Chapter 2: Diagnostic Imaging of the Head and Neck

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Head and neck imaging has become progressively more accurate and clinically useful with the availability of high-resolution computed tomography (CT) and magnetic resonance imaging (MRI). Imaging has had a great impact on clinical staging and management of head and neck tumors. For most conditions, cross-sectional imaging has replaced plain film radiographs, and the art of plain film interpretation is waning, with the exception of facial trauma where plain films still provide a good overview. However, even with facial trauma most centers proceed rapidly to obtain CT studies. Conventional tomography, rarely used for head and neck diagnosis since the development of CT, still has an occasional role in evaluating tracheal stenosis. High-resolution ultrasound and nuclear medicine techniques offer additional information. With these many choices available, the clinician and the consulting radiologist must communicate clearly to obtain the optimal imaging study or studies to best evaluate the patient for treatment and surgical planning, as well as for follow-up plans.

This chapter gives the otolaryngologist - head and neck surgeon basic guidelines to help to understand the imaging studies available and logically choose the most appropriate study or studies. The majority of the discussion will focus on the application of CT and MRI to the head and neck; however, the role of plain film imaging and conventional tomography will be addressed. Specifically, imaging techniques and principles will be discussed and an approach to imaging each anatomic region of the head and neck will be considered (Tables 2-1 and 2-2). The application of a spatial approach to film interpretation has improved the understanding of cross-sectional anatomy of the head and neck; normal spatial anatomy will be emphasized and illustrated in the suprahyoid and infrahyoid neck. Basic principles of imaging interpretation of each anatomic region will be reviewed so that the clinician and the consulting radiologist will be speaking a common language and have a similar approach to the differential diagnosis of head and neck pathologic findings. Finally, imaging of lymphadenopathy, the face, the skull base, the temporal bone, and the postoperative neck will conclude the discussion.

Imaging Techniques

Plain Film Imaging

Historically, plain x-ray films have been the initial imaging study used for assessment of the skull base, paranasal sinuses, and soft tissues of the neck. Plain films provide a limited amount of information and, in most cases, do not completely rule out an abnormality; thus cross-sectional imaging is required. For a study addressing the skull base, the submental vertex (base) view demonstrates the cranial nerve foramina well. The 0-degree posteroanterior (PA) view assesses the internal auditory canals well. The 23-degree PA (Caldwell) view shows the orbit, superior orbital fissure, floor of sella, and foramen rotundum. The Stenvers' view is one of several projections for studying the mastoid air cells. The paranasal sinuses are frequently studied by several views, utilizing a horizontal x-ray beam so that air-fluid levels may be appreciated. These sinus views include the PA, Waters', Towne, upright or cross-table lateral, and submentovertex views. Similar views are used for assessing facial trauma and an additional "bucket handle" (submentovertex) view is excellent for assessing the zygomatic arches. Plain film imaging of the mandible, upper airway, and pharynx has limited applications. The mandible may be studied with the oblique mandibular, Towne, and occlusal views or by orthopantomogram (Pan-o-rex). For the suprahyoid anterior neck and retropharyngeal space, the soft tissue lateral view is excellent for detecting an inflammatory process and for localizing a foreign body in the hypopharynx and supraglottic larynx. Hypopharyngeal and laryngeal evaluation may be supplemented by barium swallow studies using spot films or 110 mm filming of the swallowing process in the AP and lateral projections to assess for a mass in this region. On occasion, aspiration will occur, resulting in visualization of the false and true vocal cords.

Although the larynx is not well demonstrated on routine plain films, conventional pain film tomography in the AP (coronal) projection is excellent for assessing the configuration of the supraglottic and infraglottic airway. In addition, the AP projection tomogram may be useful for assessing stenosis in the upper trachea secondary to trauma or chronic intubation.

No contraindications to plain film imaging of the head and neck exist. However, radiation doses must be considered. Approximately 0.3 centiGray (1 cGy = 1 rad) is given per each plain film view obtained. The organs of the head and neck most likely to be affected by a cumulative radiation dose are the lens of the eye (since ionizing radiation has the potential to induce cataract formation) and the thyroid gland.

Computed tomography

CT is an essential imaging modality for assessment of head and neck pathologic conditions. Its advantages include high spatial resolution (0.3 to 1 mm), excellent soft tissue contrast discrimination between fat, muscle, bone, and other soft tissues, and elimination of the overlap of adjacent structures (particularly of the paranasal sinuses and skull base) that may compromise plain film examinations. CT scan sections are obtained rapidly (approximately 2 seconds per slice) resulting in relatively little motion artifact. When performing a CT examination several technical factors must be considered. The CT slice thickness may be varied from 0.5 to 10 mm depending on the scanner. In general, the thinner the slice, the better the spatial resolution, since less tissue is averaged in each slice. For most head and neck structures a slice thickness between 3 and 5 mm is obtained. For assessment of smaller structures 1 to 1.5 mm sections may be necessary. In general these slices are contiguous, although occasionally either overlap (to visualize small structures or to improve re-formations in other planes) or an interslice gap (to survey a larger volume but reduce the number of slices) may be used.

Imaging can be obtained in several planes. In most cases the axial (transaxial) plane, usually parallel to the orbitomeatal or infraorbitomeatal plane, is used with the patient lying supine. This is the most comfortable position for the patient, and the gantry of the scanner can be tipped to obtained angled sections through the structures of interest. In addition, direct coronal imaging and even direct sagittal imaging can be performed. Direct coronal imaging is desirable in many cases but may be significantly degraded by metallic dental artifact. Direct sagittal imaging requires a large-bone CT scanner, special positioning, and additional scanning time (Bluemm, 1982). These additional positions may be uncomfortable for the patient to maintain. An alternative to direct coronal or sagittal scanning is computed reformatted images that may be generated in any plane; however, to achieve good image quality, contiguous 1 to 2 mm axial sections are required. Reformatted images may be substituted for direct imaging in patients suffering multiple trauma, in those unable to flex their neck adequately, or in patients with large amounts of dental work. However, reformatted images are easily degraded by patient motion. Whenever possible, direct images are desirable to optimize spatial resolution.

CT image processing

Several reconstruction algorithms are available for the creation of a two-dimensional CT image (Fig. 2-1). The choice of the appropriate algorithm will allow optimal characterization of various structures. These algorithms vary in their degree of soft tissue contrast and edge definition (smoothing edges vs. edge enhancement). Soft tissue algorithm minimizes edge enhancement, gives good soft tissue contrast between fat and muscle, and is optimal for looking at the soft tissue structures of the neck. On the other hand, bone algorithm is very strongly weighted toward edge enhancement, giving excellent trabecular detail, a benefit for imaging the sinuses and temporal bone. Each of these imaging algorithms requires that the raw imaging data be processed separately for each algorithm chosen; that is, the data are processed by the computer twice to obtain both bone and soft tissue algorithms.

CT image display

Multiple options for both displaying the image (adjusting the window level and width parameters on the imaging console) and recording it permanently on radiographic film are available. Each pixel (picture element) of the CT image is given a density value. Water has been assigned a value of 0 on this scale developed by Hounsfield, fat is approximately -80 to -100 Hounsfield units (HU). Calcium and bone are in the 100 to 400 HU range, and most fluids are in the 0 to 30 HU range. The window level is simply the midpoint of the densities chosen for display. The range of densities chosen above and below the window level define the window width. A narrow window width of 80 HU and a level of +40 HU is frequently used for brain imaging since it centers the density at the common density of brain tissue and displays only those densities 40 HU greater than and 40 HU less than the window level. Thus any density greater than +80 HU will be displayed as white and any density less than 0 will be displayed as black on the gray scale. Any intermediate density will be spread out evenly along the gray scale. For imaging of the soft tissues of the head and neck, a window level of approximately 40 to 70 HU is usually chosen, at a midpoint approximately equal to the density of muscle. The window width frequently is in the 250 to 400 HU range, thus displaying a wider range of densities including calcification, intravenous contrast, muscle, and fat to best advantage. For imaging bony structures such as paranasal sinuses and temporal bone, window levels from 0 to +400 HU and a very wide window width of 2000 to 4000 HU may be chosen. The reason for a wide bone window width is that a wide range of densities ranging from cortical bone (approximately +1000 HU) down to gas (-1000 HU) need to be displayed on the same image. However, structures of intermediate density between bone and gas occupy a very narrow range on the gray scale at this window width and are poorly discriminated (appear washed-out) on these settings. The terminology commonly used to describe the above mentioned windows includes soft tissue windows (window width of 250 to 400 HU) and bone windows (2000 to 4000 HU).

It is important to understand that these display windows are completely independent of the mathematical imaging algorithm chosen for creation of the image. In other words, an image created by a soft tissue algorithm can be displayed with both soft tissue and bone window widths (Fig. 2-1, A and C). Conversely, the image may be computer reconstructed using a bone algorithm and displayed with either soft tissue or bone window width (Fig. 2-1, B and D). To optimize the imaging of the soft tissue lesion and the adjacent bone, both a soft tissue and a bone algorithm may be employed, generating images with the appropriate soft tissue and bone windows (see also Fig. 2-10, A and C).

Patient cooperation

Patient cooperation is necessary to obtain optimal image quality. The patient is instructed not to swallow and to stop breathing or to maintain quiet breathing during each slice acquisition to minimize motion artifact from the adjacent airway and pharyngeal structures. Occasionally, provocative maneuvers such as blowing through a small straw or using a cheek-puffing (modified Valsalva) maneuver to distend the hypopharynx or phonating to assess vocal cord movement may be necessary (Figs. 2-2 and 2-3).

CT contrast agents

Natural contrast. The presence of abundant fat within the head and neck with its low density relative to adjacent muscles, nodes, vessels, and bone generally allows for superb delineation of anatomic detail.

Intravenous iodinated contrast. IV contrast may not be necessary in trauma but is very helpful in head and neck inflammatory and neoplastic lesions. In general, it is usually not necessary to obtain both noncontrast CT (NCCT) and contrast CT (CECT). The two major purposes of CT are to detect a lesion and to define the extent of disease. CECT accomplishes both purposes by optimizing lesion conspicuity. Except for nodal metastases, intravenous contrast does not often improve specificity of diagnosis but frequently does improve the visibility of masses by increasing their density relative to the adjacent fat, muscle, or mucosa. Contrast infusion technique and timing may significantly alter the degree of vascular enhancement and ability to discriminate a vessel from an adjacent mass (Figs. 2-3 and 2-4).

Radiation dose and complications of CT

Ionizing radiation at a total dose between 200 and 500 cGy has the potential to produce cataracts. The radiation dose to the lens of the eye from a CT examination may range from 3 to 6 cGy. However, imaging planes can be chosen to avoid scanning directly through the lens of the eye. Intravenous iodinated contrast carries a 1% to 5% risk of some types of a contrast reaction, ranging from the more common nausea and vomiting or urticaria to the uncommon but more serious bronchospasm, laryngospasm, or anaphylaxis. A reaction may occur with either intravenous or, rarely, intraductal (sialogram) iodinated contrast. If the patient has a serious known allergy to iodine (shellfish or iodinated contrast) NCCT, MRI, or ultrasound film should be substituted. If contrast use is necessary in a patient with an allergic history, nonionic contrast should be used, and premedication with corticosteroids for 24 hours may be necessary. Nonionic contrast carries a lower risk of significant reaction. Finally, although the cost of CT may be several hundred dollars more expensive than the cost of a plain x-ray examination, the quality and quantity of information obtained are far greater with CT.

Magnetic resonance imaging

MRI is one of the most active areas of development and research within diagnostic radiology. MRI derives signal from hydrogen protons most abundant in tissue fat and water, by placing them in a high magnetic field. This tends to align the spinning protons in the direction of the magnetic field. Radio frequency pulses are transmitted into the subject to excite the spinning protons, changing their orientation with respect to the magnetic field. As the protons realign with the magnetic field, they lose energy and give off signal, which is measured and reconstructed by the MR scanner into an image. The quality of MRI depends on a high signal-to-noise ratio, which improves image contrast and spatial resolution (Elliott, 1987). In general, the higher the field strength of the magnet, the higher the signal-to-noise ratio. Thus MRI scanners with field strengths of 0.5 to 2.0 Tesla (T) are commonly used for imaging.

Surface coils significantly improve the quality of head and neck imaging by increasing the signal-to-noise ratio. A surface coil is a receiving antenna for the radio frequency signal that is emitted from the imaging subject after the initial radio frequency stimulation. The standard head coil is usually adequate for studying head and neck disease above the angle of the mandible. A head coil allows imaging of the adjacent brain and orbits, an advantage when head and neck lesions extend intracranially. Neck coils cover a larger area from the skull base to the clavicles and come in various configurations, for example, volume neck coil, anterior neck coil, 5-inch flat coil placed over the anterior neck, and bilateral TMJ coil. Slice thickness on MRI is most commonly 5 mm, with 3 mm sections used for smaller regions of interest. However, a thinner slice has a smaller signal-to-noise ratio. Occasionally, 1 to 2 mm sections may be needed for small structures (eg, facial nerve), requiring a volume acquisition technique. The number of slices is limited in MRI (as opposed to CT) by the specific sequence employed, ranging from six to eight slices with a short T1 inversion recovery technique up to 14 to 18 slices with a T2-weighted sequence; volume acquisition techniques will allow 60 or more thin slices.

MRI artifacts

Motion artifact, chemical shift artifact, dental work (amalgam, implants, braces, etc) and eyelid mascara degrade MR images (Fig. 2-5). Motion artifact becomes more prominent with increased field strength, increased length of individual pulse sequences, and the total length of the imaging study. A typical imaging sequence may last from 2 to 8 minutes. To limit motion artifact, sequences less than 4 minutes are preferred, and the patient should be instructed not to swallow and to breath shallowly and quietly.

Chemical shift artifact arises from the differences in resonance frequencies of water and fat protons. The result is an exaggerated interface (spatial mismapping) in areas where fat abuts structures containing predominantly water protons such as the posterior globe or a mass. Chemical shift artifact may produce the appearance of a pseudocapsule around a lesion or cause obscuration of a small-diameter structure such as the optic nerve. Chemical shift artifact may be identified by a bright band on one side of the structure and a black band on the opposite side. This is usually most noticeable on T1-weighted images.

Metallic artifact from dental work varies in severity depending on amount and composition of the metal in the mouth, as well as the pulse sequence and field strength of the MRI scanner. Most dental amalgam causes mild distortion to the local magnetic field, resulting in a mild dropout of signal around the involved teeth. Extensive dental work, metallic implants, and braces may cause more severe distortion of the image, precluding visualization of the maxilla, mandible, and floor of the mouth. Mascara containing metallic compounds can also cause localized signal loss in the anterior orbit and globe.

MRI pulse sequences

Numerous pulse sequences are available on clinical MRI units; the details of the physics of MRI may be found in most radiology/MRI textbooks (Brant-Zawadcki, 1987). Commonly used imaging protocols include T1-weighted, spin (proton) density, T2-weighted, gadolinium-enhanced T1-weighted, fat-suppressed, and gradient echo imaging; magnetic resonance angiography is infrequently obtained (Figs. 2-6 and 2-7). The abbreviations used to identify sequence parameters on hard copy film or in journal articles are repetition time (TR), echo time (TE), and inversion time (TI) and are measured in milliseconds. The following description of pulse sequences is presented in order to assist the clinician in identifying and understanding the commonly performed sequences and in determining their respective use in the head and neck.

T1-weighted images (T1WIs). T1-weighted (short TR) sequences (Figs. 2-6, A, and 2-7, A) use a short TR (500 to 700 msec) and a short TE (15 to 40 msec). T1-weighted imaging is the fundamental head and neck sequence because it provides excellent soft tissue contrast with a superior display of anatomy, a high signal-to-noise ratio, and a relatively short imaging time (2 to 5 minutes), minimizing motion artifacts. Fat is high signal intensity (bright or white) on T1WIs and provides natural contrast in the head and neck. Air, rapid blood flow, bone, and fluid-filled structures (eg, vitreous and cerebrospinal fluid (CSF)) are low signal intensity (dark or black) on T1WIs. The inherent high contrast of fat relative to adjacent structures allows excellent delineation of the muscles, globe, blood vessels, and mass lesions that border on fat. Surrounding bone is black, except for the enclosed bone marrow (eg, sphenoid wing, mandible, and thyroid cartilage), which is bright from fat within the marrow. The aerated paranasal sinuses are black, whereas retained mucous or mass lesions are of low to intermediate signal intensity. Most head and neck mass lesions will show a low to intermediate signal intensity on T1WIs. Fewer slices are available with a short TR compared to a long TR sequence. (To quickly identify a T1WI: fat is white, CSF and vitreous are black, and nasal mucosa is low signal.)

Spin (proton) density-weighted images. Spin density-weighted sequences (also known as proton density, balanced, or mixed sequences) use a long TR (2000 to 4000 msec) and a short TE (20 to 40 msec). Spin density images (Fig. 2-6, B) show air and bone as low signal intensity and fluid-containing structures and muscles as intermediate signal intensity, with fat remaining moderately high in signal intensity but somewhat decreased in signal from T1WI. A solid mass or fluid-filled lesion with a high protein content will demonstrate moderate to high signal intensity, which may improve its visibility relative to muscle but may obscure it relative to the adjacent fat. Paranasal sinus inflammation typically appears very bright on spin density images. (To quickly identify a spin density image: CSF and vitreus are intermediate in signal.)

T2-weighted images (T2WIs). T2WIs (Fig. 2-6, C) use a long TR (2000 to 4000 msec) and a long TE (50 to 90 msec) and are sometimes referred to as long TR/long TE images. Note that spin density and T2WI are acquired simultaneously from a single sequence that produces two sets of images with the same TR but different TEs; for example, spin density = 2000/30 and T2WI = 2000/80. T2WIs are most useful for highlighting pathologic lesions. T2WIs show the vitreous and CSF as high signal intensity (bright) relative to the low to intermediate signal intensity of head and neck fat and muscle. Fat loses signal intensity with increased T2 weighting. Most head and neck masses are higher signal intensity on a T2WI compared to their low to intermediate signal intensity on T1WI. The combination of the T1WI and T2WI is often useful for characterizing fluid containing structures, solid components, and hemorrhage. Bone, rapid vascular flow, calcium, hemosiderin, and air-containing sinuses are black. Inflammatory sinus disease and normal airway mucosa appear very bright. (To quickly identify a T2WI: CSF, vitreous, and nasal mucosa are white. Fat is low to intermediate in signal.)

Gadolinium enhancement. Paramagnetic gadolinium compounds are commonly used in central nervous system (CNS) imaging for lesion enhancement. Gadolinium is used in conjunction with T1WI sequences (gadolinium shortens the T1), and with the dose used it has little effect on T2WI. The advantages of gadolinium enhancement are increased lesion conspicuity and improved delineation of the margins of a mass relative to the lower signal of muscle, bone, vessel, or globe (Crawford et al, 1989). However, gadolinium enhancement (without concomitant fat suppression) has had limited usefulness within the head and neck, as well as in the orbit, because of the large amount of fat present within these regions (Fig. 2-6, D). Following gadolinium injection the signal increases within a lesion, often obscuring the lesion within the adjacent high signal intensity fat (Robinson et al, 1989). Therefore for head and neck imaging, gadolinium is optimally used with specific fat suppression techniques that turn fat dark or black (see below). Gadolinium enhances normal structures including nasal and pharyngeal mucosa, lymphoid tissue in Waldeyer's ring, extraocular muscles, and slow-flowing blood in veins, all of which may appear surprisingly bright, especially if combined with fat suppression techniques. (To quickly identify a gadolinium-enhanced T1WI: nasal mucosa is white, fat is white, and CSF and vitreous are black. Also look for Gd-DPTA or Magnevist (Berlex) printed directly on the image or on adhesive study labels.)

Fat suppression methods. Several sequences have been developed that suppress fat signal intensity. T2-weighted images, short TI inversion recovery (STIR), spectral presaturation inversion recovery (SPIR), and chemical shift selective presaturation (fat saturation) are some of the more common clinically available methods of fat suppression. One advantage of fat suppression is reduction or elimination of chemical shift artifacts by removing fat signal from the image while preserving water signal. Additionally, some fat suppression techniques take advantage of gadolinium enhancement by eliminating the surrounding high intensity signal from fat while retaining the high intensity enhancement produced by gadolinium. Most pathologic lesions have increased water content, and gadolinium exerts its paramagnetic effects while in solution in blood vessels and in the increased extracellular fluid of the lesion, but gadolinium does not enhance fat.

1. T2WIs provide a moderate degree of fat suppression and discrimination of fat from water protons, yet enough fat signal persists to obscure some head and neck inflammatory and neoplastic lesions, especially lymph nodes. This sequence may be used before or after gadolinium and, because of the long TR utilized, yields the highest number of slices.

2. STIR (Fig. 2-7, E) is superior to T2WI for suppression fat signal. The inversion time (eg, TI = 140 msec) is individually "tuned" for each patient to place fat at the null point of signal intensity and thus eliminates fat signal by turning it completely black. STIR images show the mucosa, vitreous, and CSF as very high signal intensity (Atlas et al, 1988). Most mass lesions in the head and neck will have similar high signal intensity on both STIR and T2WI. The disadvantage of STIR is image degradation secondary to a decreased signal-to-noise ratio, an increased susceptibility to motion artifacts, and increased scan time. It is inadvisable to perform STIR after gadolinium administration, since the gadolinium can result in a "paradoxical" signal loss (rather than enhancement) by shortening the T1; the longer the T1 of a structure, the brighter it becomes on STIR. STIR is often limited to six to eight slices, making full neck evaluation difficult, unless a concatenated technique is used, which increases slices acquired but requires a doubling of scan time. (To quickly identify a STIR image: fat is almost completely black; CSF, vitreous, and mucosa are white. A TI time is listed with the TR and TE times on the image.)

3. Chemical shift selective presaturation sequences (Fig. 2-7, B) used with a spin echo technique (Chem-Sat, General Electric) or with an inversion recovery technique (SPIR, Phillips) selectively suppress either water or fat signal, but fat saturation (suppression) is the most clinically useful technique. (Note that for the remainder of this chapter the terms *fat suppression* and *fat saturation* are used interchangeably and refer to chemical shift selective presaturation techniques.) T1-weighted fat saturation sequences take full advantage of gadolinium enhancement. A gadolinium-enhancing lesion within the head and neck retains its high signal intensity and is not obscured, since the fat is suppressed to become low to intermediate signal intensity. Enhancing masses within the head and neck and orbit are particularly well imaged with this technique (Hendrix et al, 1990). The disadvantages of fat saturation sequences are that non-gadolinium-enhancing lesions may be less well discriminated, that these sequences are more susceptible to artifacts, and that nonuniform fat suppression occurs. Also, two to three fever slices are acquired compared to T1WI, unless the TR time is lengthened. (To quickly identify a gadolinium-enhanced T1WI with fat saturation: mucosa and small veins are white, fat is low to intermediate intensity, and CSF and vitreous are black.)

Fat saturation can optimize long TR (spin density and T2WI) sequences (Fig. 2-7, C and D). The advantage occurs when the spin density image is performed after gadolinium, since moderate T1-shortening effects by gadolinium occur with this sequence. Most lesions and vascular structures will show a mild degree of enhancement, with an image almost equivalent with a postgadolinium fat saturation T1WI. Fat-saturated T2WIs provide excellent fat suppression almost equivalent to STIR, optimizing the high signal from normal structures and lesions that are high in water content contrasted against a black background of fat.

Gradient echo techniques. Numerous new and faster gradient echo sequences are available that have a variety of applications. Gradient echo scans have a very short TR (30 to 70 msec), a very short TE (5 to 15 msec), and a flip angle of less than 90 degrees. They have a variety of proprietary acronyms including GRASS, MPGR, and SPGR (General Electrics) and FLASH and FISP (Siemens). Gradient echo sequences take advantage of the phenomenon of flow-related enhancement; that is, any rapidly flowing blood will appear extremely bright. These sequences are useful for localizing normal vessels, detecting obstruction of flow in compressed or thrombosed vessels, or showing vascular lesions that have tubular, linear, or tortuous bright signal representing regions of rapid blood flow (Fig. 2-8). Gradient echo sequences may be obtained faster than conventional spin echo techniques, although their increased susceptibility to motion artifact diminishes the benefits of a short scan time. Gradient echo techniques also permit volume; that is, three-dimensional vs two-dimensional acquisition of images, allowing computer workstation reconstruction of any imaging plane at any desired thickness with increased spatial resolution. The disadvantage of gradient echo sequences is the increased magnetic susceptibility artifact from bone or air, thus limiting their role near the skull base or paranasal sinuses. (To quickly identify a gradient echo image: arteries and often veins are white; fat, CSF, vitreous, and mucosa may have variable signal intensities depending on the technique used.)

MR angiography. Magnetic resonance angiography (MRA) is a technique that takes advantage of phase or time-of-flight differences in flowing blood relative to motionless structures and selectively produces images of structures with rapid blood flow. Two- and three-dimensional images of normal vessels and vascular lesions can be generated. At present MRA does not equal the spatial resolution of conventional angiography, but the technology is in rapid evolution. Early experience in the head and neck indicates MRA will be useful for evaluating vascular compression and vessel patency and for characterization of vascular masses and malformations (Pernicone et al, 1990).

MRI disadvantages

Several disadvantages of MRI of the head and neck bear consideration. MRI frequently requires 45 to 90 minutes of scanning time, during which time the patient must remain motionless, a process difficult for a sick patient to accomplish. Motion artifacts are more frequently encountered than with CT, although dental artifacts may be less problematic. Although no known harmful effects during pregnancy have been demonstrated, at most institutions MRI is used sparingly during the first trimester. (MRI avoids the use of ionizing radiation, and no harmful effects have been shown with its use at current field strengths.) Absolute contraindications to MRI include patients with cardiac pacemakers, cochlear implants, and ferromagnetic intracranial aneurysm clips. Those patients at risk for metallic orbital foreign bodies should be screened with plain films or CT before MRI. Generally ocular prostheses and ossicular implants are safe. Unfortunately, MRI is also the most expensive of all the imaging modalities.

Ultrasound

High-resolution diagnostic ultrasound uses the properties of reflected high-frequency sound waves to produce cross-sectional images, obtainable in almost any plane. The transducer, a high-frequency 5 or 10 MHz probe, scans over the skin surface of the region of interest. Fat has a moderate degree of internal echoes (echogenicity). Skeletal muscle is less echogenic than fat. A solid mass has well-defined margins and variable echogenicity but is usually less echogenic than fat. A cyst has few, if any, internal echoes, a strongly echogenic back wall, and strong through-transmission of sound behind the cyst. Both calcium and bone are strongly echogenic, thus obscuring adjacent structures by an acoustic shadow. Ultrasound has no known harmful effects and no contraindications. High-resolution ultrasound is quick and accurate; further, it is relatively inexpensive compared to CT or MRI.

Nuclear medicine

Scintigraphy has several applications in the head and neck. In salivary gland imaging 99mTc pertechnetate imaging may be useful for assessing salivary gland function in autoimmune and inflammatory disease of the salivary glands. If the salivary glands are obstructed, the degree of obstruction as well as the follow-up of obstruction after treatment can be assessed. In evaluating neoplasms of the salivary glands the findings of the 99mTc-pertechnetate scan are almost pathognomonic of Warthin's tumor and oncocytoma. Spatial resolution is approximately limited to 1.5 cm, so accurate localization of the mass within the gland is difficult. Single photon emission computed tomography (SPECT) may be useful in some cases.

Techniques in thyroid imaging and therapy for thyroid disorders are described in many nuclear medicine textbooks (Mettler and Guiberteau, 1991). Most nuclear medicine imaging uses various isotopes of iodine (131I and 123I) to determine thyroid function, identify hot or cold nodules, or access extent of thyroid masses and tumors. Positron emission tomography (PET) with 2-(18F)fluoro-2-deoxy-D-glucose can demonstrate uptake in lymph nodes, in lymphatic tissues of Waldeyer's ring, and in mucosal surfaces.

Three-dimensional reconstruction techniques

Image data from either CT or MRI can be processed to create three-dimensional reconstruction, but a separate computer workstation with appropriate imaging software is necessary. CT data are loaded as a stack of contiguous two-dimensional slices that defines the scanned volume. Reconstructions are created either from choosing a specific range of densities for display or by manually tracing the outline of the desired structure. MR data for image analysis are best acquired using a "volume acquisition" method, in which data are acquired as a complete three-dimensional block rather than as individual slices. Since volume acquisition takes longer, gradient echo techniques are usually required to reduce the imaging time. Once acquired, the data are displayed in any desired plane and, by selecting a range of signal intensities or by tracing specific structures with a cursor, three-dimensional surface models are created.

The utility of three-dimensional reconstruction is best appreciated with craniofacial reconstruction (Fishman et al, 1988; Marentette and Maisel, 1988). Contiguous 1 to 2 mm noncontrast CT axial sections are processed on the workstation to obtain a three-dimensional model of the bone surfaces. Directly visualizing the three-dimensional relationships of the facial structures aids surgical planning. Three-dimensional models of the face and orbital structures are useful for teaching medical students, residents, and anatomy students. To date, the spatial resolution of CT is superior to MRI in the head and neck for displaying bony relationships. However, MRI provides a superior display of transcranial soft tissue structures, such as the entire visual pathway, and has better tissue contrast resolution than CT. Thus CT and MRI will likely have complementary roles in three-dimensional image display.

Applications of CT, MRI, and Ultrasound in the Head and Neck

Each anatomic region requires a different imaging approach to optimize the detection and characterization of the structure or lesion of interest. The following is a description of the indications for using CT, MRI, or ultrasound in specific head and neck regions, plus a general imaging approach relevant to each anatomic region in terms of imaging planes, slice thickness, contrast agents, and pulse sequences. Whenever possible CT and MRI are performed before biopsy or resection of lesions, because the resulting edema may obscure the true margins of a mass.

Application of computed tomography by head and neck region

Suprahyoid neck

Suprahyoid neck CT is often performed for simultaneous evaluation of the deep extent of mucosal-based tumors and to evaluate associated metastatic disease to the cervical lymph node chains. To cover the region from the skull base down to the root of the neck, contiguous axial 3 to 5 mm sections from the bottom of the sella down to the hyoid bone, followed by 3 to 5 mm sections at 5 mm intervals from the hyoid bone down to the sternal notch (thoracic inlet), are required. Since streak artifacts from dental fillings frequently obscure the oropharynx and nasopharynx, it is usually necessary to obtain additional angled sections to assess the pharynx directly posterior to the dental work (Fig. 2-9). Direct coronal 3 to 5 mm images are very useful in defining craniocaudal relationships in lesions of the oral cavity and facial bones. The use of intravenous contrast is continuously infused during the entire scanning sequence so that a high concentration of intravascular (both arteria and venous) contrast allows differentiation of vessels (see Figs. 2-3 and 2-4) from other higher density structures such as lymph nodes and muscle. Otherwise, determination of vascular invasion, compression, and discrimination of vessels from nodes and small muscle bundles can be extremely difficult. Contrast is best administered with a mechanical pump infusion (although a drip infusion technique may also be effective) giving a single dose (40 g iodine) up to a double dose (80 g iodine) of contrast. Frequently, only a soft tissue algorithm is necessary with each slice photographed with both soft tissue and bone windows. However, sections of the skull base and mandible may need reconstruction using a bone algorithm if a suspicion of bone erosion or destruction by tumor or inflammation exists. Direct coronal images are advantageous when assessing lesions of the tongue, floor of mouth, retromolar trigone, mandible, or skull base.

Cervical lymphadenopathy

Lymph node CT evaluation is concomitantly performed during CT investigation of most suprahyoid and infrahyoid tumors or inflammation. Axial 3 to 5 mm slices must extend from the skull base to the clavicles to encompass the many node chains that extend the length of the neck. As mentioned above, the quality of lymph node assessment depends very much on the success of achieving a high concentration of contrast in the arterial and venous structures of the neck; otherwise, nodes and vessels may appear remarkably similar.

Postoperative neck

Imaging the postoperative neck uses the same techniques as the suprahyoid/infrahyoid neck. Thinner sections or supplemental coronal images in the region of suspected recurrence may be required.

Salivary glands

Salivary gland CT is most frequently performed with the axial plane parallel to the infraorbitomeatal line and can be used for assessment of both the parotid and the submandibular gland. However, dental amalgam can cause significant streak artifacts that obscure the parotid or submandibular gland parenchyma. If the dental work is identified on the lateral scout view (scanogram), dental artifacts can usually be avoided if an oblique semiaxial projection is chosen with the scanner gantry angled in a negative direction (between a coronal and an axial plane), thus avoiding the teeth. This plane has the advantage of visualizing both parotid and submandibular glands in the same slice and is parallel to the posterior belly of the digastric muscle (van den Akker, 1988). The direct coronal projection may yield additional anatomic information for evaluating both the parotid and the submandibular glands and avoids creating dental artifacts through the parotid gland, but the dental artifacts may still compromise visualization of the submandibular duct and gland. A slice thickness of 3 to 5 mm is generally adequate for evaluating the gland parenchyma. Occasionally, supplemental 1 to 2 mm slices are required for evaluating smaller lesions.

With the current generation of high-resolution scanners, noncontrast computed tomography (NCCT) may suffice for the salivary glands. However, contrast-enhanced computed tomography (CECT) is preferable to NCCT in most cases, because CECT maximizes the tissue contrast resolution between a salivary lesion and the adjacent normal gland, fat, and muscle (Curtin, 1988; Som, 1990). CECT is also essential for assessment of salivary tumor metastases to the lymph node chains of the neck. A normal parotid gland is a relatively fatty structure with a density intermediate between the low-density facial fat and the higher-density adjacent masseter muscle. However, the parotid gland has a wide variation in normal density and may have increased density approaching that of muscle in children and adults or in patients with chronic inflammation. The submandibular gland normally has density just slightly less than skeletal muscle and lymph nodes. In those occasional cases in which the gland parenchyma is similar to muscle in density, either MRI, CECT, or even CT sialography may be necessary to discriminate the margins of a suspected mass from the surrounding glandular tissue.

Sialography and CT sialography (CTS)

Conventional sialography remains the best radiographic method for evaluating ductal anatomy in obstructive, inflammatory, and autoimmune salivary gland diseases. Supplemental CT sialography may be performed when routine sialography shows an unexpected mass lesion or in the infrequent situation when noncontrast (or contrast-enhanced) CT shows a dense, enlarged gland in which a mass is suspected but not clearly demarcated. CT sialography is unnecessary in most salivary tumor cases because of the much improved capabilities and thin sections of the high-resolution third- and fourth-generation CT scanners compared with early-generation scanners. However, MRI may be the preferred alternative method of studying dense salivary glands. CTS may be obtained at the time of intraductal injection of fat-soluble or water-soluble contrast or after a routine sialogram (the gland may be reinjected during the CT with the catheter left in place). The plane of study is the same as that used for NCCT and should be similarly angled to avoid dental filling artifacts. The use of concentrated sialographic contrast material may cause significant streak artifacts if too much contrast collects in dilated ducts, acini, or large pools, all of which can obscure smaller masses in the gland. For optimal CTS, the injection is extended into the acinar phase to maximize parenchymal opacification and thereby silhouette mass lesions within the parenchyma (Evers et al, 1985).

Larynx and infrahyoid neck

Laryngeal and infrahyoid neck CT is most commonly requested to evaluate squamous cell carcinoma of the larynx or hypopharynx, associated cervical lymph node metastasis, trauma, and inflammation. Thus axial imaging from the angle of the mandible down to the sternal notch is required to survey the lymphatic chains and infrahyoid neck, using 3 to 5 mm contiguous sections and intravenous contrast infusion. However, the fine detail of the larynx and vocal cords requires thinner contiguous sections of 2 to 3 mm. When assessing the true vocal cords and the arytenoid cartilages, 1 to 1.5 mm contiguous sections may occasionally be necessary to get adequate spatial resolution. Sections through the vocal cords are optimally obtained parallel to the plane of the cords by angling the scanner gantry parallel to the plane of the hyoid bone or the closes adjacent cervical disk space. Since assessment of vocal cord mobility is important in staging glottic carcinoma, various provocative techniques may facilitate laryngeal imaging in those cases where the vocal cords are obscured on physical examination. Quiet breathing places the cords in a partially abducted position. By having the patient blow through a straw or do a modified Valsalva maneuver (puffing out the cheeks) the hypopharynx and supraglottic larynx can be distended, allowing better separation of the aryepiglottic folds from the hypopharynx, while simultaneously abducting the cords (see Fig. 2-3). The vocal cords can be assessed by phonating ("eeee"), which causes the cords to adduct and move to a paramedian position (see Fig. 2-3). Breath holding will also adduct the vocal cords, close the glottis, and significantly reduce motion artifacts. By scanning the larynx twice, once to adduct and a second time (sections limited to the glottis) to abduct the vocal cords, the radiologist can assess vocal cord motion and identify fixation. Intravascular contrast should be given to differentiate vascular structures from adjacent nodes and muscles and to assess tumor margins. Evaluation of laryngeal trauma may not require intravenous contrast. Bone windows are helpful for assessing cartilage fractures or tumor erosion. In a cooperative patient with a flexible neck it may be possible to obtain direct coronal images to assess the configuration of the true and false vocal cords, yielding similar information to that obtained by conventional AP tomography of the larynx.

Thyroid and parathyroid glands

Thyroid gland CT is performed in the same manner as the scanning of the larynx. The indication for performing CT arises when physical examination, ultrasound, or a nuclear medicine study suggests an unusually large or fixed mass. CT can help determine the extent of invasion and compression of adjacent structures in the larynx, hypopharynx, and mediastinum. The 3 to 5 mm sections are obtained from the hyoid bone to the top of the aortic arch to cover potential sites of ectopic thyroid and parathyroid tissue. Although the normal thyroid is hyperdense because of its natural iodine content NCCT, a CECT is preferred for this study. The normal thyroid enhances intensely on CECT, with most mass lesions of the thyroid enhancing less. The parathyroids are rarely imaged primarily by CT, because nuclear medicine and ultrasound techniques are excellent procedures for localizing these small glands.

Paranasal sinuses

Paranasal sinus CT can be approached in several ways depending on the anticipated disease process. Plain films may be used as the initial screening device for evaluating sinusitis or facial trauma. Once a mass or inflammatory lesion is detected within the sinuses, CT is the method of choice for further evaluation. A better substitute for the plain film series is a screening axial sinus NCCT (Fig. 2-10, A), which gives superior information on specific sinus involvement by inflammatory processes as well as better delineation of bony sclerosis or destruction. One method is to use 5 mm-thick sections obtained at 10 mm intervals (5 mm gap), which can cover the entire paranasal sinuses with six to eight slices. Using a bone algorithm and photographing using bone windows, an accurate assessment of the presence or absence of sinus disease can be made. Another advantage of using the axial plane rather than the coronal plane for screening the sinuses is the inclusion of the mastoid air cells and middle ear, which can be another source of infection in a patient with a fever of unknown origin.

When endoscopic sinus surgery is anticipated, direct coronal NCCT imaging of the sinuses is mandatory for preoperative evaluation of the extent of sinus disease, to detect anatomic variants, and for planning the surgical approach (Fig. 2-10, B). This study is done with thin sections ranging from 2 to 3 mm of thickness. Five mm slice thickness is frequently suboptimal, causing volume averaging of small structures and obscuring the fine details of ostiomeatal anatomy. Coronal imaging may be performed with the neck extended in either the prone or the supine position. An advantage of the prone position is that free fluid in the maxillary sinus layers dependently in the inferior portion of the sinus. In the supine position, fluid and mucus layer superiorly at the maxillary sinus ostium and may cause confusion with inflammatory mucosal thickening. Frequently, only the bone algorithm with its edge enhancement properties is needed for evaluating the detailed anatomy of the ostiomeatal complex. Contrast-enhanced sinus CT is usually not necessary for routine sinusitis, although when severe nasal polyposis is suspected, contrast may be useful to demonstrate the characteristic "cascading" appearance of the enhancing polyps or to characterize an associated mucocele. A soft tissue algorithm with soft tissue windows may be useful when using CECT for intracranial complications from sinus inflammatory processes. A nasal decongestant may be used to help diminish normal but asymmetric nasal mucosa congestion (normal nasal mucosal cycle) from a mucosal-based mass.

The assessment of sinus tumors requires the most detailed imaging. Both axial CECT and coronal CECT with 3 mm sections are used to precisely determine the extent of sinus tumor spread into adjacent compartments including the anterior and middle cranial fossa, orbit, and parapharyngeal space. For an optimal study, both soft tissue and bone algorithms are used, allowing differentiation of the soft tissue component as well as evaluating subtle bony destruction (Fig. 2-10, A and C). The coronal plane is best for evaluating the cribriform plate. CECT is used to maximize the enhancement characteristics of the tumor and differentiate it from adjacent soft tissue structures. In some cases it may be necessary to extend the axial sections beyond the sinuses to include the cervical lymph node chains of the neck. If this is the case, a constant infusion technique is performed, scanning from the sternal notch up to the top of the paranasal sinuses, followed by the coronal images through the paranasal sinuses. This permits the optimal concentration of intravascular contrast to be obtained in the lower neck to distinguish vessels from lymph nodes.

Facial trauma

Facial trauma CT characterizes fractures and facial soft tissue injury very well. Both axial NCCT and coronal NCCT are obtained to optimally determine the three-dimensional relationship of fracture fragments. Scanning may be performed with either 3 mm sections in both planes or, alternatively, contiguous 1.5 mm sections with coronal reformatted images when the patient cannot tolerate the coronal position because of other trauma or cervical spine instability. However, reformatted images are frequently degraded by motion artifact, and spatial resolution is usually unsatisfactory unless thin sections are used. Bone algorithm is preferred; images are photographed with bone and soft tissue windows. Soft tissue algorithm for assessing orbital and facial soft tissue injury is optimal and requires additional image reconstruction time. Three-dimensional reconstructions may help the surgeon plan facial restoration.

Temporal bone and skull base

In the past, evaluation of the skull base and temporal bones was principally performed using plain films and conventional tomography performed in the AP and lateral projections to assess bone destruction and mastoid or middle ear opacification. Tomograms are now rarely done or needed. The development of CT has completely eliminated the need for tomography in this region since the spatial and contrast resolution is superior; also, overlapping structures do not degrade the CT image. CT of the temporal bones requires imaging, preferably in two planes, using this sections. Contiguous 1 to 1.5 mm sections are frequently obtained in the axial and the direct coronal planes. In some cases if the need for reformatted images is anticipated, scanning in the axial plane with a 0.5 mm overlap may optimize reformatted coronal and sagittal images. In general intravenous contrast is not necessary for temporal bone imaging, although vascular tumors or squamous cell carcinoma invading the temporal bone may require the use of intravenous contrast plus supplemental soft tissue algorithms to best image the extracranial and intracranial soft tissue component of the lesion. However, bone algorithm with bone windows is used in all temporal bone imaging. CECT of other lesions of the skull base proper may require both axial and coronal 3 mm sections. Bone and soft tissue algorithms are necessary for assessing skull base tumor spread.

Application of magnetic resonance imaging by head and neck region

Suprahyoid neck

MRI is ideally suited for imaging the suprahyoid neck (including nasopharynx, oropharynx, oral cavity, and tongue). Surface oils that improve signal detection may be use for imaging this area. The standard head coil will permit visualization of the suprahyoid neck structures caudally down to approximately the level of the inferior margin of the mandible and floor of mouth. For imaging the oral cavity, floor of mouth, submandibular space, and cervical lymph node chains, a head coil will not suffice. Either an anterior or volume neck coil is needed to visualize the entire neck from the skull base to the thoracic inlet (from dura to pleura). Several pulse sequences and imaging planes using 5 mm thick sections are required to adequately assess the deep and superficial structures of the neck. (Implicit in this discussion of MRI technique for all areas of the head and neck is the fact that a sagittal T1WI is obtained as the initial sequence in all of our studies and is used primarily as a scout view for the proper positioning in other imaging planes, as well as for anatomic information.) A precontrast axial T1WI and often a coronal T1WI are required to optimally assess fat planes in the neck. Fat provides an excellent white background from which muscle and fascial planes, bone, sinus, and vascular structures can easily be discriminated. The coronal plane is particularly useful for visualizing the relationships of the suprahyoid neck structures to the skull base and also for delineating the anatomy of the tongue and floor of mouth. A T2WI, usually obtained in the axial plane, is required to detect structures with a long T2 (eg, water, tumors, edema, proteinaceous cysts) that appear brighter than the background muscle and fat (fat loses signal intensity with increased T2 weighting). Post-gadolinium T1WIs with fat saturation (suppression) in the axial and coronal plane are frequently helpful to discriminate the enhancing margins of a lesion or to detect perineural spread of tumor. The T2WI may also be combined with fat suppression and gadolinium usage to optimize the information obtained by this more time-consuming long TR sequence.

Lymphadenopathy

Before the widespread use of gadolinium and fat suppression techniques, MRI was often less sensitive and less specific than CT in detecting cervical lymph node metastases. However, improved MRI scanner technology, gadolinium enhancement, and fat suppression sequences have allowed considerable progress toward that goal. Also, the MRI detection of carotid artery invasion by extracapsular spread of tumor from nodes is often superior to CECT. Controversy still exists in defining the role of MRI in cervical lymph node imaging. Prospective studies of MRI in head and neck tumor and node staging are planned.

An anterior or volume neck coil using 5 mm thick sections with a small 1 to 2 mm interslice gap is necessary to encompass the entire lymph node chains throughout the neck from the skull base to the clavicles within the imaging field of view. The axial plane is frequently used, but the full craniocaudal extent of nodal disease is often better appreciated on coronal and sagittal views. Since the primary tumor is being scanned concomitantly, a choice between pulse sequences for characterizing both the lymph nodes and primary lesion must be made, yet with a minimum number of sequences (shortening the total scan time). Although most of the following sequences are quite sensitive for detecting adenopathy, few of them are specific in discriminating malignant metastatic nodes from reactive (inflammatory) adenopathy. The detection of cervical lymphadenopathy with MRI may be accomplished with (in decreasing order of sensitivity) a STIR sequence, a fat saturation T2WI, a fat saturation postgadolinium T1WI, a conventional T2WI, or a precontrast T1WI. Although STIR is the most sensitive sequence, it also yields the fewest slices, making full nodal evaluation problematic. However, a fat saturation T1WI can be obtained in a much shorter time than either a STIR or T2WI, and the fat saturation T1WI promise improved MRI specificity in metastatic node differentiation from inflammatory disease. The significance of a ring-enhancing node on MRI should be analogous to ring enhancement of a metastatic node seen with the current gold standard, CECT.

Salivary glands

MRI of the parotid gland can be accomplished with a standard head coil using 3 to 5 mm slices but at the risk of excluding a portion of the submandibular gland that lies at the edge of the usable field of view. A volume neck coil is the better coil for imaging both parotid and submandibular glands within the same field of view, especially if a malignancy is suspected and cervical lymph node metastases are sought lower in the neck. A smaller temporal mandibular joint (TMJ) coil may be necessary for evaluation of perineural tumor spread along with facial nerve into the mastoid segment of the facial nerve canal. As discussed above in assessing the suprahyoid neck (in which the salivary glands also reside) the MRI sequences that are most suited to salivary imaging include axial or coronal precontrast T1WI or both, axial and coronal fat saturation postgadolinium T1WI, axial T2WI (precontrast or postgadolinium with fat saturation), and often an axial or coronal STIR (for lymph node detection). T1WIs allow for detection of a low-intensity mass within the high-intensity background of a fatty parotid gland or for assessment of the adjacent fat planes (Curtin, 1988). The fat saturation postgadolinium T1WI is used for detecting the margins of a mass within a less fatty parotid or submandibular gland, for detection extension beyond the margins of the gland, and especially for detecting perineural tumor spread along the fifth and seventh cranial nerves (best appreciated in the coronal plane). T2WIs are useful for localizing a tumor with a high water content or one with cystic or necrotic areas (Som, 1990).

Larynx and infrahyoid neck

The larynx and infrahyoid neck require either an anterior or a volume neck coil, preferably using no thicker than 3 mm sections for the larynx. The field of view should include the area from the inferior margin of the mandible to the clavicles. Although the larynx can be examined well by both axial CECT and MRI, laryngeal MRI has a higher proportion of suboptimal studies. Laryngeal MRI is more susceptible to motion artifacts than MRI of other regions of the neck because of a combination of swallowing, breathing, and vascular pulsation from the adjacent common carotid arteries. A brief training session instructing the patient how to minimize swallowing and breathing artifacts may significantly improve results if it is done immediately before scanning. Additionally, shorter pulse sequences (ie, T1WI) are more likely to be free of swallowing artifacts. Precontrast axial and coronal T1WIs are essential to assess the paralaryngeal (paraglottic) fat planes; the coronal plane, angled parallel to the airway, is especially useful for determining transglottic tumor spread (Teresi et al, 1989). Fat saturation postgadolinium T1WIs in the axial and coronal planes are best for detecting lesion margins, invasion of adjacent cartilage, and associated malignant nodes. T2WI in the axial plane may help detect moderately increased tumor signal and improve detection of high signal cystic or necrotic neck lesions. The longer T2WI and STIR sequences are more prone to motion artifacts and are occasionally suboptimal in quality.

Thyroid and parathyroid glands

The same techniques and slice thickness as those of the larynx are used for the thyroid and parathyroid glands. The field of view may need lower centering to include the upper mediastinum and ensure complete evaluation of the inferior extent of a thyroid tumor or an ectopic parathyroid gland. Coronal and sagittal views aid understanding of the craniocaudal extent of the lesion relative to the aortic arch, great vessels, and mediastinum; this information is especially useful to the surgeon. Although MRI may detect an unsuspected thyroid or parathyroid lesion during routine neck or cervical spine imaging, MRI is less frequently used for primary evaluation of these lesions because of the cost of the study and susceptibility to motion artifacts. The normal thyroid gland will enhance mildly on both gadolinium-enhanced MRI and CECT. A solid mass in the thyroid or parathyroid is usually low intensity on T1WI and high signal on T2WI, and it may enhance with gadolinium. Cystic lesions are bright on T2WI.

Paranasal sinuses

Sinus MRI is primarily indicated for evaluating sinus tumors (and occasionally inflammatory disease such as a mucocele) and may be accomplished with a standard head coil, using 3 to 5 mm slices. The principle value of MRI over CT for sinus tumors is the ability of MRI to distinguish between tumor and obstructed sinus secretions and to predict the true extent of the tumor. A precontrast sagittal, axial, or coronal T1WI will provide a good demonstration of the sinuses, nasal cavity, cribriform plate, masticator and parapharyngeal spaces, and orbits. T1WI may differentiate hydrated from viscous sinus secretions; secretions are low signal when hydrated or fluidlike and are intermediate to high signal when viscous and desiccated. Coronal T2WIs or axial T2WIs (either pregadolinium, or postgadolinium with fat saturation) are useful for detecting inflammatory sinus secretions, which are high signal when hydrated or fluid and are low signal when viscous and desiccated. However, tumors tend to be intermediate in signal on T2WI. Since fat is not present to any significant degree in the paranasal sinuses, a STIR sequence frequently adds little over a T2WI and is unnecessary. Sagittal, coronal, or axial fat saturation. T1WI is recommended to better define the sinus tumor margins when the tumor extends directly or by perineural spread beyond the sinus into the anterior cranial fossa, orbit, parapharyngeal space, or pterygopalatine fossa. The sagittal and coronal planes are very helpful for evaluating cribriform plate extension; the coronal and axial planes are best for orbital, cavernous sinus, pterygopalatine fossa, and parapharyngeal space spread.

Temporal bone

MRI has significantly improved the detection of internal auditory canal (IAC), facial nerve canal, and jugular foramen lesions. Gadolinium-enhanced MRI has eliminated the need for air-contrast CT cisternography to detect a small intracanalicular acoustic schwannoma. MRI is useful, in combination with CT, for assessing expansile or destructive lesions of the temporal bone and external auditory canal. A standard head coil is adequate for most temporal bone lesions, but a smaller 5 to 10 cm TMJ coil may be needed for evaluating the mastoid and parotid segments of the facial nerve. The small size of the temporal bone structures and their respective lesions requires high spatial resolution images, which may be accomplished by using thinner slices of 0.5 to 3 mm (preferably without an interslice gap), smaller surface coils (higher signal-to-noise ratio), volume acquisition, or T1WI (higher signal-to-noise ratio). Precontrast T1WI in the sagittal and axial planes is useful for defining anatomy and for detection of high-signal lesions such as fat, methemoglobin, and viscous or proteinaceous cysts. Postgadolinium T1WIs (without or with fat saturation) in the axial and coronal planes are essential for detecting small enhancing lesions and determining the extent of larger lesions. In fact, for routine evaluation of a suspected acoustic schwannoma only a postgadolinium axial and coronal T1WI study may be required. T2WIs are frequently unnecessary for IAC tumors but may be helpful when brainstem ischemic or demyelinating disease, meningioma, blood products, proteinaceous secretions, or a large destructive tumor is suspected or is being further evaluated after a preliminary temporal bone CT. A facial nerve lesion in the mastoid segment of the facial nerve canal is best evaluated for proximal and distal extension using a TMJ coil with sagittal and coronal pregadolinium and postgadolinium T1WIs.

Skull base

MRI may be indicated for primary lesions of the skull base or for intracranial and extracranial lesions that secondarily involve the skull base. A standard head coil using 3 to 5 mm slices images this region well. Pregadolinium sagittal, axial, and/or coronal T1WI allows for assessment of the fat planes of the suprahyoid neck and detection of high-signal-intensity blood breakdown products, proteinaceous fluids, or fat within the lesion. Postgadolinium axial and coronal (occasionally sagittal) fat saturation T1WIs are excellent for determining the extent of an enhancing lesion above, below, and within the skull base. T2WI in the axial or coronal plane may be helpful for detecting a high-signal lesion. STIR images usually give similar information to T2WIs in the skull base and may not be necessary.

Ultrasound applications in the head and neck

High-resolution ultrasound evaluation of the suprahyoid neck, salivary glands, and infrahyoid neck is limited to the more superficial neck structures because of the impediment to sound transmission caused by the highly reflective facial bones, mandible, mastoid tip, and air within the oral cavity and pharynx. The ultrasound technique, using a high-frequency, 5 to 10 MHz probe and multiple imaging planes, is similar for all these regions. A small superficial lesion is best seen with a high-frequency probe, whereas a larger and deeper lesion may require a lower frequency probe. Color flow Doppler technique may help differentiate vascular structures from a cystic or solid lesion. Head and neck ultrasound is performed less frequently in North America than in Europe, perhaps because of the common availability of CT in North America and the perception of the greater accuracy of CT. Head and neck ultrasound has no role as a staging modality for skull base and sinus neoplasms.

Suprahyoid neck

Ultrasound may be used for the assessment of tumors of the floor of the mouth, anterior two thirds of the tongue, malignant adenopathy, and invasion of the carotid artery and jugular vein. The deep structures centered around the parapharyngeal space are inadequately assessed by this technique and are better investigated by CT and MRI. Ultrasound can assess tumor extent in the floor of the mouth and tongue but has limitations: The mandible obscures the pterygoid muscles; pharyngeal air hides the posterior pharyngeal wall and epiglottis (Fruehwald, 1988). Ultrasound excels in differentiating cystic from solid masses; a cyst has few internal echoes, a strongly echogenic back wall, and strong through-transmission of sound, whereas a solid mass has many internal echoes and no additional through-transmission.

Metastatic lymphadenopathy

Ultrasound is very sensitive for detecting metastatic involvement of the lower two thirds of the internal jugular, spinal accessory, submental, and submandibular nodes. Its accuracy may exceed CT for detecting enlarged lymph nodes, but ultrasound does not reliably differentiate large reactive nodes from metastatic nodes (Hagek et al, 1986). The upper one third of the internal jugular, retropharyngeal, and tracheoesophageal groove nodes are poorly evaluated because of obscuration by bone or airway structures. Ultrasound may be the best method (possibly better than MRI or CT) for determining the presence of tumor invasion of the common or internal carotid artery and internal jugular vein by adjacent primary tumor or extracapsular spread from metastatic nodes. Invasion of the carotid artery is characterized by loss of the echogenic fascial plane between the vessel wall and the tumor.

Salivary glands

Ultrasound has indications for both inflammatory and neoplastic disease. It may detect salivary duct stones as small as 2 mm. An obstructed dilated duct may appear as a tubular cystic structure. An abscess may be detected and drained under ultrasound guidance during the acute stage of sialadenitis, a time during which sialography is contraindicated. A mass in the superficial parotid gland is easily assessed by ultrasound, but the deep lobe of the parotid gland is obscured by the mandible, styloid process, and mastoid tip. Ultrasound is also very sensitive for a mass in the submandibular gland. Although ultrasound can determine the sharpness of margins of the lesion (well-defined margins usually indicate a benign mass and infiltrative margins suggest malignancy), an aggressive neoplasm or inflammatory process extending beyond the margins of the gland is better evaluated by MRI or CECT, since the deep landmarks are more easily demonstrated with MRI or CECT.

Infrahyoid neck

Ultrasound using a high-frequency transducer is usually the first imaging modality for evaluating superficially located thyroid gland and parathyroid gland masses, since it is relatively inexpensive and easily performed. In the infrahyoid neck, ultrasound is not used for the larynx, retropharyngeal space, or thoracic inlet because overlying cartilage, airway structures, sternum, and clavicles cause acoustic shadows that may obscure lesions. The right, left, and pyramidal lobes may be evaluated by scanning in the axial, sagittal, and oblique planes. A thyroid mass and highly echogenic calcification are easily assessed. A parathyroid adenoma is readily evaluated if its location is cranial to the sternum. Ultrasound-guided fine needle biopsy of a thyroid or parathyroid mass is possible at the time of scanning. Large cystic and solid masses of the infrahyoid neck may be differentiated by ultrasound. Lymphoma of the neck may appear weakly echogenic, sometimes simulating a cyst.

Principles of Image Interpretation

Strategy for image interpretation and differential diagnosis

This section is included to aid the beginning surgeon or oncologist in developing a basic strategy for image interpretation. Normally, the radiologist chooses and supervises the appropriate imaging study, evaluates and interprets the images, and communicates its significance to the referring physician. However, frequent dialogue between the referring physician and the radiologist will significantly improve interpretation of the imaging study. Accurately interpreting an imaging study of the head and neck requires a systematic method of observation, a knowledge of the complex anatomy, spaces, and pathophysiology, and an understanding of imaging principles. The differential diagnosis of lesions of the head and neck requires a systematic approach as well. One such diagnostic imaging process is summarized below:

1. Obtain clinical data: age, sex, history, physical findings.

2. Survey the films for all abnormalities and summarize these findings.

3. Compartmentalize the lesion.

4. Interpret the chronicity and aggressiveness of the observations: acute or chronic, nonaggressive or aggressive, benign or malignant.

5. Develop a differential diagnosis. Use pathologic categories: congenital, inflammatory, tumor, trauma, vascular. Use clinical and radiographic information to narrow the choices and arrive at the most appropriate diagnosis.

By using such a strategy it is unlikely that important findings will be missed, since all the images have been evaluated. This may be done by looking at all the anatomic spaces on each slice and proceeding sequentially through all the slices; alternatively each anatomic space can be evaluated on serial slices, followed by the next anatomic space, and so on. Characterizing a lesion requires specific observations: location, anatomic space of the epicenter, size, definition of margins, extent of spread in each direction, invasion of adjacent compartments, involvement of neurovascular structures, enhancement pattern, cysts, calcification, density, signal intensity, echogenicity, hemorrhage, and lymphadenopathy. Next, summarizing the findings helps to tie them together into a logical pattern. Compartmentalizing a lesion is the last step in the observational process and requires placing the epicenter or site of origin of the lesion in a specific anatomic space, although some lesions may be multicompartmental. The origin of a lesion is limited by the types of tissue that reside in each specific space. An example of such a summary would be, a "A 35-year-old male has a cystic, nonenhancing mass in the sublingual space". A frequent cause of misdiagnosis is the failure to make all the observations first; interpretation and differential diagnosis of the lesion are the final steps.

The interpretation of the significance of a lesion uses both its radiologic and clinical features; for example, inflammatory (edema; abscess cavity; fever), nonaggressive (remodeling of bone; slow progression of symptoms), aggressive (destruction of bone; rapid progression), benign neoplastic (well-defined margins; displacement of adjacent structures; nonpainful), malignant (poorly defined margins; invasion and destruction of adjacent structures; pain and neuropathies), or cystic (low density center with a thin rim of enhancement; fluctuant). The differential diagnosis is narrowed by further refining the interpretation, "A 35-year-old male has an asymptomatic cystic, nonenhancing mass in the sublingual space that appears chronic and nonaggressive". With knowledge of the relevant clinical findings, the proper differential diagnosis, which is specific for each anatomic space, can then be constructed and limited to one (or at least a few) possible pathologic causes. In this example, a ranula would be the most likely consideration.

Imaging Anatomy, Site-Specific Lesions, and Pseudotumors of Head and Neck

Spaces of suprahyoid neck

The traditional approach to radiographic interpretation of the head and neck region has been to follow a surgical compartmental approach: nasopharynx, oropharynx, oral cavity, pharynx, and larynx. The nasopharynx extends vertically from the skull base to the soft palate; the oropharynx encompasses the area from the soft palate/hard palate to the hyoid bone. The oral cavity is located anterior to the oropharynx. Below the hyoid bone reside the larynx anteriorly and the hypopharynx more posteriorly. With the advent of cross-sectional imaging in radiology, first with CT and later with MRI, the radiologic interpretative approach changed from a pattern based on surgical compartmental anatomy to one dependent on fascial spaces. However, a combination of the two interpretative approaches, for example, parapharyngeal space at the nasopharyngeal level (with the compartmental designation serving as a modifier) may be more helpful in precisely defining a lesion location.

The head and neck region, the anatomic territory that extends from the skull base to the thoracic inlet, is best and most conveniently divided into the suprahyoid and infrahyoid neck with the hyoid bone serving as the divisional point (Harnsberger, 1990). Figs. 2-11 to 2-13 demonstrate normal cross-sectional CT and MRI anatomy of the suprahyoid neck. The suprahyoid neck may be divided into a series of fascial spaces based on the division and layers of the superficial and deep cervical fascia. The superficial cervical fascia surrounds the face and neck, providing a fatty layer on which the skin is able to slide. The underlying deep cervical fascia is separated into three distinct layers: superficial (investing) layer, middle (visceral) layer, and deep (prevertebral) layer. (Space limitations and the complexity of the fascial spaces do not allow for a detailed description or explanation of the deep cervical fascia. Although not usually visualized on CT or MRI, these fascial layers divide the suprahyoid neck into distinct anatomic and surgically defined spaces:

1. Parapharyngeal space (PPS).
2. Pharyngeal mucosal space (PMS).
3. Parotid space (PS).
4. Carotid space (CS).
5. Masticator space (MS).
6. Retropharyngeal space (RPS).
7. Prevertebral space (PVS).
8. Oral cavity (OC).
9. Sublingual space (SLS).
10. Submandibular space (SMS).

Inflammatory and neoplastic disease, the major pathophysiologic processes of the head and neck territory, tend to grow and spread in the boundaries and confines of these fascial spaces (Batsakis, 1979). Nevertheless, this approach based on the use of fascial anatomy allows delineation of specific anatomic spaces, with identification of disease-specific lesions for each of these spaces. As a consequence, a more accurate differential diagnosis and resulting final diagnosis are attained.

Parapharyngeal space

The crucial anatomic center point to understanding suprahyoid anatomy is the parapharyngeal space (PPS); this fibrofatty fascial space extends from the skull base to the level of the hyoid bone and serves as a marker space around which the remaining fascial spaces are arranged. It contains fat, portions of the third division of cranial nerve V, the internal maxillary artery, the ascending pharyngeal artery, and the pterygoid venous plexus. In the axial plane, this space has a triangular configuration and demonstrates bilateral symmetry. In the coronal plane the PPS has an hourglass shape, thicker at the skull base and hyoid level and thinner in the midsuprahyoid neck.

The PPS is clearly defined and located on both the axial and coronal planes with both CT and MRI (Silver et al, 1983a). With the former technique, the predominant fat content serves as a low-density marker between the medial muscles of deglutition found in the pharyngeal mucosal space and the muscles of mastication, located more laterally. With MRI the PPS has a bright signal intensity on T1WI (the scanning sequence that best highlights fat and muscle tissue differences); with longer TR times and more T2 weighting this fatty space becomes less intense in signal.

Because this space is the epicenter around which the other fascial spaces are arranged, it serves as a potential marker or pivotal space. By noting the position and direction of displacement of the PPS, one can determine the epicenter and fascial space origin of a suprahyoid lesion. Because the PPS contains few structures from which lesions arise, most lesions found in this space have spread here secondarily from an adjacent fascial space (Silver et al, 1983b).

The fascial spaces that are centered about the parapharyngeal space include the pharyngeal mucosal space (PMS), the carotid space (CS), the parotid space (PS, the masticator space (MS), the retropharyngeal space (RPS), and the prevertebral space (PVS). Each space has well-defined anatomic boundaries, contains major structures of importance, and gives rise to pathologic processes that are site selective for that space. For consideration of pathologic processes in each fascial space, it is convenient to use the following outline: congenital, inflammatory, neoplastic (benign and malignant), pseudolesions, and miscellaneous. This approach, using these few disease categories, elicits most of the major lesions to be found in the head and neck and is used in the following discussion of suprahyoid and infrahyoid lesions.

Pharyngeal mucosal space

The pharyngeal mucosal space (PMS) lies medial to the parapharyngeal space and anterior to the prevertebral space. It encompasses the mucosal surfaces of the inner boundaries of the nasopharynx and oropharynx and includes lymphoid (adenoidal) tissue, minor salivary glands, portions of the constrictor muscles, and muscles of deglutition; the medial portion of the eustachian tube passes through it. These structures lie medial to or on the airway side of the buccopharyngeal fascia; this fascial structure may be seen on MRI as a band of low signal intensity. On CECT or gadolinium-enhanced MRI studies, the overlying pharyngeal mucosa enhances.

The PMS extends from the skull base to the lower margin of the cricoid cartilage, extending into the upper portion of the infrahyoid neck. It encompasses the nasopharynx, oropharynx, and portions of the hypopharynx. Lesions in this space displace the PPS laterally.

In general, caution is used when interpreting the mucosal surfaces of the pharynx, oral cavity, and larynx. The normal mucosa is high signal on T2WI and STIR and enhances on postgadolinium T1WI (and with CECT); it may be confused with a superficial mucosal-based malignancy. Likewise, a small superficial mucosal-based tumor may be indistinguishable from the adjacent normal mucosa. The direct clinical examination of the mucosal surfaces is still superior to cross-sectional CT or MR imaging in detecting superficial tumor; however, both CT and MRI excel in detecting submucosal tumor and deep invasion. Mucosal irregularity and slight asymmetry are common, especially near the fossa of Rosenmüller (the lateral pharyngeal recesses of the nasopharynx), and care is taken in ascribing abnormality. Repeat studies with a modified Valsalva maneuver to distent the airway may be helpful. Involvement of the submucosal muscles and adjacent deep structures, such as the PPS, will confirm the presence of a suspected neoplastic mucosal lesion. Lymphoid (adenoidal) tissue is often hypertrophic and prominent, especially in children and young adolescents, and may encroach on the airway. On CT lymphoid tissue is isodense to muscle; with MRI it has a similar intensity to muscle on T1WI but has a bright signal on T2WI. It lies superficial to the buccopharyngeal fascia and is relatively homogeneous.

Inflammatory lesions of the PPS include pharyngitis, abscess (especially tonsillar abscess), and postinflammatory retention cysts (Fig. 2-14). Benign mixed salivary tumor is the most common benign neoplasm.

A Thornwaldt cyst is a common congenital lesion of the midline posterior nasopharyngeal mucosa and only rarely becomes secondarily infected. It is very bright on long TR sequences on MRI.

Squamous cell carcinoma (SCCA), the most common tumor of the upper aerodigestive tract, originates from the PMS; the majority of lesions arise from squamous epithelium in the region of the lateral pharyngeal recess (Figs. 2-15 and 2-16). Small submucosal lesions may be missed on the clinical examination but may be detected with cross-sectional imaging. Involvement of the adjacent musculo-fascial spaces confirms the presence of a mucosal lesion. It may become large and lead to extensive invasion and destruction of the neighboring fascial spaces or extend medially to involve the PPS. With CT, SCCA demonstrates inhomogeneous lesion enhancement, commonly with extension into adjacent spaces. With MRI it is of intermediate intensity on T1WI and high intensity on T2WI and enhances after gadolinium infusion (Rafto and Gefter, 1988). It may cause serous otitis media and mastoid cell opacification because of dysfunction of the eustachian tube from invasion or mass effect. Extension superior to the skull base is common; the foramen lacerum, foramen ovale, carotid canal, jugular foramen, and clivus may be affected. Perineural tumor spread along cranial motor nerve V is common and its presence should be diligently sought, especially if these is unilateral atrophy of the muscles of mastication innervated by the mandibular division of the fifth cranial nerve. Inferiorly, nasopharyngeal SCCA may extend to involve the soft palate, tonsillar pillars, and nasal cavity. Asymptomatic cervical adenopathy with involvement of the superior internal jugular and spinal accessory lymph node chains is the presenting mode in over 50% of patients. Lymph nodes are usually considered positive when over 1.5 cm in diameter; an enhancing lymph node rim with necrotic low-density center on CECT indicates neoplastic involvement. On MRI lymph nodes have bright signal intensity on T2WI; on T1WI postgadolinium administration, lymph node enhancement may be seen.

The extensive lymphoid tissue in this space is a source for development of non-Hodgkin's lymphoma (Fig. 2-17). Both squamous cell carcinoma and lymphoma may have extensive lymph node involvement; the nodes associated with squamous cell carcinoma commonly have necrotic centers whereas those of lymphoma are usually noncavitary and homogeneous. Malignant minor salivary gland tumors also occur in this space. The above three malignant lesions are difficult to separate radiologically.

Parotid space

The parotid space (PS), the home of the parotid gland and the extracranial portion of the facial nerve, lies lateral to both the PPS and the carotid space (CS) and posterior to the masticator space. It extends superiorly from the level of the midsquamous temporal bone to the angle of the mandible inferiorly. It contains the parotid gland, multiple lymph nodes (within and outside the parotid gland parenchyma), the facial nerve, the retromandibular vein, and branches of the external carotid artery. The parotid gland overlies the posterior portion of the masseter muscle; its deep retromandibular portion lies posterior to the mandible and lateral to the PPS and the CS. The posterior belly of the digastric muscle separates the PS from the CS.

Because of its high fat content, especially in the adult, the parotid gland parenchyma is frequently low density on CT but may vary and approach muscle density. It is high intensity on T1WI (slightly less than subcutaneous fat) and has decreased intensity on T2WI but often retains its bright T2 signal intensity relative to muscle. The retromandibular vein lies just posterior to the lateral margin of the mandibular ramus. The diagonal course of the facial nerve, paralleling a line drawn from the stylomastoid foramen to a point just lateral to the retromandibular vein, divides the parotid gland into superficial and deep portions. Although this is not a true anatomic division, it is useful for surgical planning. The facial nerve may be seen on some MRI studies. Its course must be considered and determined when removal of deep parotid lobe lesions is planned.

Lesions in the parotid space are usually surrounded by parotid gland tissue and are better defined with MRI than CT (Som et al, 1988). With NCCT, lesions are usually isodense to the normal gland or increased density; with MRI, lesions are muscle intensity on T1WI and usually hyperintense to normal parotid gland on T2WI (Schwartz et al, 1989). When small, parotid lesions tend to be homogeneous; with increase in lesion size areas of hemorrhage, necrosis, and calcification may develop. If the lesion extends or originates from the deep portion of the gland, it displaces the PPS medially and occasionally anteriorly. Large lesions in the parotid gland proper will cause widening of the stylomandibular notch, the space between the posterior border of the mandible and the styloid process; comparison to the contralateral side will make subtle widening of this space evident (Harnsberger, 1987). Deep lobe lesions, if large, may displace the carotid artery posteriorly. Benign lesions as a general rule are usually well defined; malignant lesions have indistinct margins and may invade adjacent structures. Lesions in the PPS or CS may extend laterally into the parotid space, mimicking a parotid lesion clinically.

Congenital lesions of the PS include hemangioma, lymphangioma, and first and second branchial cleft cyst, the latter presenting as a cystic-appearing lesion with smooth walls (Harnsberger et al, 1984). Enhancing margins of the cyst indicate it is secondarily infected. Inflammatory disease may present as diffuse swelling or as a localized abscess; infection of the adjacent skull base is best demonstrated with CT. Infection may occur secondary to calculus disease.

Calculi are also best demonstrated by sialography as intraluminal filling defects or by CT because of its tenfold higher sensitivity over plain films for detecting calcified calculi. Sialadenitis, autoimmune disease, and strictures are still best evaluated by conventional sialography, which best demonstrates ductal anatomy. Chronic sialadenitis will cause the affected parotid gland CT density to approach that of muscle; this appears as lower parotid gland signal on T1WI and brighter signal on T2WI than that of the contralateral parotid gland. Autoimmune diseases such as Sjögren's syndrome demonstrate bilateral parotid enlargement. Bilateral gland enlargement by benign lymphoepithelial cysts is seen in acquired immunodeficiency syndrome.

Benign pleomorphic adenoma (benign mixed tumor), the most common benign neoplasm of the parotid gland, is well defined and demonstrates variable degrees of contrast enhancement (Fig. 2-18). It is usually ovoid in configuration and may involve either the superficial or deep lobe of the parotid gland or less commonly both. Rarely, benign mixed tumors may arise from salivary rest tissue medial to the deep lobe and have a fat border on both their medial and lateral margins. Calcification is occasionally seen within the tumor. The tumor is hypointense on T1WI and hyperintense on T2WI. Both the superficial and deep lobes of the parotid gland may be involved, leading to a dumbbell configuration of the mass and associated widening of the stylomandibular notch.

Malignant lesions include mucoepidermoid carcinoma, adenoid cystic carcinoma, acinic cell carcinoma, and malignant mixed tumor (Fig. 2-19). High-grade malignant lesions have infiltrative borders. MRI is superior to CT for showing lesion margins and extent. Because of the abundant lymph node tissue within the parotid gland, lymph node involvement may be seen with non-Hodgkin's lymphoma, and metastatic involvement may be seen with squamous cell carcinoma and malignant melanoma. Basal cell carcinoma of the adjacent ear and cheek may metastasize to the parotid lymph nodes.

Carotid space

The carotid space (CS), the space of vessels, nerves, and lymph nodes, lies posterior to the PPS, lateral to the retropharyngeal space, anterolateral to the prevertebral spaces, and medial to the parotid space and styloid process. The posterior belly of the digastric muscle separates the CS from the parotid space. The CS is formed from portions of all three layers of the deep cervical fascia. The CS extends from the temporal bone and base of the skull superiorly to the mediastinum inferiorly (Fruin et al, 1991). It contains the common carotid artery, its major divisions, the internal and external carotid artery, the jugular vein, cranial nerves IX to XII, sympathetic plexus, and lymph nodes. The jugular vein lies lateral and posterior to the carotid artery; the vagus nerve lies in the posterior groove between the two vessels. Cranial nerves IX, XI, and XII migrate to the anteromedial portion of the CS lower in the neck. Lesions of the CS displace the PPS anteriorly and, if large, may remodel the styloid process, displacing it anterolaterally.

Infection of the CS occurs most commonly secondary to spread of infection from adjacent fascial spaces. Reactive inflammatory lymph nodes, which are characteristically homogeneous and less than 1 cm in size, may be seen in any portion along the carotid space and be seen with such varied infectious processes as sinusitis, infectious mononucleosis, and tuberculosis. Suppurative lymph nodes may have low-density centers and may not be distinguished from malignant lymph nodes; clusters or groups of lymph nodes lumped into large masses are not uncommon. Cellulitis causes a loss of normal soft tissue planes; abscesses are characterized by focal fluid collections with enhancing margins.

On CECT, normal blood vessels demonstrate contrast enhancement; with dynamic CECT a wash-in phase (early visualization of contrast) may be demonstrated within normal vessels and within the feeding or draining vessels of a mass, which further indicates the vascular etiology of a lesion. On MRI, blood vessels appear as circular or linear areas of flow void, because of flow of fast-moving blood. Turbulent or slow flow may lead to areas of mixed signal intensity. Vessel ectasia, dissection, aneurysm, pseudoaneurysm, and thrombosis may be diagnosed readily with either cross-sectional imaging technique. Assessment of adjacent sectional images will demonstrate a tubular configuration to the lesion. An ectatic carotid artery or an asymmetrically enlarged jugular vein may present clinically as a lateral neck mass but is readily discernible radiologically. The right jugular vein is usually larger than the left and at times may be several times larger than the left, reflecting its greater venous drainage from the brain. Thrombosis, either arterial or venous in nature, appears as a linear or tubular intraluminal filling defect with or without associated mass effect on CECT, since the vasa vasorum of the vessel wall enhances in a ringlike fashion (Albertyn and Alcock, 1987). Subacute thrombosis or vessel wall hemorrhage secondary to dissection or trauma will yield a bright signal on T1WI because of the T1 shortening effects of paramagnetic methemoglobin, a blood breakdown product.

Most mass lesions originating in the CS are of neoplastic origin. Most neurogenic tumors are schwannomas (Fig. 2-20). A schwannoma arises from Schwann cells that form the covering of nerves and most commonly originate from the vagus nerve and less commonly from the sympathetic plexus. A neurofibroma contains mixed neural and Schwann cell elements and arises from the peripheral nerves. Neurofibromas are rare and when present usually are multiple and part of neurofibromatosis, type two. Both tumors are well defined with CT with either tumor having a low-density component because of fat infiltration. On CECT neurofibromas demonstrate variable degrees of enhancement; on MRI they have a similar appearance. On both CT and MRI most neural tumors have similar density and intensity characteristics to salivary gland tumors and often may not be differentiated. Neural tumors may have dense enhancement and simulate paragangliomas. On angiography, neuromas characteristically are hypovascular in contrast to paragangliomas, which are hypervascular. Neurogenic lesions arise posterior to the internal carotid artery and thus cause anterior displacement of the latter.

Paragangliomas, lesions developing from neural crest cell derivatives, may arise in the jugular foramen (glomus jugulare), along the course of the vagus nerve (glomus vagale), or at the carotid bifurcation (carotid body tumor) (Figs. 2-21 and 2-22). Paragangliomas are multiple in up to 5% of patients. The lesion is ovoid with smooth margins. Because of its marked hypervascularity, it is densely enhancing on CT; angiography reveals a very vascular tumor with dense capillary staining. At the skull base, it erodes the jugular spine and causes permeative bone erosion of the jugular foramen in contradistinction to a schwannoma, which causes a smooth expansion with intact cortical margins. A jugular foramen paraganglioma may extend into the temporal bone or infiltrate through the skull base, presenting as a posterior fossa mass. In the midneck a paraganglioma causes characteristic displacement of the carotid artery anteriorly and the jugular vein posterolaterally. At the carotid bifurcation a lesion causes splaying of the internal and external carotid arteries. On MRI it is recognized by its hypervascularity characterized by multiple areas of signal void and flow-related enhancement from enlarged feeding and draining vessels (Olsen et al, 1987).

Lymph node involvement in the CS may be seen most commonly with metastases from squamous cell carcinoma or as part of a general involvement by non-Hodgkin's lymphoma. Lymph node involvement may be the initial manifestation of squamous cell carcinoma. Extracapsuar spread of disease may occur; complete encasement of the carotid artery (carotid fixation) may indicate inoperability. However, the carotid artery may be sacrificed at operation if the patient successfully tolerates a carotid balloon occlusion test. Metastatic lymph nodes are characteristically inhomogeneous, especially after contrast enhancement.

Masticator space

The masticator space (MS), the space of the muscles of mastication and the posterior portion of the mandibular ramus, lies anterior to the parotid space and is separated from the muscles of deglutition in the pharyngeal mucosal space by the PPS (Curtin, 1987). It contains the masseter, temporalis, and medial and lateral pterygoid muscles, motor branch of the third division of cranial nerve V, inferior alveolar nerve (sensory second division of cranial nerve V), internal maxillary artery and its branches, pterygoid venous plexus, and the ramus and posterior body of the mandible. It includes the temporal fossa (suprazygomatic MS) superiorly, encompasses the zygomatic arch, and extends inferiorly to include the infratemporal fossa and structures on both sides of the mandible. A mass in the MS displaces the PPS posteriorly and medially.

Infection (cellulitis, abscess, osteomyelitis) may involve the mandible or the muscles of mastication; extension through the skull base or involvement of the suprazygomatic masticator space may occur and should be ruled out (Fig. 2-23). Abscesses commonly arise from an odontogenic focus or from poor dentition. The bone changes of osteomyelitis are best demonstrated with CT.

Benign lesions include hemangioma and lymphangioma (Fig. 2-24). Nasopharyngeal angiofibroma, a tumor of young adolescent males, arises in the pterygopalatine fossa and commonly extends into the masticator space (Fig. 2-25). Primary bone neoplasms may arise from the mandible; chondrosarcoma and osteosarcoma present with chondroid calcification and new bone formation, respectively. The bone lesion is characteristically muscle intense on

T1WI and hyperintense with T2WI; postgadolinium T1WI demonstrates extensive enhancement. An infiltrating mass with mandibular destruction may be indistinguishable from metastatic disease. Non-Hodgkin's lymphoma may present with bone involvement, with a soft tissue mass, or as a lymph node mass. Squamous cell carcinoma presents as an infiltrating mass and occurs secondary to extension from a neighboring fascial space (Fig. 2-26). Perineural spread of tumor is common in the MS; the fifth nerve should be assessed for thickening and enhancement along its course as it passes from the brainstem to the cavernous sinus, through the foramen ovale, and eventually below the skull base as it passes from the brainstem to the cavernous sinus, through the foramen ovale, and eventually below the skull base as it passes inferiorly to innervate the individual muscles of mastication (Fig. 2-27). The foramen ovale may be increased in size and tumor may be found within the cavernous sinus. Tumor involvement of the inferior alveolar nerve may cause erosion, irregular enlargement, or destruction of the inferior alveolar canal of the mandible (Ator et al, 1990).

Pseudotumors may mislead the unwary. An accessory parotid gland overlying the anterior border of the masseter muscle or asymmetric enlargement of the parotid gland may simulate tumor. In both situations the parotid gland variant retains MRI signal characteristics identical to the normal parotid gland. Hypertrophy of the masseter muscle may occur secondary to teeth grinding, mimic a mass lesion, or be bilateral. If the fifth cranial nerve is injured or invaded by tumor resulting in denervation of the muscles, ipsilateral atrophy of the muscles of mastication and fat infiltration ensue; the normal contralateral muscle group may be incorrectly considered enlarged and misinterpreted as tumor involvement.

Retropharyngeal space

The retropharyngeal space (RPS), a potential space between the middle and deep layers of the deep cervical fascia, lies posterior to the pharyngeal mucosal space, anterior to the prevertebral space, and medial to the carotid space. It extends from the skull base superiorly to the T3 level of the upper mediastinum inferiorly (Davis et al, 1990). Its importance derives from its potential to serve as a passageway for infection to spread among the head, neck, and mediastinum. Its contents are fat and lymph nodes, the principle nodes being the nodes of Rouvier (the classical lateral retropharyngeal nodes) and the medial retropharyngeal nodes. This nodal group is commonly involved in children, and up to 1 cm in size is considered normal; but a node over 5 mm is viewed with suspicion in an adult.

A mass lesion in the RPS will displace the PPS anterolaterally. Infection, either pharyngitis or tonsillitis, may give RPS lymph node involvement. Diffuse cellulitis or abscess may occur, the latter usually secondary to infection of the pharyngeal mucosal space or prevertebral space. Infection or mass in the lateral alar portion of the infrahyoid RPS may have a "bow-tie" appearance on axial imaging (Fig. 2-28). Squamous cell carcinoma may invade the RPS directly or may present solely with lymph node involvement; the pattern is one of inhomogeneous enhancement, commonly with necrotic low-density centers. With non-Hodgkin's lymphoma, lymph nodes are homogeneous and multiple, commonly involving more than one of the fascial spaces.

Prevertebral space

The prevertebral space (PVS), also defined by the deep layers of the deep cervical fascia, is divided into anterior and posterior compartments. The former encompasses the anterior cervical vertebral bodies, extending from one transverse process to another; the posterior compartment surrounds the posterior spinal elements. The PVS contains the prevertebral, scalene, and paraspinal muscles, the brachial plexus, the phrenic nerve, the vertebral body, and the vertebral artery and vein. Similar to the anatomy of the RPS, the PVS extends from the skull base superiorly to the mediastinum inferiorly.

The PVS lies directly posterior to the RPS and posteromedial to the carotid space. An anterior compartment PVS mass causes thickening of the prevertebral muscles and displaces the prevertebral muscles and the PPS anteriorly. A mass in the posterior compartment of the PVS displaces the paraspinous musculature and the posterior cervical space fat laterally, away from the posterior elements of the spine. Infection and malignant disease, the common disease processes of the PVS, usually involve the vertebral body.

Infection, including tuberculosis and bacterial pathogens, characteristically involves the vertebral body as well as the adjacent intervertebral disk space. Benign processes, although much less common, include chondroma, osteochondroma, aneurysmal bone cyst, giant cell tumor, and plexiform neurofibroma. Malignant disease processes include metastatic disease, leukemia, lymphoma, and direct invasion by squamous cell carcinoma. Vertebral body destruction with associated soft tissue mass may be seen; the spinal canal and dural sac may be compromised.

Oral cavity

The oral cavity, the space of the anterior two thirds of the tongue and the floor of the mouth, lies below the hard palate, medial to the superior and inferior alveolar ridge and teeth, anterior to the oropharynx, and superior to the mylohyoid muscle, the muscle stretching between the inferomedial margins of the mandible. The oral cavity is separated from the oropharynx posteriorly by the circumvallate papillae, tonsillar pillars, and soft palate. The oral cavity includes the oral tongue (the anterior two thirds of the tongue), whereas the oropharynx contains the base of the tongue (the posterior one third of the tongue), the soft palate, the tonsils, and the posterior pharyngeal wall.

The oral cavity can be divided into two major spaces, the sublingual space (SLS) and the submandibular space (SMS). The mylohyoid muscle, which constitutes the floor of the mouth, is the boundary marker between these two spaces. Other areas of the oral cavity include the floor of the mouth, oral tongue, hard palate, buccal mucosa, upper alveolar ridge, lower alveolar ridge, retromolar trigone, and lip; assessment of these regions is also needed.

Most masses in the oral cavity and oropharynx are amenable to direct clinical assessment; mucosal lesions are readily visualized. The purpose of sectional imaging is to evaluate the degree of submucosal involvement. The majority of neoplasms of the oral cavity are readily detected on clinical examination; squamous cell carcinoma accounts for approximately 90% of oral cavity and oropharyngeal neoplasms (Figs. 2-29, 2-30, and 2-31). Cross-sectional imaging has an important role to play in estimation of tumor size, identification of tumor invasion, and assessment of nodal metastasis.

Congenital lesions include lingual thyroid and cystic lesions (epidermoid, dermoid, and teratoid cysts). Most infections of the oral cavity are dental in origin. Dental infections anterior to the second molar tend to involve the sublingual space and lie superior to the mylohyoid muscle; infections of the posterior molars usually involve the submandibular space and lie inferior to the mylohyoid muscle. Knowledge of which space is involved is crucial to plan adequate surgical drainage.

Sublingual space

The sublingual space (SLS) is located in the anterior tongue, lateral to the intrinsic muscles of the tongue (genioglossus and geniohyoid) and superior and medial to the mylohyoid muscle. Anteriorly, it extends to the genu of the mandible, and posteriorly, it connects freely with the submandibular space at the posterior margin of the mylohyoid muscle. It contains the anterior portion of the hyoglossus muscle, the lingual nerve (sensory division of cranial nerve V), the chorda tympany branch of cranial nerve VII, the lingual artery and vein, the deep portion of the submandibular glands and ducts, and the sublingual glands and ducts.

Congenital lesions of the sublingual space include epidermoid, dermoid, lymphangioma, and hemangioma. Lingual thyroid tissue will result if there is failure of normal descent of developing thyroid tissue from the base of the tongue into the lower neck. On CT the lingual thyroid is midline in the posterior portion of the tongue and demonstrates dense contrast enhancement; nuclear medicine thyroid scans demonstrate functioning thyroid tissue.

Cellulitis and abscess may occur secondary to dental or mandibular infections or arise as a consequence of calculus disease of either the submandibular or sublingual glands. Abscess is characterized by central areas of low density with or without boundary enhancement (Fig. 2-32). As with parotid gland calculi, CT readily identifies calcified stones and demonstrates bone destruction and sequestra of mandibular osteomyelitis. Ranula, a postinflammatory retention cyst of the sublingual gland, presents as a cystic low-density lesion. As it enlarges, it extends posteriorly and inferiorly into the submandibular space, where it is referred to as a "diving ranula" (Fig. 2-33).

Squamous cell carcinoma, the most common malignancy of the SLS, may spread from the oropharynx, oral cavity, alveolar ridge, or anterior portion of the tongue. A mass with irregular areas of enhancement, ulceration, central necrosis, and lymph node involvement is characteristic; normal fat planes may be obscured. Tumor spread across the midline of the tongue, along the lingual or mandibular nerve, or invasion of the cortex or medulla of the mandible is an important finding that alters treatment planning.

Submandibular space

The submandibular space (SMS) lies inferior and lateral to the SLS; it is located inferior to the mylohyoid bone and superior to the hyoid bone. It contains the anterior belly of the digastric muscle, fat, submandibular and submental lymphnodes, the superficial portion of the submandibular gland, the inferior portion of the hypoglossal nerve, and the facial artery and vein.

Congenital lesions are not uncommon and include second branchial cleft cyst, thyroglossal duct cyst, and cystic hygroma (lymphangioma). Branchial cleft cyst occurs most commonly at the angle of the mandible, posterior to the submandibular gland, anterior to the sternocleidomastoid muscle, and anterolateral to the carotid space (Fig. 2-34). It may have an associated fistula or sinus tract. Thyroglossal duct cysts are midline in location and are found anywhere from the tongue base to the midportion of the thyroid gland. Cystic hygroma, a malformation of lymphatic channels, is a multilocular fluid density lesion that may involve both the SLS and SMS in the adult.

Ranula, a retention cyst of the sublingual gland commonly extends into and may predominantly involve the SMS; it is unilocular in configuration. Its tail of origin should be carefully searched for in the SLS, since this will aid in establishing its origin and diagnosis.

Benign tumors include benign mixed cell tumor, lipoma, dermoid, and epidermoid. Most malignant disease represents secondary submandibular and submental nodal involvement, commonly from SCCA of the oral cavity and face. Multiple enlarged lymph node involvement may be seen with non-Hodgkin's lymphoma.

Spaces of infrahyoid neck

The infrahyoid neck extends superiorly to the hyoid bone and inferiorly to the clavicles and contains the following spaces:

1. Infrahyoid retropharyngeal space (RPS).
2. Infrahyoid prevertebral space (PVS).
3. Anterior and posterior (lateral) cervical space.
4. Hypopharyngeal mucosal space (PMS).
5. Visceral space and larynx.
6. Carotid space (CS).

Normal cross-sectional anatomy of the infrahyoid neck is presented in Figs. 2-35 to 2-37. The parapharyngeal space ends at the hyoid bone and does not continue into the infrahyoid neck. The mucosal, carotid, retropharyngeal, prevertebral, and posterior cervical spaces are all continuous superiorly with the suprahyoid neck and extend inferiorly to the thoracic inlet (Smoker, 1991). These spaces are discussed in more detail under the suprahyoid neck section, except for the posterior cervical space, which is described below. Lesions may secondarily invade the structures of the infrahyoid neck from the cranial margin (submandibular, parapharyngeal, carotid, retropharyngeal, and oropharyngeal mucosal spaces), posterior margin (prevertebral space and vertebrae), and inferior margin (mediastinum and chest wall).

Infrahyoid retropharyngeal space

The infrahyoid retropharyngeal space (RPS), a potential space containing a thin layer of fat and no lymph nodes, is bounded by the middle layer of deep cervical fascia anteriorly, the alar fascia of the carotid sheath laterally, and the deep layer of deep cervical fascia posteriorly (Davis et al, 1991). Unlike the suprahyoid retropharyngeal space, which contains both fat and lymphnodes, the infrahyoid RPS only contains fat. On CT and MRI the normal infrahyoid RPS is an inconsistently demonstrated fat stripe overlying the anterior margin of the longus colli muscles, nestled between the two carotid sheaths.

The infrahyoid RPS may be involved by processes arising from tissues within this space, but more commonly it is affected by external invasion from the adjacent spaces. Lesions within this space have a characteristic "bow-tie" configuration and lie anterior to the longus colli muscles (Fig. 2-38). Lipomas and lymphangiomas are two low-density congenital lesions arising primarily in or secondarily extending into the infrahyoid RPS. Inflammation of this space may arise from pharyngeal mucosal laceration, diskitis, or osteomyelitis from the prevertebral space or from infections tracking in through the posterior cervical space. Gas in this space suggests laceration of the pharynx, larynx, or trachea, pneumomediastinum, or the presence of gas-forming organisms (Fig. 2-39). Edema from inflammation in an adjacent space may track into the RPS and occasionally mimic a true fluid collection or abscess. Neoplasms arising in the hypopharyngeal mucosal space, carotid space, posterior thyroid gland, and larynx may involve the RPS. Extracapsular spread of internal jugular and spinal accessory metastatic nodes, as well as recurrent visceral space neoplasms, occasionally may invade the RPS. One common pseudomass that indents into this space is a tortuous common or internal carotid artery, usually seen in the middle aged and elderly.

Infrahyoid prevertebral space

The infrahyoid prevertebral space (PVS) continues superiorly into the suprahyoid PVS and inferiorly to the mediastinum. This space is susceptible to the same pathologic processes as the suprahyoid component, which include inflammatory and infectious processes (arthritis, diskitis, osteomyelitis), as well as neoplasms arising in the spinal canal, brachial plexus, paraspinous musculature, or vertebral bodies (Fig. 2-40).

Anterior and posterior cervical (lateral cervical) spaces

The posterior cervical (lateral cervical) space corresponds to the posterior triangle and is a fibrofatty layer containing the internal jugular, spinal accessory, and transverse cervical lymph node chains, as well as the spinal accessory and phrenic nerves. The posterior cervical space is limited by the sternocleidomastoid muscle and investing layer of deep cervical fascia anterolaterally, the carotid sheath anteriorly, and the prevertebral fascia posteromedially. It extends superiorly from the mastoid process and skull base down to the first rib and clavicles inferiorly (Parker et al, 1991). Thus a small portion of the posterior cervical space extends into the suprahyoid neck, with the majority occupying the infrahyoid neck.

A transspatial lesion (lymphangioma, plexiform neurofibroma, lipoma, hemangioma) may invade two or more anatomic compartments, without respect for fascial boundaries (Vogelzang et al, 1991). Congenital lesions of the posterior cervical space include a second branchial cleft cyst, which tends to lie along the anterior margin of the sternocleidomastoid muscle, and a lymphangioma or cystic hygroma (Fig. 2-41). Both lesions are CSF density on CT, low intensity on T1WI, high intensity on T2WI, and may ring-enhance if secondarily infected. Inflammation may enter this space from cutaneous lesions or from abscessed lymph nodes. Benign neoplasms include neurogenic tumors (plexiform neurofibroma, schwannoma), a lipoma, or a hemangioma. Malignant neoplasms in the posterior cervical space are most commonly metastatic to the spinal accessory or internal jugular lymph nodes, with squamous cell carcinoma representing the largest group of both primary and secondary tumors involving this space. Less commonly sarcomas such as liposarcoma, leiomyosarcoma, or malignant fibrous histiocytoma arise here. Normal structures such as the scalene muscles, poorly opacified vessels on CT, and high-signal, flow-related enhancement in vessels on MRI may be misinterpreted as a pseudomass. Denervation atrophy of the sternocleidomastoid muscle or other neck muscles may occasionally cause an incorrect interpretation of the contralateral (normal-sized) muscles as representing masses.

Hypopharyngeal mucosal space

The hypopharyngeal mucosal space forms the walls of the hypopharynx and includes the continuation of the pharyngeal mucosal space below the hyoid bone posteriorly, the piriform sinus laterally, the aryepiglottic folds and epiglottis anteriorly, and the cricopharyngeus muscle inferiorly. The hypopharyngeal mucosal space, piriform sinuses, and aryepiglottic folds are frequently challenging to evaluate on CECT and MRI, because they are relatively thin membranous spaces that are normally collapsed together when the pharynx is relaxed. A modified Valsalva maneuver is usually required to distend the hypopharynx enough to obtain adequate imaging (see Fig. 2-2).

As with the suprahyoid pharyngeal mucosal space, caution must be exercised in assigning abnormality to this space since redundancy of the mucosa and incomplete distension may mimic tumor. Foreign bodies, inflammation, and SCCA may cause ulceration or swelling of the mucosa, with gas or a ring-enhancing fluid collection suggesting the diagnosis; reactive lymph nodes are common. The best indicator of hypopharyngeal malignancy is a bulky mass with invasion and destruction of submucosal and deep structures including the retropharyngeal space, aryepiglottic folds, cricoid cartilage and larynx, as well as associated necrotic lymph nodes (Fig. 2-42).

Visceral space and larynx

The visceral space, corresponding to the muscular triangle, is confined by the middle layer of deep cervical fascia with the anterior fascial layer splitting around the thyroid gland. The visceral space contains the larynx, trachea, hypopharynx, esophagus, parathyroid glands, thyroid gland, recurrent laryngeal nerve, and tracheoesophageal lymph nodes (Babbel et al, 1991). The superior margin is the hyoid bone, and the inferior border is the mediastinum. The skeleton of the larynx includes the thyroid, cricoid, arytenoid, cuneiform, and corniculate cartilages. These cartilages may reveal a variable degree of calcification or ossification; these findings progress with age. Ligaments from the stylohyoid and stylothyroid muscles frequently calcify. Knowledge of the normal patterns of calcification is helpful for distinguishing opaque foreign bodies, such as chicken bones, from normal structures on plain films or CT.

Larynx. The hyoid bone supports the laryngeal skeleton and is occasionally fractured in blunt trauma or destroyed by neoplasms. Fractures of the laryngeal skeleton appear on CT as linear lucencies, often with displacement or distortion of the cartilage. A fracture is best appreciated (on bone windows) in well-ossified cartilage, but its identification is more challenging in noncalcified cartilage requiring the use of a narrower window width and careful scrutiny of cartilage configuration. Laryngeal trauma may result in hematomas of the aryepiglottic folds, false cords, true cords, or subglottis and may potentially compromise the airway (Fig. 2-43). Adjacent subcutaneous emphysema may result from trauma to the laryngopharyngeal mucosa, from a penetrating injury to the neck, or from upward dissection from the chest wall or mediastinum.

Laryngoceles are formed by increased intraglottic pressure (eg, horn players, glass blowers) or from obstruction of the laryngeal ventricle and its distal appendix by inflammatory or neoplastic lesions (Fig. 2-44). An internal laryngocele tracks superiorly within the paralaryngeal (paraglottic) fact, is air- or fluid-filled (obstructed laryngocele), and cause variable compromise of the supraglottic larynx. A mixed (external) laryngocele extends further superolaterally, piercing the thyrohyoid membrane, and may present as a neck mass. A mucocele (mucus retention cyst) of the supraglottic laryngeal mucosa may be indistinguishable from an obstructed internal laryngocele. Inflammation of the supraglottic larynx may lead to epiglottitis, thickening the epiglottis and aryepiglottic folds and compromising the airway (Fig. 2-45).

Apart from routine evaluation of adenopathy from suprahyoid neck and sinus tumors, laryngeal and hypopharyngeal SCCA is the most common indication for imaging the infrahyoid neck. Because both CECT and MRI are relatively insensitive to superficial mucosal-based lesions, knowledge of the physical examination findings and specific locations of concern is mandatory to facilitate lesion localization and characterization. Findings that help identify SCCA of the superficial mucosa of the larynx or pharynx are a mass, mucosal irregularity or asymmetry, and ulceration. Fat planes in the laryngopharynx are critical for determining the extent of deep invasion or inflammation. The fat in the preepiglottic space, epiglottis, and aryepiglottic folds and paralaryngeal fat of the supraglottic larynx are major landmarks that are easily identified on axial CT and MRI. Coronal T1WIs are particularly useful for evaluating the configuration of the airway and for determining the craniocaudal margins of a supraglottic, glottic, infraglottic, or transglottic lesion, since the vertically oriented paralaryngeal fat plane terminates inferiorly at the true vocal cords (thyroarytenoid muscle). A lesion becomes transglottic when the fat interface between the thyroarytenoid muscle (true vocal cord) and the paralaryngeal fat (false vocal cord) is eliminated, indicating the tumor has crossed the laryngeal ventricle (Fig. 2-46, A). The anterior commissure should be less than 1 mm thick; greater thickness in this area represents tumor spread from the anterior margin of one cord to another. A diagnosis of vocal cord fixation may be made when the involved cord remains paramedian during quiet breathing or with a modified Valsalva maneuver (Fig. 2-46, B).

Cartilage invasion or destruction by aggressive infections or tumors is an important part of staging and is often difficult to predict on CECT or MRI when the cartilage is incompletely calcified. If the cartilage has ossified, CECT and MRI are relatively sensitive for detecting cartilage erosion. MRI using a combination of T1WI, T2Wi, and postgadolinium fat saturation T1WI may be more sensitive than CECT to invasion of the central layer of the thyroid cartilage, especially if the cartilage has ossified and the central fatty marrow has been locally replaced by invading tumor. The best indicator of cartilage invasion is the presence of tumor on the external margin of the cartilage in the strap muscles (Fig. 2-47).

Thyroid gland. The thyroid gland lies within the anterior leaves of the middle layer of deep cervical fascia (within the visceral space) anterior and lateral to the thyroid, cricoid, and upper tracheal cartilages. It consists of the lateral thyroid lobes, isthmus, and pyramidal lobe. Normal iodine content of the thyroid gland makes it higher density than muscle on NCCT. The gland is normally homogeneous with enhancement on both CECT and MRI, but internal inhomogeneity from calcification, goiter, colloid cyst, or a solid mass is occasionally encountered on routine neck imaging. When physical examination, ultrasound, or thyroid scintigraphy raises the suspicion of a thyroid carcinoma or thyroid lymphoma, CECT or MRI may be used for further characterization, especially if it is a low thoracic inlet thyroid or parathyroid mass.

Absence of the thyroid gland at the level of the thyroid cartilage should redirect attention to the tongue for an ectopic lingual thyroid gland (Fig. 2-48). A thyroglossal duct cyst is a remnant of the embryonic thyroglossal duct and may occur anywhere along its migratory path from the foramen cecum in the tongue to the pyramidal lobe, although most occur just inferior to the hyoid bone (Fig. 2-49). Inflammatory thyroiditis may enlarge the thyroid gland. Benign enlargement may also result from colloid cysts and goiters. Thyroid calcification is nonspecific and occurs in goiters as well as in benign thyroid adenomas. Primary malignancies of the thyroid include papillary, follicular, mixed, and anaplastic carcinomas, we well as non-Hodgkin's lymphoma, all of which may have a similar imaging appearance (Fig. 2-50). Indistinct margins of a thyroid mass, infiltration of adjacent tissues, and necrotic lymph nodes are all indications of thyroid malignancy. Metastasis to the thyroid gland more commonly arises from extracapsular spread of squamous cell carcinoma in adjacent nodes than from hematogenous deposits.

Parathyroid glands. The parathyroid glands are usually four to six in number and underlie the posterior surface of the thyroid gland. Since they are quite small, normal parathyroid glands are frequently not visualized on routine neck imaging. An ectopic parathyroid gland may occur in the mediastinum (Fig. 2-51). A parathyroid adenoma is usually a discrete mass lying deep to the thyroid lobes. Occasionally, an adenoma may be detected on routine CT or MRI as a nodular, enhancing mass that may be differentiated from lymph nodes by its location posterior to the thyroid gland.

Lymphadenopathy

Lymph node anatomy and classification

The nodes of the superficial triangles of the neck are organized by major lymphatic chains. The traditional classification of lymph nodes of the head and includes 10 groups: lateral cervical, anterior cervical, submandibular, submental, sublingual, parotid, facial, mastoid, and occipital. The lateral cervical chains are further subdivided into the deep and superficial chains. The deep lateral cervical chain includes the internal jugular, spinal accessory, and transverse cervical (supraclavicular) nodes; the superficial lateral cervical chain consists of the external jugular nodes. The anterior cervical (juxtavisceral) group contains the prelaryngeal (Delphian), pretracheal, prethyroid, and lateral tracheal (tracheoesophageal or paratracheal) nodes (Som, 1987). The cervical lymph node chains are found throughout several of the spaces of the neck:

1. Posterior cervical space: spinal accessory, transverse cervical, and internal jugular (posterior to the internal jugular vein) nodes.

2. Carotid space: internal jugular nodes (anterior to the internal jugular vein posterior margin).

3. Submandibular space: submandibular and submental nodes.

4. Parotid space: parotid nodes.

5. Suprahyoid retropharyngeal space: medial and lateral retropharyngeal nodes.

6. Visceral space: prelaryngeal, prethyroid, pretracheal, and tracheoesophageal nodes.

7. Subcutaneous tissues of the scalp and face: occipital, mastoid, and facial nodes.

A condensation of this nomenclature into seven groups with Roman numerals (levels I to VII) has been proposed and is a useful shorthand for node documentation and statistical analysis. Since this later classification is not standard at all institutions, to prevent confusion its use should be agreed to by the head and neck surgeons, radiation therapists, oncologists, and radiologists. Level I combines the submandibular and submental lymph nodes. Levels II to IV divide the internal jugular chain roughly into thirds, using landmarks that are easily recognizable on cross-sectional imaging. Level II is the jugular-digastric group of internal jugular nodes from the skull base down to the hyoid bone (approximately the level of the common carotid bifurcation). Level III is the supraomohyoid internal jugular chain from the hyoid bone to the cricoid cartilage (approximately the level of the omohyoid muscle). Level IV includes the infraomohyoid internal jugular nodes from the cricoid to the clavicles. Level V combines the spinal accessory and transverse cervical (supraclavicular) nodes from the skull base to the clavicles. Separation of internal jugular nodes from the spinal accessory nodes on cross-sectional imaging may be difficult, especially in the suprahyoid neck, since these two chains converge at the skull base. A somewhat arbitrary distinction between these chains is made using the posterior margin of the internal jugular vein as the dividing line on axial imaging; any nodes anterior to this line are defined as internal jugular nodes, and those posterior to this margin are called spinal accessory nodes. Level VI contains the prethyroid nodes. Level VII consists of the tracheoesophageal nodes. The retropharyngeal nodes are not included in this classification and are mentioned separately.

Lymph nodes: normal and pathologic

CECT remains the gold standard for detecting and classifying cervical lymphadenopathy as benign or malignant. The important considerations in radiographic lymph node detection and characterization are location, size, number, clustering, enhancement pattern, calcification, sharpness of margins, and invasion or displacement of adjacent structures. First the nodes must be detected and localized to a specific nodal chain or level using one of the conventions for labelling node regions discussed above. Node involvement is described as unilateral or bilateral and in terms of the specific level(s) or chain(s) affected.

Inflammatory (reactive) lymph nodes on CECT tend to be less than 10 mm (rarely larger than 20 mm), have central hilar or mild homogeneous enhancement, and have well-defined margins (Fig. 2-52). Node margins should remain sharp in reactive adenopathy, except in cases with large abscessed nodes that elicit an inflammatory reaction in the adjacent fat, obscuring the node margins (Fig. 2-53). Calcification is a common finding in previously infected or healed nodes and frequently occurs in tuberculosis or bacterial infections. Multiple nodes may be present, but they tend not to cluster. On MRI these reactive nodes are enlarged and have well-defined margins on all sequences. They are muscle intensity on T1WI, enhance moderately and homogeneously on postgadolinium fat-suppressed T1WI, and are bright on T2WI and STIR.

The correlation of lymph node size with sensitivity and specificity in predicting malignant metastasis has been performed for different neck regions in patients with head and neck carcinoma, allowing more appropriate size criteria for distinguishing normal from abnormal lymph nodes (Som, 1987). Although CT can readily detect lymph node enlargement, it has also proven capable of accurately diagnosing metastases in "normal size" nodes from head and neck primary squamous cell carcinoma. The upper range of normal for cervical lymph node size is between 5 and 10 mm, with the jugular digastric node ranging up to 15 mm. The exceptions are the submandibular and submental nodes, which are usually abnormal if larger than 5 mm, and the retropharyngeal nodes when greater than 10 mm in children or greater than 5 mm in adults. Generally, cervical nodes larger than 10 to 15 mm are potentially malignant and nodes smaller than this are considered reactive or inflammatory. Nodes larger than 20 mm are frequently malignant, since the average size of a clinically positive metastatic node is 21 mm by physical examination and 20 mm by CT. Clinically occult neck disease occurs in 15% to 40% of patients with head and neck squamous cell carcinoma; clinically occult nodes average 12 mm (Fig. 2-54). Studies comparing clinical and CT staging of nodal metastases have shown that physical examination of the neck has an accuracy of 70% to 82% compared with 87% to 93% for CT. In patients with no nodal disease on examination, CT is likely to upstage an N0 neck to N1 in 20% to 46% and upstage clinical staging of the neck between 5% and 67% overall. CT may downstage the clinical neck examination in 3% to 36% of cases (Close et al, 1989; Mancuso and Dillon, 1989).

The enhancement pattern on CT is very helpful, but not infallible, in distinguishing inflammatory nodes from metastatic nodes. Node detection is improved by performing CECT with a constant infusion technique. The presence of a focal defect (central low density) or peripheral enhancement is characteristic of malignancy even in normal-sized nodes less than 15 mm. A focal defect in an enlarged node is a strong indication of a necrotic node metastasis, although tuberculosis or an abscessed node may mimic this appearance. Central dense or linear enhancement of the hilum of an enlarged node without ring enhancement is usually a distinguishing sign of a reactive node. Nodes larger than 20 to 40 mm without central necrosis often indicate lymphoma or sarcoidosis (Fig. 2-55). Treated lymphomatous nodes may have dystrophic calcification, and rarely, calcium matrix-forming tumors (osteosarcoma, chondrosarcoma) may have radiodense metastases. When margins of an enlarged node with central necrosis are indistinct, extracapsular penetration of the tumor through the node capsule has likely occurred (Fig. 2-56). This sign may decrease the 5-year survival by 50%. The number of nodes involved is important; multiple nodes suggest a more widespread inflammatory or neoplastic process. Clustering of multiple nodes, sometimes into a seemingly single, complex mass, suggests malignancy and may be palpable as a single large mass. Round rather than bean-shaped nodes, clusters of nodes, and indistinct margins suggest malignancy but are less specific than size greater than 15 mm, ring enhancement, oro-focal defect.

MRI of malignant adenopathy has both advantages and limitations compared with CECT. Malignant nodes appear as muscle intensity on T1WI, may show ring enhancement on postgadolinium fat-suppressed T1WI, are very bright on STIR, and are usually bright on

T2WI (although necrosis may give both high and low signal on long TR sequences) (Fig. 2-57). Fat-suppressed long TR sequences will diminish background fat signal, further improving detection. The STIR image is superior to CECT in sensitivity for any enlarged lymph node but is nonspecific for metastases. MRI and CECT rely on the same criteria of size, clustering, margin sharpness, and shape for characterization of abnormal nodes. The specificity of ring enhancement on CECT is the main advantage of CT for diagnosis of metastases. The same finding of ring enhancement on postgadolinium fat-suppressed T1WI likely represents focal tumor or central necrosis as well. Otherwise, the other MRI sequences described above are nonspecific. MRI may better demonstrate invasion of adjacent structures, especially muscles, than does CECT.

With extracapsular spread, adjacent fat, bone, cartilage, and muscle are commonly compressed or invaded. Secondary invasion of adjacent structures and anatomic spaces by aggressive lymph node lesions may develop in the carotid sheath structures, skull base, prevertebral space and vertebrae, and mandible. The superficial nodes may invade adjacent muscle and skin. Internal jugular and spinal accessory nodes may invade the carotid, parapharyngeal fat, prevertebral, and infrahyoid visceral spaces. Parotid nodes may violate the surrounding parotid parenchyma, skin, masticator space, and parapharyngeal space. Suprahyoid retropharyngeal nodes may extend laterally into the carotid space, posteriorly into the prevertebral space, anteriorly into the mucosal space, and superiorly into the skull base. The tracheoesophageal nodes may involve the common carotid artery and the internal jugular vein in the carotid space, the recurrent laryngeal nerve, the visceral space structures of the larynx and thyroid, and the mediastinum.

Invasion of the carotid artery carries a poor prognosis with local recurrence rate of 46% and a distant metastatic rate of 56% to 68%. For patients with tumor involving the carotid artery, the 5-year survival rate decreases to 7% and the mean survival decreases to less than 1 year. Prolonged survival is possible if the involved carotid artery is resected. Detection of carotid artery invasion by MRI may be more accurate than ultrasound. The best imaging modality among CECT, MRI, or ultrasound for evaluating carotid fixation remains controversial (Langman et al, 1989). Surprisingly, criteria for carotid invasion are not well established in the literature. CT and MRI criteria, based on the work of Picus in aortic invasion by esophageal carcinoma, include effacement of the fascial plane surrounding greater than 25% of the vessel circumference (Picus et al, 1983). More recent criteria suggest a very high likelihood of fixation exists if tumor involves three fourths or more of the circumference of the carotid and if nodal extracapsular penetration has occurred (see Fig. 2-56). Ultrasonography is a potentially valuable adjunctive technique capable of demonstrating invasion of the common and internal carotid artery, as well as the internal jugular vein.

Sinuses and Skull Base

Nose and paranasal sinuses

The sinonasal region can be divided into three major regions: the sinuses, the ostiomeatal complex, and the nasal cavity. The paranasal sinuses are mucosal-lined, air-filled cavities that are named after the bones of the face in which they develop. This mucosa is prone to both inflammatory and neoplastic disease. The frontal, maxillary, ethmoid, and sphenoid sinuses all drain through ostia into the nasal cavity. The frontal, maxillary, anterior ethmoid, and middle ethmoid sinuses drain into the semilunar hiatus under the middle turbinate. This area represents the ostiomeatal complex or unit; a small lesion here can cause obstruction to multiple sinus ostia. The posterior ethmoids and sphenoid sinus drain under the superior turbinate or spheno-ethmoidal recess. The nasal cavity extends from the nares anteriorly to the choana posteriorly and from the hard palata inferiorly to the cribriform plate superiorly. The midline nasal septum, lateral turbinates, and maxillary and ethmoid sinuses form the walls.

The compartments adjacent to the sinuses that are at risk for invasion by aggressive inflammatory or neoplastic processes include the anterior cranial fossa, orbits, cavernous sinus (from the sphenoid sinus), masticator space, pterygopalatine (pterygomaxillary) fossa, oral cavity, and anterior soft tissues of the face. These compartments are carefully viewed for dural or brain invasion, optic nerve and extraocular muscle compromise, perineural spread into the skull base, or direct extension into the deep compartments of the suprahyoid neck and oral structures. Involvement of any one of these secondary compartments can significantly alter treatment planning and surgical approach.

Paranasal sinuses

Congenital and developmental anomalies of the sinonasal cavities are sought on all CT examinations. Common anatomic variants include pneumatization or paradoxical curvature of the turbinates, deviated septum, sinus hypoplasia, and Haller air cells (Fig. 2-58). Sinus underdevelopment may range from aplasia to hypoplasia. Pneumatization implies sinus development has occurred; aeration indicates that the pneumatized portion of the sinus is air filled. Mucosal thickening or opacification signifies the pneumatized section is filled with soft tissue inflammation or fluid. Either hypoplasia or the reactive new bone formation (chronic inflammation) may cause thickening and sclerosis of the sinus walls.

In general, evaluation of the paranasal sinuses involves assessment of two components: (1) the sinus contents (including the mucosa) and (2) the bony walls. Normal sinus mucosa is very thin and not seen on CT or MRI, and the bone is normally thin and delicate in the posterior maxillary, ethmoid, and sphenoid sinuses. CT or MRI readily reveals the presence of a normally aerated sinus, mucosal thickening (chronic sinusitis, retention cyst, or polyps), an air-fluid level (acute sinusitis, intubation, and trauma), or complete opacification (mucocele, trauma, and acute or chronic sinusitis) (Fig. 2-59). The normally delicate posterolateral maxillary sinus wall is a much better indicator of bony sclerosis than the anterior wall; the normally thick anterior wall of the maxillary (and frontal) sinus may range from 1 to 3 mm (see Fig. 2-10, A and C). Beginning observes frequently forget to assess the bone for important clues such as thickening and sclerosis (chronic sinusitis or hypoplasia), fractures, remodelling (slowly expanding mucocele or neoplasm), or destruction (malignancy or aggressive infection such as mucormycosis).

Deciding which portion of the opacified sinus, sinuses, or nasal cavity contains tumor and which contains obstructed mucous secretions is clinically important with a sinus or nasal tumor. The question is more problematic with NCCT or CECT since tumor and sinus secretions are frequently similar in density, and both the tumor and the mucosa may enhance; however, MRI is usually much more informative (Fig. 2-60). Evaluation of this problem requires a knowledge of signal intensity patterns of tumor versus mucus. Sinonasal tumors tend to be low to intermediate signal intensity on T1WI and intermediate signal intensity on T2WI, although minor salivary tumors and adenoid cystic carcinoma may be of high signal intensity (Shapiro and Som, 1989). The highly cellular aggressive neoplasms tend to have a lower water content and are less bright on T2Wi. Tumors enhance moderately and, more or less, uniformly with gadolinium. Sinus secretions are complex in their patterns. Hydrated, nonviscous mucus is low intensity on T1WI and high intensity on T2WI. Desiccated, viscous mucus tends to be high intensity on T1WI and low to intermediate intensity on T2WI. Extremely desiccated mucus may lack signal intensity on T1WI or T2WI, simulating bone or air. Both an obstructed sinus and an expansile mucocele frequently have two or more layers of mucus in a concentric ring pattern with the most desiccated, viscous secretions located centrally. The peripheral mucosa of an obstructed sinus enhances in chronic sinusitis or with a pyomucocele but does not enhance with a simple mucocele. The presence of tumor vs obstructed secretion is best solved by comparing the respective change in signal intensity of each component on the T1WI, T2WI, and postgadolinium T1WI and is rarely answered by a single sequence; a minimum of T1WI and a T2WI is required.

Ostiomeatal complex

The ostiomeatal complex has become an area of active radiologic and pathophysiologic investigation with the development of endoscopic sinus surgery for inflammatory sinus disease. Coronal thin section NCCT is the best means of demonstrating the anatomy of this area (see Fig. 2-58). Pertinent observations include (1) the individual's sinonasal anatomy and the presence of any anatomic variants (hypoplastic maxillary sinus, concha bullosa, agger nasi air cells, Haller's air cells, deviated septum, deviated uncinate process, prominent ethmoid bulla, paradoxical curvature of the middle turbinate), (2) the location of obstructed air cells, (3) the extent of the chronic or acute sinus disease and whether this pattern is consistent with obstruction of the ostiomeatal complex, and (4) the presence of any prior surgical alterations (Caldwell-Luc, internal or external ethmoidectomy, uncinatectomy, etc). Ostiomeatal complex obstruction may result from anatomic compression, mucosal inflammation, polyps, benign neoplasms, and SCCA. Mucoceles, indicated by sinus expansion and low-density mucus on CECT or by concentric rings of variably desiccated mucus in an expanded sinus on MRI, are a complication of chronic sinus obstruction (Fig. 2-61). A mucocele only shows peripheral enhancement when it is infected and is then called a pyomucocele.

Nasal cavity

The nasal cavity is occasionally the site of symptomatic disease. Anatomic variants include choanal atresia, concha bullosa, paradoxical curvature of the middle turbinate, wide nasal cavity from a hypoplastic maxillary sinus, and septal deviation. The nasal mucosa of the turbinates may be asymmetric in thickness because of the normal nasal cycle or the presence of polyps or inflammation. Obstruction of the ostiomeatal complex and other sinuses may occur with benign (antrochoanal polyp, neural tumors, inverting papilloma) or malignant (SCCA, adenocarcinoma, adenoid cystic carcinoma) tumors (Fig. 2-62). If a nasal mass is present, the extent of the mass within the nasal cavity, adjacent sinuses, or orbits or involvement of the cribriform plate may be determined by coronal CECT or sagittal and coronal MRI, since this may affect the surgical approach and postoperative therapy.

Facial trauma

Facial trauma is briefly included here because of the intimate relationship of the facial bones and sinuses. Thin-section axial and direct coronal NCCT is the ideal method for determining the full extent of facial trauma. One strategy for evaluating the extent of sinus trauma is to visually trace each bony outline on consecutive slices in both imaging planes, looking for fractures, normal fissures and canals, and displacements. However, the quickest way to locate sinus fractures is to search for indirect signs of fracture (Fig. 2-63): an air-fluid level, complete opacification of a sinus with blood, and the presence of gas outside the sinus (pneumocephalus, subcutaneous emphysema, infratemporal fossa, or orbital gas). Identification of the fractures allows determination of fracture classification: nasal, orbital blowout, trimalar or tripod, Le Fort (I, II, III, and complex), or nasoethmoid complex fracture (Fig. 2-64). Assessment is made of the extent of soft tissue trauma, particularly the orbital soft tissues of the lens, globe, extraocular muscles, and optic nerve. Displaced orbital floor fractures may entrap fat or the extraocular muscles and result in enophthalmos or dysfunction of ocular motility.

Skull base

Anatomically, the skull base can be divided into the anterior, middle, and posterior fossae. The lesser and greater wings of the sphenoid bone divide the anterior fossa from the middle fossa while the petrous pyramid and mastoid portions of the temporal bone divide the middle and posterior fossae. The parietal and occipital lobes of the brain do not directly contact the skull base.

The skull base is formed from five bones: frontal, ethmoid, temporal, sphenoid, and occipital; the frontal and temporal bones are paired. Each of these bones can be subdivided into component bone; for example, the occipital bone has basioccipital, condylar, and squamosal portions. The skull base has its longest diameter in the AP plane, extending from the region of the crista galli to the posterior margin of the foramen magnum posteriorly. It is the thinnest in its superior inferior direction, ranging between 3 and 5 mm in most areas with the exception of the much thicker petrous temporal bone.

With CT the skull base may be imaged using the axial or the coronal plane (only a modified coronal plane is possible because of limited gantry tilt). The coronal plane is excellent for delineating the superior inferior extent of a lesion. CT gives excellent visualization of bone detail, especially when bone algorithm techniques are used. In addition to the axial plane, MRI allows imaging both in a true coronal plane and in the sagittal plane, the latter especially useful for the study of midline lesions (eg, chordoma). MRI also yields improved lesion contrast and conspicuity and more accurate delineation of lesion extent.

Using an anatomic approach skull base lesions may be classified as anterior, middle, or posterior fossae and a unique differential then developed for the medial and lateral portions of each fossa. Lesions may also be categorized as primary, those arising within the skull base itself and secondary, those arising within the skull base itself and secondary, those extending down from the cranial cavity above (endocranial lesions) or growing up from below (exocranial lesions). Endocranial masses are extracerebral and intracerebral lesions, whereas the exocranial lesions are secondary to extension superiorly from a disease process of the orbit, suprahyoid head and neck, cervical spine, and prevertebral muscles.

The skull base contains multiple foramina that allow the exit of cranial nerves and inflow and outflow of arteries and veins. These foramina also provide an access route for disease processes to spread from the cranial cavity to the infracalvarial structures and vice versa (Batsakis, 1979). MRI performed after gadolinium infusion and with the use of fat suppression techniques allows sensitive detection of perineural spread, most readily seen with involvement of the fifth and seventh cranial nerves (Laine et al, 1990).

Skull base fractures are readily detected with CT using thin slice sections and re-formation techniques. Sinus air-fluid levels, sinus opacification, and clouding of the temporal bones may herald the presence of a fracture. Similarly, sinus opacification and fracture location may indicate the site of a CSF leak.

Inflammatory skull base lesions are now less common. Osteitis is seen as sclerosis of bone margins. Osteomyelitis usually involves all three skull tables and is characterized by irregular serpiginous lytic areas, occasionally with areas of bone sequestration present.

The osseous changes of neoplastic disease may be erosive, infiltrative, expansive, lytic, sclerotic, or of mixed density. Primary skull neoplastic lesions are uncommon; benign conditions include osteoma, chondroma, giant cell tumor, cholesterol granuloma, and aneurysmal bone cyst (Fig. 2-65). Osteosarcoma, chondrosarcoma, fibrosarcoma, and rarely Ewing's sarcoma and lymphoma are examples of malignant lesions. Metastatic lesions are more common than primary skull base lesions and frequently have an associated soft tissue component (Fig. 2-66). Osteoblastic metastases are most commonly caused by carcinoma of the prostate or breast; sclerotic changes may be seen occasionally in lymphoma (Fig. 2-67). Lytic lesions are more common than osteoblastic findings and are usually secondary to carcinoma of the lung, breast, kidney, or colon.

Intracerebral neoplastic processes may have associated osseous changes. Cerebral gliomas rarely cause local bone erosion or expansion; however, optic gliomas may cause expansion of the optic canal. Neuromas (nerve sheath tumors) may cause smooth expansion of skull base foramina: internal auditory canal (cranial nerve VIII), jugular foramen (cranial nerves IX, X, and XI), hypoglossal canal (cranial nerve XII), and lateral wall clivus and foramen rotundum (cranial nerve V). Paragangliomas cause irregular erosive changes in the skull base foramina (Fig. 2-68). A meningioma is often heralded by hyperostosis (bone sclerosis), especially common with a lesion of the middle fossa involving either the greater or lesser sphenoid wing. Chordoma, a tumor of notochordal remnants, typically causes destruction of the clivus (basisphenoid and basiocciput), typically with associated soft tissue mass and calcification (Moore et al, 1986; Sze et al, 1988). Erosion of the sella floor and sella expansion are characteristic of pituitary adenomas.

Temporal bone

Determination of temporal bone abnormality requires assessment of the external ear, middle ear, mastoid air cells, petrous apex, inner ear, internal auditory canal (IAC), facial nerve canal, and vascular compartment (jugular foramen and carotid canal). The adjacent compartments into which an aggressive temporal bone lesion can spread, or from which a lesion can invade the temporal bone include cerebellopontine angle (meningioma, acoustic schwannoma), middle cranial fossa (geniculate schwannoma, cholesteatoma), jugular foramen (schwannoma, paraganglioma, glomus tumor), skull base and clivus (chordoma), carotid space (aneurysm, schwannoma), parotid space (adenoid cystic carcinoma), and soft tissues of the external ear and scalp (squamous cell carcinoma).

For the external ear and external auditory canal (EAC) the search for abnormality may be accomplished with either high-resolution CT or MRI. Abnormal development (external ear hypoplasia, fibrous or bony EAC atresia), soft tissue opacification (cerumen, EAC cholesteatoma, mucormycosis, squamous cell carcinoma), bone formation (exostoses), or scutum erosion (pars flaccida cholesteatoma) can easily be detected and their extent defined by CT. MRI may add additional information on soft tissue involvement below the skull base or on infiltration of the auricle and scalp.

The middle ear is best evaluated with high-resolution CT. Ossicular chain anomalies (fusion, dislocation, prosthesis, stapedial foot-plate sclerosis), air-fluid level (trauma, acute otitis media), soft tissue opacification (acute or chronic otitis media, cholesteatoma, trauma, chronic endotracheal or nasogastrial intubation), and tympanic membrane thickening (otitis media) may all be characterized (Fig. 2-69). The radiographic approach to the mastoid air cells and petrous apex is similar to that of the paranasal sinuses and consists of the evaluation of the mastoid and petrous apex soft tissue contents and the bony walls. Assessment is made of development or pneumatization of these regions (pneumatization or opacification by soft tissue), the bony septae and walls (hypoplasia or sclerosis from chronic otomastoiditis), the margins of the mastoid or petrous apex (expanded by a primary or secondary cholesteatoma (Fig. 2-70) or a cholesterol granuloma), bone destruction (squamous cell carcinoma, malignant fibrous histiocytoma, glomus tumor). MRI may complement CT for assessment of larger petrous apex or mastoid masses. A normal unpneumatized, fatty (marrow-filled) petrous apex is high signal on T1WI and low signal on T2WI, but a cholesterol granuloma is high signal on T1WI and T2WI from the methemoglobin (see Fig. 2-65). Mucus in air cell is low intensity on T1WI, is very high intensity on T2WI, and enhances mildly with gadolinium. A primary cholesteatoma is similar to cerebrospinal fluid in intensity, appearing low intensity on T1WI and moderately high signal on T2WI, and does not enhance with gadolinium. Postoperative findings encountered on CT and MRI include metallic ossicular prostheses, cochlear implants, and various types of mastoidectomies.

The inner ear structures are best assessed by high-resolution CT with attention to anatomic variants and bone density. A saccular vestibule is one of the more common congenital anomalies. A cochlea with less than 2.5 to 2.75 turns represents a Mondini malformation (Fig. 2.-71). The basal turn of the cochlea and round window may be identified on both axial and coronal CT images. The horizontal (lateral) semicircular canal cortex may be eroded by a cholesteatoma. The oval window and foot plate of the stapes are thickened in stapedial otosclerosis, and the ring of the otic capsule is demineralized in labyrinthine otosclerosis (otospongiosis). The entire petrous bone may be abnormally low density with dysplasias such as osteogenesis imperfecta or sclerotic in osteopetrosis and Paget's disease. Inflammatory or neoplastic lesions may involve the cochlea and vestibule without obvious bone changes on CT; however, MRI with gadolinium-enhanced T1WI may show an enhancing lesion.

The IAC and facial nerve canals are best evaluated by high-resolution CT for bony detail and by gadolinium-enhanced MRI for the soft tissue abnormality. On CT the findings might include widening (acoustic schwannoma, surgery) or narrowing (bone dysplasia, hyperostosis from a meningioma) of the IAC. The facial nerve canal may be traced along its entire course in both axial and coronal planes for areas of erosion (facial neuroma, paraganglioma, hemangioma) or abnormal position (anterior location of mastoid segment with EAC atresia). Gadolinium-enhanced MRI is the modality of choice for evaluating the seventh and eight cranial nerves within the IAC and temporal bone (schwannomas of the facial nerve, of the vestibular nerve, or within the cochlea) or for demonstrating seventh cranial nerve inflammation (Bell's palsy) (Figs. 2-72 and 2-73). Note that the facial nerves may normally enhance mildly and usually symmetrically within the facial nerve canal; asymmetric enhancement is more likely to be abnormal.

Postoperative Neck and Face

A preoperative CECT or MRI is extremely helpful for interpreting the postoperative neck, skull base, or face for sites of concern and potential tumor recurrence. Likewise, a baseline CECT or MRI 3 to 6 months after surgery and radiation further improves the ability of imaging to detect posttreatment tumor recurrence. The posterior cervical space is the most frequently altered neck space, and part of all of its contents may be resected for staging and treatment of head and neck carcinoma; note is made of missing structures (Glazer et al, 1986). A radical neck dissection (Fig. 2-74, A) removes the sternocleidomastoid muscle, internal jugular vein, regional lymphnodes, and most of the fibrofatty tissue that comprises this space. Modified radical, functional, and supraomohyoid neck dissections remove less.

The oral cavity and face are also affected by surgery. Facial trauma is frequently treated by internal fixation with metallic screws and plates. Internal fixation is also performed as part of composite reactions where the mandible is split or when the mandible is partially resected for invasion by tumor. Metal wires, screws, and plates may cause artifacts obscuring sites of posttraumatic CSF leak or potential tumor recurrence. Sinus and palate tumors may require resection of the maxilla, palate, orbital walls and soft tissue, and cribriform plate. The fat, muscle, or bone contained in free flaps, myocutaneous flaps, and osteocutaneous flaps placed in the surgical cavity further complicates image interpretation (Fig. 2-74, B). Laryngeal surgery may remove part or all of the laryngeal skeleton, often placement of a tracheostomy. The remaining soft tissues of the collapsed visceral space are difficult to accurately evaluate.

Radiation therapy frequently causes an edematous pattern, characterized on CT by a streaky increase in density of the subcutaneous, parapharyngeal, and posterior cervical space fat planes (Fig. 2-75, A); on MRI it may have increased signal on T2WI. The mucosal space of the pharynx and larynx may also develop swelling and edema, appearing as diffuse mucosal thickening and enhancement on CECT, while MRI may show high signal on long TR sequences and on gadolinium-enhanced T1WI (Fig. 2-75, B). Postradiation edema, particularly of the larynx and pharynx, may mimic recurrent neoplasm for as long as 6 months to 7 years after radiation therapy (Glazer et al, 1985). Finally, treated lymph nodes may decrease in size or totally disappear, leaving a "dirty fat" appearance.

Recurrent tumor spread often produces strands or nodules of soft tissue density within or replacing the normal fat planes. However, CECT has difficulty detecting small (<1 cm) or mucosal-based tumors and reliably differentiating between recurrent carcinoma and fibrosis or edema. A new bulky, ring-enhancing mass, local tissue invasion, or further bone destruction is a strong sign of recurrent tumor. MRI is reportedly capable of distinguishing tumor from radiation-induced fibrosis in some cases. Posttreatment fibrosis or scarring is similar to or lower than muscle in signal on all sequences (particularly on T2WI), is usually linear, is not masslike, and may enhance mildly in a linear fashion. MRI is superior to CT (particularly NCCT) in discrimination of recurrent tumor from muscle and vascular structures. In the posttreatment neck, gadolinium-enhanced MRI may have the potential to identify tumor recurrence and allow separation of tumor from fibrosis, since recurrent tumor may ring-enhance, a pattern not seen with scar.