intracranial spread of tumor, or failure of antibiotic therapy in immunocompromised or diabetic patients.

Allergic polypoid sinusitis caused symmetric mucosal thickening of all paranasal sinuses. In chronic allergic sinusitis, greatly thickened polypoid hypertrophy of the sinus mucosa may be seen with complete opacification of the sinus. Asymmetric involvement of the sinuses and air-fluid levels is almost always due to bacterial infection.

Serous cysts and mucous retention cysts appear as smooth, oval, homogeneous soft tissue masses most frequently seen along the floor and lateral wall of the maxillary sinus. Although these may almost completely fill the sinus cavity when large, they are separated from the sinus wall by a thin crescent of air and do not destroy bone.

Mucoceles are the most common lesions causing expansion of the bony walls of the paranasal sinuses; 65 per cent occur in the frontal sinuses, 25 per cent in the ethmoid sinuses, and 10 per cent in the maxillary sinuses. Although blockage of the sinus ostium by infection is the most common cause, trauma, tumor, allergy, and cystic fibrosis may also be factors. When mucous secretions fill the entire sinus cavity, no air crescent is seen separating the secretions from the walls of the sinus. As the volume of secretions increases, expansion remodeling and destruction of the sinus walls occur.

Frontal mucoceles may extend intracranially. Ethmoid mucoceles tend to expand into the orbits, and sphenoid mucoceles may mimic sellar, parasellar, or nasopharyngeal masses. An enhancing rim occurs if these lesions become infected pyoceles.

Spread of infection from the paranasal sinuses into the periorbital and orbital soft tissues is best studied by CT. Orbital infection is most often associated with frontal sinusitis in adults and ethmoid sinusitis in children. Orbital cellulitis produces edema of the orbit and periorbital tissues, associated with opacification of the infected sinus. A subperiosteal abscess frequently forms between the lamina papyracea and periosteum of the orbit; on CT a soft tissue mass is seen adjacent to the lamina papyracea, displacing the periosteum and medial rectus muscle inward and effacing the fat planes between these two structures. Subperiosteal abscesses related to frontal sinusitis are located along the superolateral aspect of the orbit. Intracerebral complications, such as meningitis, subdural empyema, epidural or intracranial abscess, and cavernous sinus thrombosis, may coexist and be discovered by CT.

In immunocompromised or debilitated patients, fungal infections should be considered when simultaneous sinus and orbital infection occurs. Rapid blood vessel invasion and intracranial spread produce a high mortality rate in these patients. Soft tissue thickening and bone destruction mimic the appearance of aggressive carcinoma.

Slowly enlarging lesions, such as allergic polyps, neurofibromas, epidermoids, dermoids, aneurysms, and pituitary adenomas, may expand and remodel the bony walls of the paranasal sinuses when they enlarge.

Squamous cell carcinomas present as a soft tissue mass with aggressive bone destruction in 90 per cent of cases. Since the orbital floor forms a maxillary sinus wall, and since the pterygopalatine and intratemporal fossae lie immediately posterior and laterally to the antrum, a careful search for invasion of these structures as evidenced by bone destruction, obliteration of surrounding fat planes, and the presence of soft tissue mass should be carried out. Eighty per cent of squamous cell carcinomas occur in the maxillary sinus.

Rhabdomyosarcomas usually occur in children under 12 years of age. They are large, aggressive tumors that destroy bone. They generally extend into the paranasal sinuses from the nasopharynx or orbits.

Tumors may both expand and destroy bone. Inverting papillomas (with occasional coexistent carcinoma), adenocarcinomas, and olfactory esthesioneuroblastomas are usually bulky tumors. Inverting papillomas arise in the lateral wall of the nasal cavity and invade the adjacent maxillary sinus. Adenocarcinomas are slightly more common in the ethmoid sinus. Esthesioneuroblastomas originate in the middle and upper part of the nasal cavity, with extension into the paranasal sinuses. In more aggressive forms of this tumor, extension occurs through the cribriform plate and along the course of the olfactory nerve into the anterior cranial fossa.

Lymphomas are large lesions, usually in the antral-ethmoidal complex, which tend to infiltrate rather than destroy bone. Tumor mass may be seen on either side of normalappearing bony septa. These tumors may also cause destruction with or without expansion of sinus walls.

Since squamous carcinoma of the maxillary sinus is confined to the sinus in only 25 per cent of cases at the time of diagnosis, CT, with its excellent soft tissue imaging capabilities, can be used to delineate the boundaries of tumor spread. Contrast enhancement is helpful in delineating tumor margins and outlining the relationship of tumor to adjacent vessels. It also demonstrates intracranial spread of tumor.

Surgical treatment and radiation portals can both be planned, and treatment monitored by CT scanning. Further, CT is sometimes useful in tissue characterization of tumors. A mass with multiple calcified or ossified densities and bone destruction is diagnostic of either a chondrosarcoma or an osteosarcoma. Differentiation of tumors from aneurysms and carotid-cavernous fistulas, and the identification of vascular tumors such as juvenile angiofibromas, may be accomplished by contrast infusion or dynamic CT scanning after bolus injection of contrast.

Isolated facial bone fractures are well demonstrated by plain films or polytomography. The more complex orbital floor fractures may be imaged either by complex motion tomography or by CT, depending on the information sought. In severe trauma, 5.0-mm axial CT slices through the facial bones and 10-mm slices through the brain and skull are obtained. Coronal views are made either by direct scanning or from reconstruction, if movement of the cervical spine and repositioning of the patient are contraindicated. Conventional as well as three-dimensional CT can accurately demonstrate the position and amount of displacement of bone fragments, as well as complications such as entrapment of the optical nerve, orbital foreign bodies, intracranial hemorrhages, pneumocephalus, and CSF leaks. The extent of reconstructive surgery can be accurately predicted by preoperative CT scans.

Nasopharynx

Nasopharyngeal carcinomas may produce a detectable mucosal abnormality, which can be visualized by fiberoptic endoscopy. However, this surface observation is only the tip of the iceberg. CT with its superb soft tissue and bone imaging capabilities is essential for the evaluation of the deep dimension and spread of nasopharyngeal carcinoma. Deformity of Rosenmüller's fossa is an early sign of nasopharyngeal carcinoma. However, asymmetry of the nasopharynx in this region may also be caused by hypertrophic lymphoid tissue. Fungating tumors may project into and produce obvious distortion of the nasopharyngeal airway. Mucosal spread to adjacent tensor and levator palati muscles may occur, with resultant enlargement of these structures, obliteration of their normal margins, and asymmetry and distortion of the deep soft tissues and airway. Invasion of the parapharyngeal space, with obliteration of normally present fat in this region, is the most reliable sign of the presence of tumor.

Bone destruction with erosion of the carotid canal, clivus, sphenoid, and orbit and intracranial extension may be demonstrated. Blockage of the ostium of the eustachian tube by tumor may produce a secondary serous otitis media.

Juvenile angiofibromas, the most common benign nasopharyngeal tumors, characteristically produce expansion of the pterygomaxillary fossa by displacing the posterior maxillary sinus wall anteriorly (the antral sign) and the pterygoid plates posteriorly. Bone is thinned but not destroyed. Extension into the nose, the paranasal sinuses, the infratemporal fossa, and then the adjacent parapharyngeal spaces may be seen. Since juvenile angiofibromas tend to spread through the superior and inferior orbital fissures, intracranial structures should be carefully studied for tumor involvement. CT permits a precise diagnosis of juvenile angiofibroma. It delineates tumor location and extent, allowing appropriate treatment planning and often altering the surgical approach.

Larynx

The major role of CT of the larynx is in the pretreatment staging of carcinoma, the evaluation of large benign intrinsic and extrinsic tumors, and the assessment of laryngeal trauma. Routinely, axial contiguous scans 5.0 mm thick or less are obtained with administration of 150 mL of 60 per cent Hypaque during quiet respiration. Overlapped sections or thin sections are selectively obtained either prospectively or retrospectively for exquisite imaging detail, especially to detect focal cartilage destruction. Coronal reformations can allow useful images from axial slice data. CT is an excellent imaging modality to display the deeper soft tissues of the larynx, hypopharynx, and adjacent neck, as well as the cartilaginous laryngeal skeleton.

CT is excellent in imaging the effects of trauma to the larynx, especially when severe supraglottic edema and soft tissue swelling preclude adequate direct or indirect laryngoscopic mucosal examination. CT can demonstrate clinically undetectable amounts of subcutaneous emphysema, thus alerting the clinician to the presence of mucosal lacerations or disruptions within the larynx or trachea, or cricotracheal separation. CT defines the extent of soft tissue injury and the degree of airway narrowing. The presence, extent, and position of fractures of the laryngeal skeleton can all be accurately displayed. The basis of traumatic glottic dysfunction can often be clarified as soft tissue edema, disruption of the cricoarytenoid articulations with arytenoid dislocation, cricoid and/or thyroid cartilage fractures, epiglottic avulsions, and recurrent laryngeal nerve paralysis. Importantly, CT allows simultaneous assessment of trauma to the brain, facial bones, and cervical spine without moving or harming the patient.

Benign tumors of the larynx are surface assessed by direct or telescopic laryngoscopy, but CT is critical to the evaluation of deep soft tissue and laryngeal skeletal involvement. Osteochondroma of the cricoid signet is an excellently depicted entity in which the hypopharyngeal encroachment is well displayed by CT.

Laryngoceles are easily diagnosed by CT but may be easily and more inexpensively shown by laryngeal tomography. CT is important when laryngocele mimics a soft tissue mass; it is also important to help rule out a ball-valve trap mechanism in which tumor might produce a laryngocele sac. Mixed laryngoceles occurs in 44 per cent of cases, internal laryngoceles in 30 per cent, and external laryngoceles in 26 per cent. Although laryngoscopic findings may strongly suggest that a laryngocele exists, the presence of an underlying neoplasm causing prominence of the false cord and aryepiglottic fold, or of a neoplasm associated with laryngocele, must be ruled out. Laryngoceles frequently have CT densities of air and/or water that differ from the higher attenuation number of tumors. Demonstration of a mixed laryngocele when only an internal laryngocele was suspected clinically will change the surgical management of this lesion.

CT (and MRI) are now routinely used for the exact staging of laryngeal cancer. CT can reliably and precisely determine tumor location in the glottic, supraglottic, or subglottic regions; the tumor size and extent; the presence of gross cartilaginous destruction; and tumor spread to cervical lymph nodes. This information is essential for the planning of proper surgical approaches (ie, total versus partial laryngectomy).

Radiation portals may be determined by CT with precise estimation of tumor size and extent. Response to radiation therapy or recurrence of tumor can be assessed with follow-up scans.

Glottic carcinoma is the most common laryngeal carcinoma (60 to 70 per cent). Small, clinically definable lesions may require no imaging beyond endoscopic photography. Small tumors may be undetectable on CT imaging or may simply produce a focal soft tissue bulge or irregularity on CT. However, the major role for CT is in the evaluation of endolaryngeal or exolaryngeal soft tissue extension of larger lesions, in order to T-stage them properly. Extension into the anterior commissure is suspected when more than 1.0 to 2.0 mm of soft tissue is seen at the anterior commissure. Larger glottic lesions produce a mass in the paralaryngeal tissues between the conus elasticus and the thyroid cartilage. Asymmetry of the normal fat planes on the inner surface of each thyroid ala is usually indicative of tumor in the paralaryngeal space. Tumor may spread to and invade the pre-epiglottic space, perforate the thyroid cartilage and/or the cricothyroid membrane, and insinuate itself between the thyroid and arytenoid or thyroid and cricoid cartilages. A soft tissue thickness of 1.0 to 2.0 mm between thyroid and cricoid cartilages or asymmetry of soft tissues between the arytenoid and thyroid cartilages indicates the presence of tumor in this region. The upper surface of the cricoid cartilage may be eroded as tumor exits posterolaterally into the hypopharynx.

Supraglottic carcinomas (constituting 30 to 35 per cent of laryngeal carcinomas) are typically larger and more extensive at presentation than glottic carcinomas. Extension into adjacent structures should be carefully anticipated and searched for with CT. Invasion of valleculae, epiglottis, pre-epiglottic space, aryepiglottic folds, and paralaryngeal space by supraglottic tumors may be shown by CT. Inferior extension to the glottis may occur, with subsequent destruction of the thyroid cartilage. Transglottic tumors are most frequently associated with thyroid cartilage destruction. Sixty per cent of transglottic neoplasms, 50 per cent of subglottic lesions, and 45 per cent of piriform sinus tumors had associated cartilaginous invasion in one review. A higher incidence of cartilage destruction may be seen when tumors are larger than 3.0 cm or when the bulk of the tumor lies at or below the level of the arytenoids. Invasion of thyroid cartilage by tumor most commonly appear as breaks or fenestrations in the thyroid cartilage, demineralization of cartilage, or a tumor mass in the intramedullary cartilage space. Masses adjacent to cartilage can cause bowing deformities and displacement of the cartilage. CT can reliably detect moderate or severe destructive changes in the thyroid cartilage. Differentiation of subtle destructive changes from normal, poorly inhomogeneously mineralized areas may be difficult. Ultrasonography and imaging-directed biopsy are necessary in these cases. The presence of soft tissue along the inner surface of the cricoid cartilage below the level of the true cords is indicative of subglottic tumor. Any soft tissue thickness between the air-filled piriform sinus and the inner surface of the thyroid cartilage signifies tumor in the pyriform sinus.

Nodal metastases should be sought; they occur frequently with supraglottic tumors.

Parotid and Submandibular Glands

CT is an excellent way of imaging the salivary glands. Contiguous axial cuts of 5 mm are obtained during infusion of 150 mL of 60 per cent Hypaque from the level of the external auditory meatus to below the level of the mandible to demonstrate the parotid gland, and from the level of the tooth roots of the mandible to the hyoid bone to assess the submandibular gland. Contrast infusion allows differentiation of vessels from lymph nodes, provides landmark identification (the posterior facial vein) for the position of the seventh nerve, and shows the effect of a mass (impression, displacement) on adjacent vessels. CT sialography may occasionally provide additional information. Combined CT sialography is particularly useful in differentiating masses in the deep lobe of the parotid gland from parapharyngeal masses and in identifying small masses in the parotid gland. While sialography may be the best investigative procedure for demonstrating nonopaque calculi, ductal obstruction, and sialectasis, it provides inadequate and nonspecific information about neoplasms.

Well-circumscribed superficial tumors need only aspiration biopsy without additional imaging procedures. Ill-defined masses should be studied with CT. Seemingly small superficial lesions may sometimes be show to extensively invade the parotid gland. The relationship of the facial nerve to infiltrative masses can be assessed by CT so that appropriate surgical management may be planned. MRI is becoming a more sensitive way of accurately depicting the course of the facial nerve in the parotid gland and in the temporal bone.

Because it is composed largely of fatty tissue, the normal parotid gland appears more lucent than adjacent muscles. The gland lies adjacent to the mandible and masseter muscle, with the mastoid process, styloid process, and sternocleidomastoid muscles along its posterior surface. The deep lobe curves around the mandible to lie on its inner surface, with the pterygoid muscles anteriorly and the parapharyngeal space medially.

The facial nerve exits the stylomastoid foramen and lies laterally to the styloid process and medial to the mastoid process. The nerve then passes lateral to both the retromandibular vein and the external carotid artery, and parallels the course of Stensen's duct. Superficial lymph nodes are present on the surface of the parotid gland, and deep nodes within the gland. The submandibular gland is denser than the parotid gland. It consists of a superficial lobe inferolateral to the mylohyoid muscles.

Pleomorphic adenomas appear as homogeneously enhancing round masses. When larger than 2.0 to 3.0 cm, they develop lobulated boundaries. Warthin's tumors are well defined but lobulated, usually in the posteroinferior aspect of the superficial lobe. Multiple or bilateral lesions may be seen. Well-differentiated malignant tumors may have a benign appearance. More aggressive carcinomas are ill-defined masses with a central lucency due to tumor necrosis.

Lymphadenopathy may be associated. Irregular patchy enhancement of the gland parenchyma occurs with contrast administration owing to invasion and destruction of the gland. Ductal obstruction or encasement also may be seen. If tumor is demonstrated within 3.0 to 4.0 mm of the region of the stylomastoid foramen, surgical resection of the mastoid process or retrograde exploration of the facial nerve is usually necessary.

Infections cause enlargement and a diffuse increase in the density of the parotid gland. When extraglandular extensions of inflammatory processes occur, differentiation from neoplasms may be difficult. Sialosis usually appears as bilateral, diffuse enlargement of the parotid glands with a slight increase in density of the glands. The density decreases when there is fatty replacement of parenchymal tissue. Diffuse sialectasis causes areas of increased density in the parotid gland owing to fibrosis, as well as lucent areas corresponding to fibrosis, as well as lucent areas corresponding to the cystic spaces that have formed secondary to ductal and glandular tissue destruction.

Neck

CT assessment of the neck may demonstrate the location, nature, and extent of most neck masses. Thyroglossal duct cysts, cystic hygromas, and bronchial cleft cysts can be positively identified. Lipomas have a characteristically low attenuation value (less than that of water) on CT studies. CT can differentiate cellulitis, with swelling and edema of soft tissues and obliteration of fascial planes, from an abscess that appears as an area of low attenuation with an enhancing rim. It can also demonstrate complications of neck infections such as venous thrombosis.

Before the advent of MRI, CT was the best way of assessing the extent of neck tumors. Occult nodes in regions difficult to assess clinically may be demonstrated by CT, thus altering tumor staging and treatment. Cervical lymph nodes larger than 1.5 cm may be readily seen by CT (and MRI) scans. At present, CT has a better spatial resolution, but MRI is better at differentiating enlarged nodes from adjacent tumor or muscles. Currently, thin-section CT is the best tool to study extracapsular nodal extension of metastatic squamous cell carcinoma, and perhaps to upstage the clinically N0 neck.

The thyroid gland is best studied physiologically by radionuclide scans and morphologically by high-resolution ultrasonography. CT is of value in extrathyroid extension of tumor. CT may detect enlarged parathyroid glands, which appear as enhancing nodules, but this is an inferior morphologic study to diagnostic ultrasound. Ultrasonography is the preferred screening procedure, followed by nuclear scanning, angiography, or CT if an ectopic adenomas is suspected.

Magnetic Resonance Imaging (MRI)

Magnetic resonance imaging is a new modality complementary to CT scanning. Whereas CT demonstrates bone and soft tissue (with considerable effectiveness), MRI has an exquisite capability for soft tissue imaging. With its rapid technologic advances, MT scanning will completely supplant CT assessment for many areas of soft tissue interest to the otolaryngologist and head and neck surgeon.

The basic principles relating to MRI are as follows. Protons, subjected to a powerful magnetic field, align themselves parallel to the direction of the magnetic field. If a gradient is applied to the magnetic field, the protons oscillate or precess at different frequencies, depending on their positions in the magnetic field. When a signal of a particular radiofrequency is applied, protons with the same frequency absorb and then emit energy. The location of particular protons can be determined by the frequency of the signal emitted, and this information can be compiled to produce an image. The density of nuclear spins directly correlates with the amplitude of the MR signal. However, T1 (spin-lattice) and T2 (spin-spin) relaxation times, which are observed when the radiofrequency signal is turned off and equilibrium is being reestablished, are the main determinants of tissue contrast. T1 is the time required for net magnetization to return to its initial state; T1 is longer for solid structures than liquids. T2 is dependent on differences in a group of processing nuclei and is longer for homogeneous than for heterogeneous structures. Solid structures such as cortical bone with tightly bound nuclei produce no signal at all.

By using various pulse sequences, such as spin echo, partial saturation, and inversion recovery; by varying the repetition time (TR) between pulse sequences; and by changing the echo time (TE), ie, the time between the pulse and the echo it produces, T1 or T2 relaxation times can be manipulated and contrast between structures can be controlled. Changing the width of the radiofrequency pulse or the strength of the magnetic field alters slice thickness. The greater advantage of MR scanning is its improved soft tissue contrast compared with CT. In addition, bone artifacts that degrade the CT image are eliminated, since bone produces no signal on MR scans.

Scanning may be electronically chosen in any plane desired. Major vessels are well seen and no radiation or contrast material employed. The disadvantages of MRI are the high cost, longer scan time, and inability to depict cortical bone. It also cannot be used in patients with pacemakers or when ferrous materials, such as surgical clips, are present. Current scanners have a spatial resolution of less than 1.0 mm and slice thickness as small as 5.0 mm.

MRI is replacing CT in the assessment of the nasopharynx. T2 weighted images allow distinction between mucosal surfaces and underlying muscles. This information cannot be obtained with CT. In addition, MRI produces far superior visualization of each of the tensor palati and levator palati muscles, the individual muscles of mastication in the infratemporal fossa, and the parapharyngeal space compared with CT. Pathologic processes around the low-intensity carotid artery may be accurately assessed without the use of contrast material. Extension of nasopharyngeal tumors may be more easily mapped by MR than by CT because of the ease of obtaining MR slices in any desired plane and because of the superior soft tissue contrast of images, which allows improved delineation of tumor borders relative to adjacent uninvolved tissues. MRI imaging has been used to study the tongue and oropharynx and may eventually replace CT assessment of this region as well. The larynx has also been excellently imaged by MRI.

The delineation of paranasal sinus tumors by CT is sometimes limited by the inability of CT to differentiate tumor in the paranasal sinuses from mucosal inflammation or retained secretions, all of which may have similar attenuation values. CT may overestimate the extent of tumor in such cases. Since there is a great difference in the MR signals produced by tumor and those produced by inflammatory processes, the extent of tumor is sometimes better delineated by MRI. Tumor borders in the region of the orbits or edematous brain may also be better demonstrated by MR scans. Because of the multiplanar imaging capabilities of MRI, the extent of chordomas within the nasopharynx or intracranially can be shown.

The bony anatomy of the temporal bone produces no signal on MRI and is best studied by CT. However, MR scans provide excellent visualization of the vestibule, cochlea, and semicircular canals, as well as the horizontal and vertical course of the facial nerve. Cholesteatomas have a short T1 relaxation time and are best seen with T1 weighted images. Inflammatory fluid in the mastoid air cells appears as a bright echo on T2 weighted images.

MRI can demonstrate the seventh and eight cranial nerves in the internal auditory canal. Small acoustic neuromas less than 0.8 cm in size may be missed on enhanced CT scans and may require air-CT studies for diagnosis. However, these small tumors may be readily seen on MRI without the need for intravenous contrast or intrathecal air. Intracanalicular acoustic neuromas may be seen on MR studies as small masses obscuring the nerves in the internal auditory canal. Because meningiomas appear separate from the seventh and eight nerves on MRI, they may be differentiated from acoustic neuromas.

Cranial nerves IX to XI in the jugular foramen are well shown by MRI without the interference of images from adjacent bone and vascular structures. Because MRI actually delineates the individual nerves, it is more accurate in detecting glomus jugulare tumors than CT, which requires intravenous contrast and depends on bony erosion of the jugular foramen for the diagnosis.

MR scanning is useful for imaging structures in the neck. Lymph nodes can be easily distinguished from adjacent muscles and vascular structures. Thyroid nodules and cysts as well as parathyroid adenomas can be beautifully demonstrated. Although MRI affords excellent soft tissue contrast, it cannot distinguish inflammatory from malignant lymph nodes or benign from malignant thyroid nodules.