

Chapter 150: Imaging the Petrous Bone and Associated Intracranial Structures

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Computed tomography (CT) and magnetic resonance imaging (MRI) have become the most important imaging modalities for evaluating the petrous bones and mastoid air cells and their associated intracranial parenchymal structures (Vignaud et al, 1986). There is now little use for plain films or multidirectional tomography, and angiography is used primarily for preembolization mapping of the vascular supply to a tumor or vascular malformation. The first part of this chapter discusses these imaging techniques, emphasizing CT and MRI. The second portion of the chapter reviews the significant radiographic findings in a variety of diseases. These diseases are divided into pathologic categories and secondarily separated according to the portion of the petrous bone or intracranial structure that they involve. This chapter does not attempt to provide an all-inclusive discussion of each disease or its diversity of imaging presentations. Much more detailed discussion of each pathologic entity will be found elsewhere in this volume. Rather, there is emphasis on the general principles of imaging diagnosis, especially using CT and MRI.

Imaging Techniques

Plain films

A variety of plain film projections have been developed for the visualization of the air cells of the petrous bone and mastoid and for the evaluation of the middle ear and bony labyrinth. These projections are associated with eponyms, including the Schüller, Law, Stenvers, Towne, Guillen, and Chausee III projections, among others, along with the submentovertex (base) and transorbital views (Etter, 1973; Phelps and Lloyd, 1983). The subtleties of bone erosion of middle and inner ear structures, for which these views were developed, are much better visualized on CT scans, with both CT and MRI demonstrating the associated soft tissue lesions that these views could never demonstrate. Plain films are occasionally obtained for an overall evaluation of the development and opacification of air cells. However, this type of evaluation is also made on the CT scan, and hence plain films are now rarely ordered.

Multidirectional tomography

Multidirectional tomography of the petrous bones is of historical significance only. This technique expanded the ability to document subtle abnormalities of the petrous bones over plain films, including subtle erosion of the internal auditory canal (IAC) from tumor and of the ossicles from cholesteatoma. Multidirectional tomography has been replaced by CT and MRI because of better spatial resolution, better soft tissue evaluation, and lower radiation exposure.

Computed tomography

CT is currently the single best test for evaluating the petrous bone and the associated mastoid air cells. CT is the examination of choice for infectious lesions involving the petromastoid complex, for fractures, for congenital anomalies producing abnormalities of hearing balance, and for bone erosion from tumor (Vignaud et al, 1986).

We obtain high-resolution studies of the petromastoid in two projections, using bone algorithm. Axial scanning with 1.5 mm-thick sections every 1 mm gives excellent visualization of the bony structures, and the overlap produces better sagittal and coronal reformatted images than just contiguous slices. The second projection is a coronal oblique, approximately 20 degrees less than a true coronal projection, with contiguous 1.5 mm-thick slices.

Magnetic resonance imaging

MRI is the procedure of choice for evaluating retrolabyrinthine lesions, that is, lesions involving the internal auditory canal (IAC), cerebellopontine angle (CPA), and cerebral parenchyma (particularly the brain, stem, cerebellum, and cerebral parenchyma as high as the third ventricle, that is, the locations of the ascending tracks for hearing and balance) (Armington et al, 1988; Curati et al, 1986; Gentry et al, 1987). MRI is significantly more sensitive to abnormalities of soft tissue than is CT, which is better for bony abnormalities. In addition, there is no transpetrous artifact that so frequently mars the quality of even thin-section CT scans of this area. Hence, MRI is better for tumors involving the IAC/CPA and lesions of the cerebral parenchyma (Daniels et al, 1987; Enrmann and O'Donohue, 1987; Latchaw et al, 1990b; Shaffer, 1990).

Plain MRI is complemented by contrast-enhanced MRI. Gadolinium-diethylenetriamine penta-acidic acid (DPTA) is a paramagnetic contrast agent that is injected intravenously and demonstrates abnormalities that produce a breakdown of the blood-brain barrier or that allow an accumulation of contrast material within the lesion, similar to enhanced CT scanning in which an iodinated contrast material is injected. Enhanced MRI is significantly more sensitive than enhanced CT for cerebral tumors, infections, and inflammatory lesions and has replaced CT for evaluation of these diseases (Brant-Zawadzki et al, 1986; Haughton et al, 1988; Jungreis and Grossman, 1990; Latchaw et al, 1990b; Runge et al, 1983, 1988).

The most sensitive study of the IAC/CPA for tumor requires obtaining T1-weighted thin (2 mm) MRI sections in the axial projection following gadolinium-DTPA intravenous injection (Enzmann and O'Donahue, 1987; Haughton et al, 1988). A nonenhanced study is also obtained if there is a history of previous surgery, since fat or other postoperative tissues having a high intensity on a T1-weighted sequence will mimic a gadolinium-enhancing lesion. A new three-dimensional acquisition gradient echo sequence with relative T1-weighting (the SPGR sequence, General Electric Corp) acquires a block of thin cuts from the foramen magnum to the third ventricle. The study is extended to the mid-third ventricle to cover all pathways devoted to hearing and balance. Coronal scans are added as needed if a lesion is demonstrated on the axial projection. A similar protocol is used for possible inflammatory disease affecting seventh and eighth cranial nerve function.

A T2-weighted sequence, utilizing a long TR with multiple echoes and 5 mm-thick cuts to cover the entire brain, is frequently added, particularly if multiple sclerosis, cerebral ischemia, or other parenchymal disease is suspected.

Finally, it should be emphasized that new MRI sequences are being developed, such as the high-resolution technique to evaluate the bony structures of the petrous bone itself (Brogan et al, 1991). The fluid-filled structures of the bony labyrinth are well demonstrated, and this new technique may in fact replace CT for evaluating the petrous bone. For now, however, CT remains the technique of choice for bony evaluation.

Positive and negative contrast-enhanced CT cisternography

Positive-contrast CT cisternography was developed in the late 1970s for the demonstration of a subtle tumor. It consisted of the lumbar subarachnoid injection of 5 mL of a water-soluble contrast agent that was run into the CPAs, with subsequent thin-section CT scanning (Rosenbaum et al, 1978). This technique was soon replaced by air CT cisternography, which consisted of the injection of 5 cc of air into the spinal subarachnoid space, with the manipulation of that air into the CPA and IAC for subsequent thin-section CT scanning (Pinto et al, 1982; Sortland, 1979). Gadolinium-enhanced MRI is so easy, sensitive, and accurate that this technique has now replaced the more invasive CT procedures (Gentry et al, 1987). The only use for air CT cisternography at this time is for the demonstration of a vascular loop coursing across the seventh and eighth cranial nerve complex, which may produce tinnitus, vertigo, or other symptoms (Esfahani and Dolan, 1989). The nerve complex may then be surgically decompressed by separating the vascular and neural structures (Janetta, 1975). However, the diagnosis and therapy of these disorders remain controversial. MRI replace this last indication for air CT cisternography.

Angiography

Cerebral angiography is occasionally performed for a more complete evaluation of a large CPA/IAC tumor, particularly if that neoplasm is greater than 2 cm in size (Keiffer et al, 1975; Kendal and Syman, 1977; Takahashi et al, 1971). The degree of vascularity and the demonstration of the positions of the anterior inferior cerebellar artery and petrosal vein are considered important by some surgeons (DiTullio et al, 1978).

The diagnosis of a chemodectoma (paraganglioma) is generally suspected from the initial CT or MRI scans. Angiography is then undertaken to confirm the diagnosis and to map the vascularity in preparation for embolization of the tumor, which is performed in the same sitting (see Chapter 186).

Finally, cerebral angiography is occasionally performed if there is suspicion of a tinnitus-producing arteriovenous malformation (particularly of the dural type), aneurysm involving the CPA/IAC, or fibromuscular dysplasia of the carotid artery and for confirmation of the presence of an aberrant carotid artery (Remly et al, 1990; Sila et al, 1987; Swartz et al, 1985). The presence of a high jugular bulb is well demonstrated on CT, and angiography is not necessary. A vascular loop coursing across the seventh/eighth cranial nerve complex is too subtle for angiography, particularly with multiple overlapping vessels, and MRI or air CT cisternography is necessary for that evaluation (Esfahani and Dolan, 1989).

Diseases and Their Appearances on Imaging Studies

Inflammatory lesions

Middle ear and mastoid

Mastoiditis during development produces a decrease in the degree of aeration of the developing petrous bone and mastoid air cells. Infection following air cell development produces opacification of those air cells, with aggressive infections leading to destruction of bony septae.

Acute otitis media (AOM) is characterized by fluid/soft tissue density without bone destruction within the middle ear and mastoid air cells. Sometimes air fluid levels are present. Otitis media with effusion (OME) exhibits similar findings, often with the addition of tympanic membrane retraction; air fluid levels are less common. Chronic otitis media (COM) is characterized by the deposition of granulation tissue and thickened mucosa with or without free pus within the confines of the middle ear and mastoid air cell system. Before bone destruction occurs with COM, the radiographic features cannot be distinguished from AOM or OME. COM occurs either with or without cholesteatoma. The bone destruction associated with COM without cholesteatoma usually has indistinct margins and represents breakdown of the cell walls of several air cells in any region of the air cell complex. Bone destruction from cholesteatoma is usually more discrete and circumscribed. The typical acquired cholesteatoma at the level of the pars flaccida of the tympanic membrane begins in the attic between the scutum and the ossicles (Prussak's space), producing bone erosion and medial displacement of the ossicles as the earliest findings (Fig. 150-1). The cholesteatoma mass may extend through the aditus to the antrum, or there may be blockage of fluid drainage producing opacification of the antrum and mastoid air cells. Differentiation between cholesteatoma and blocked secretions depends on the presence of bone destruction, such as Koerner's septum in the superior antrum. The cholesteatoma may also extend along the promontory to produce erosion of the bony margin of the lateral semicircular canal, leading to profound dizziness, or erosion of the seventh cranial nerve canal, leading to facial weakness. Rarely, the cholesteatoma extends through the oval window into the vestibule or erodes the tegmen leading to intracranial extension and infection (Johnson et al, 1983; Mafee et al, 1986; Meyerhoff et al, 1978; Swartz et al, 1983).

The far less common type of acquired cholesteatoma is seen through the pars tensa and occupies the mesotympanum, producing ossicular erosion. There may be extension into the sinus tympani, which is a relatively blind area both at otoscopy and surgery.

All of these inflammatory diseases within the middle ear are best studied with CT in two planes. To date, MRI offers no advantages over CT. Contrast-enhanced CT of the cerebellum and temporal lobe is necessary if cerebritis or abscess is suspected.

Congenital cholesteatoma occurs most commonly within the middle ear of a child without a history of ear infection, presenting as a soft tissue mass behind the tympanic membrane that is easily visible to the otologist. Congenital cholesteatoma or epidermoid also affects the petrous apex and will be considered under tumors later in this chapter.

External otitis

External otitis is a chronic infection that usually occurs in elderly patients with diabetes, secondary to chronic *Pseudomonas* infection. This is a virulent disease that produces extensive destruction of cartilage and bone and may mimic invasive squamous cell carcinoma on CT (Fig. 150-2) (Chandler, 1968; Mendelson et al, 1983).

Petrous apex infections

Petrous apicitis is an infection involving the air cells of the petrous apex, leading to the Gradenigo syndrome, which consists of palsies of the fifth and sixth cranial nerves. Tuberculosis was at one time one of the more important causes of this syndrome, although bacterial infections now are the primary cause. CT scanning demonstrates opacification of air cells in the petrous apex (Fig. 150-3, A) and often bone destruction from chronic infection (Mafee et al, 1985a). MRI shows the hyperintensity of inflammatory tissue on long TR sequences (Fig. 150-3, B).

Neuronal inflammation

Inflammation of the seventh and eighth cranial nerves may lead to decreased hearing, tinnitus, abnormalities of balance, or facial muscle weakness. In the past no imaging study could demonstrate such inflammation, but gadolinium-enhanced MRI can now be utilized to make this diagnosis (Figs. 150-4 and 150-5). Bilateral nerve enhancement must be viewed with caution, since cranial nerves can occasionally enhance normally from the presence of perineural vascular complexes (Fig. 150-5). However, patients with neuronitis may have bilateral involvement, and hence clinical correlation is necessary. Unilateral enhancement is probably always pathologic, but again the need for clinical correlation is obvious (Tien et al, 1990).

Trauma

Fractures of the petrous bone may be divided into longitudinal (80%) and transverse (20%) types. The longitudinal fractures courses in the direction of the long axis of the petrous bone, although the fracture line is generally not in a perfect line along the long axis but rather is frequently somewhat oblique (Fig. 150-6). It is commonly associated with a fracture of the temporal bone from direct trauma to the side of the head. Disruption of the ossicles occurs frequently (Fig. 150-6), producing a conductive hearing loss, but involvement of the cochlea and other inner ear structures is uncommon. Involvement of the seventh cranial nerve is usually along the promontory, near the geniculate ganglion, or occasionally in the descending portion of the fallopian canal (Healy, 1982; Hough, 1980).

The transverse fracture is directed at right angles to the long axis of the petrous bone. It occurs with a blow to the occiput or frontal bones producing a coup/contrecoup type of injury, with the vector of the force directed perpendicular to the petrous bone. The fracture line commonly courses across the bony labyrinth, producing profound sensorineural hearing loss or seventh nerve palsy (Heady, 1982; Hough, 1980).

CT scanning is by far the most accurate technique for the visualization of these fracture, with thin-section non-enhanced scanning in two planes and reformatted images in multiple planes the best method for defining the extent of the fractures (Fig. 150-6) (Schubiger et al, 1986). Vascular injuries may be associated with petromastoid trauma. The fracture line may pass through the sigmoid plate, with a secondary occlusion of the sigmoid sinus. This may lead to further dural sinus occlusive disease and secondary increased intracranial pressure, cerebral venous thrombosis, and hemorrhagic infarction. Arteries may also be involved, given the vectors of force. A temporal bone fracture may be associated with a torn middle meningeal artery, producing a temporal fossa epidural hematoma. The internal carotid artery may be torn in its high cervical or petrous segments, leading to vascular occlusive disease either from the primary thrombosis or subsequent embolization. MRI is excellent for the demonstration of the occluded vessels and the subsequent effect on the cerebral parenchyma, with angiography utilized for confirmation as necessary.

Mass lesions

CPA/IAC masses

Schwannoma. Schwannoma (acoustic neuroma, neurinoma, neurilemmoma, neurofibroma) may occurs spontaneously as a unilateral tumor or bilaterally as part of the neurofibromatosis (NF-II) syndrome. The superior vestibular nerve is usually the site of origin of this tumor, although a balance disorder as the presenting symptom is significantly less common than tinnitus, hearing loss, or seventh nerve palsy. The tumor may be purely intracanalicular, generally occurring above the crista falciformis, because of its origin from the superior vestibular nerve, but it may also begin at the porus or more medially nearer the pontomedullary junction (Danzinger et al, 1975).

On CT, the typical schwannoma is isodense to the brain stem and enhances dramatically. Tumor greater than 1 cm may have low-density portions representing central necrosis or cyst formation. This is in contradinstinction to the typically homogeneous meningioma. CT scanning is excellent for demonstrating extracanalicular tumors greater than 1 cm in size, but a lesion less than 1 cm in size or purely intracanalicular may be missed on even thin-section, enhanced CT scans (Davis et al, 1977; Moller et al, 1978; Naidich et al, 1976; Parker and Davis, 1977).

Gadolinium-enhanced MRI is the methodology of choice for the demonstration of a schwannoma (Haughton et al, 1988; Latchaw et al, 1990b; Schaffer, 1990). Purely intracanalicular tumors are easily diagnosed using axial and coronal MRI, with this imaging technique having replaced all others for this diagnosis. A tumor as small as a few millimeters may be easily visualized as a markedly hyperintense mass within the IAC (Fig. 150-7). Tumors less than 1 cm in the CPA are easily demonstrated on enhanced MRI because of their marked hyperintensity without obscuring artifacts typical of CT scanning. Larger tumors within the CPA may be less homogeneous, typical of their CT appearance. Nonenhanced MRI typically demonstrates a tumor that is isointense to slightly hypointense relative to the brain stem on the T1-weighted sequence, with marked hyperintensity on the long TR, long TE study, with an intensity similar to cerebrospinal fluid (CSF). Hence, small (< 5 mm) lesions may be missed on the long TR study because of partial volume averaging with the CSF (Enzmann and O'Donohue, 1987). Because of these characteristics, the lesion is not nearly

as conspicuous on enhanced MRI as with a gadolinium-enhanced study.

Angiography is only utilized for a large tumor when certain angiographic parameters are considered important for surgical removal. Embolization has no part in the management of this tumor.

Patients with schwannoma who are not operated on should have yearly studies. Laasonen and Troupp (1986) have shown the doubling time of schwannomas to range between 205 and 1090 days. MRI with gadolinium enhancement is the procedure of choice for this follow-up (Fig. 150-7), as it is for the postoperative patient (remembering to also obtain a nonenhanced study) (Houghton et al, 1988).

Meningioma. Meningioma is the second most common tumor in the CPA. It differs from schwannoma in that it only rarely extends into the IAC, since it is a broad-based tumor occurring along the petrous bone, commonly at a slight distance from the IAC. On CT the tumor is relatively isodense to the brain stem and cerebellum on the nonenhanced study and enhances intensely and homogeneously (Fig. 150-8). The tumor is frequently seen to extend through the tentorial incisura, displacing the mesencephalon laterally, with extension into the cavernous sinus. This type of extension is extremely rare for schwannoma in our experience (Latchaw and Hirsch, 1991; Latchaw et al, 1990b).

Nonenhanced MRI demonstrates meningioma to be isointense to slightly hypointense to the cerebellum on a T1-weighted study, with isointensity to slight hyperintensity relative to cerebellar gray matter on the long TR, long TE sequence (Latchaw et al, 1990b; Mikhael et al, 1985). This lack of more hyperintensity in the typical meningioma differs from schwannoma. Gadolinium-enhanced T1-weighted MRI demonstrates the typical homogeneous hyperintensity analogous to that seen on CT (Latchaw et al, 1990b).

Arachnoid cyst. The cerebellopontine angle is a relatively common location for an arachnoid cyst, which is an accumulation of CSF between the leaves of the arachnoid. The overwhelming majority of these lesions are congenital, with posttraumatic or postinfectious etiologies being far less common (Latchaw et al, 1990b; Latchaw and Nadell, 1976; Schuknecht and Fao, 1983). The lesion may exert a mass effect on the seventh/eighth nerve complex and on the contiguous brain stem and cerebellum. A small lesion may be inconspicuous on the CT scan because its density is equal to the CSF within the surrounding subarachnoid cisternae. The very thin membrane between the cyst and surrounding CSF is usually not visible. Suspicion for the presence of the lesion is aroused by the presence of local mass effect (Fig. 150-9). The lesion does not enhance (Latchaw et al, 1990b).

MRI may be of value in identifying the lesion, but because the fluid within the cyst is equal in intensity to CSF within the subarachnoid cisternae (Fig. 150-9), demarcation of the cyst may also be difficult. Positive-contrast CT cisternography will definitely show the lesion, with its low density demarcated from the higher-density contrast-containing CSF within the subarachnoid cisternae (Drayer et al, 1977).

Epidermoid. The overwhelming majority of epidermoids are congenital in etiology and grow slowly, producing a local mass effect similar to an arachnoid cyst. The epidermoid contains keratin, cholesterol, and debris from desquamated epithelium. The combination of these secretions and tissues usually produces a mass having a CT density equal to CSF, although lesions somewhat higher or lower in density have been encountered (Braun et al, 1977; Davis et al, 1976). It, too, does not enhance, but there may be calcification of its rim. Rupture of the capsule reveals an internal frondlike nature that may be coated by air or positive contrast. A characteristic is the insinuation of the epidermoid into crevices between normal neural tissues, with extension of the epidermoid from the CPA superiorly through the tentorial incisura (Latchaw et al, 1990c).

MRI may make the distinction of epidermoid from arachnoid cyst and from the surrounding CSF spaces. On the short TR (T1-weighted) study, the lesion is typically grayer than the blacker surrounding CSF. Using a very long TR and TE, the surrounding CSF will remain hypointense while the epidermoid decreases in intensity, allowing demarcation (Latack et al, 1985b; Latchaw et al, 1990c).

Metastasis. Tumors may occasionally metastasize to the cerebellopontine angle, producing a mass lesion simulating a schwannoma. On the nonenhanced CT scan, most metastases are relatively isodense to surrounding cerebellum and brain stem and enhance either homogeneously or with a low-density centrally necrotic component. On nonenhanced MRI, the typical metastasis is isointense or slightly hypointense to surrounding brain tissue on the T1-weighted sequence, becoming hyperintense to that tissue on the T2-weighted study, similar to a schwannoma. Enhancement is similar to that seen on the CT scan. Obviously, although a metastatic tumor may simulate a schwannoma, the growth rate, bone destruction, and presence of other lesions suggest metastatic tumor.

Jugular fossa masses

Chemodectoma (glomus jugulare tumor). The glomus jugulare tumor usually presents with symptoms of nerve compression involving cranial nerves IX through XI, and cranial nerve XII if the tumor is large. Pulsatile tinnitus is also common. Asymmetry in the size of the jugular foramina is normal and common, whereas bone destruction is the diagnostic criterion for a chemodectoma and is well shown on CT (Figs. 150-10 and 150-11). Even though the tumor is benign, bone destruction is usually irregular and may be extensive, simulating a more malignant tumor. The tumor may extend inferiorly into the upper neck (Fig. 150-11), superolaterally into the middle ear by destroying the normal bony septum separating the middle ear cavity from the jugular fossa (Fig. 150-10), posteromedially and posterolaterally into the posterior fossa, and anteriorly through the base of the middle cranial fossa. The tumor is very vascular, enhancing homogeneously on both CT and MRI (Fig. 150-11). The unenhanced CT demonstrates a tumor of density equal to cerebellum, with the multiple sequences on the unenhanced MRI demonstrating tissue having an intensity equal to cerebellum (Kalovidouris et al, 1984; Latchaw et al, 1990c; Vogl et al, 1989).

Angiography is diagnostic, always demonstrating a markedly hypervascular tumor that is supplied from multiple sources, depending on the size of the neoplasm (Fig. 150-11). The most common angiographic supply is from the ascending pharyngeal artery, the artery supplying the dura in the region of the jugular fossa. As the tumor extends superiorly, it may derive supply from the posterior division of the middle meningeal artery, with other supplies being from the stylomastoid branch of the occipital artery and from the posterior auricular artery. The extension along the petrous carotid artery may parasitize small petrous branches, with the anterior and posterior meningeal branches of the vertebral artery supplying tumor near the foramen magnum (Duncan et al, 1979; Monet et al, 1982). Angiographic evaluation is followed by embolization, especially using particulate materials, to decrease the vascular supply preoperatively (see Chapter 186).

Schwannoma. A schwannoma may arise from any of the cranial nerves IX through XII, although this is distinctly rarer than the schwannoma arising from the seventh/eighth cranial nerve complex. Like the schwannoma of the CPA/IAC, enhanced CT and MRI demonstrate intense enhancement, which is homogeneous when the tumor is small and nonhomogeneous because of central necrosis when the tumor enlarges. The jugular fossa tumor is indistinguishable from that in the CPA other than for its more inferior location (Latchaw et al, 1990b). It is hypovascular to minimally hypervascular on angiography.

Meningioma. Jugular fossa meningioma is a rare lesion but has radiographic findings similar to that of the CPA meningioma. It is mildly to moderately hypervascular on angiography.

Tympanic cavity masses

Chemodectoma (glomus tympanicum tumor). This reddish blue mass arises along the promontory and is similar to that seen in the region of the jugular fossa. It is necessary to differentiate a primary tympanic tumor from extension of a larger glomus jugular tumor. CT scanning demonstrates the intact bony septum between the hypotympanum and the jugular fossa with the typical glomus tympanicum tumor (Fig. 150-12, A) (Som et al, 1983). It is also necessary to exclude a jugular bulb invaginating into the middle ear or an aberrant carotid artery. The bony findings related to these entities are described later in this chapter. The major arterial supply to the glomus tympanicum tumor is from the caroticotympanic branch of the internal carotid artery (Fig. 150-12, B) (Lasjaunias and Moret, 1978). Embolization plays no role with this tumor.

Vascular masses. The aberrant carotid artery and high jugular bulb are described later in this chapter.

Cholesteatoma. Cholesteatoma has been previously described. Clinical differentiation between cholesteatoma and the blue-red glomus tympanicum tumor is usually not a problem, although the addition of granulation tissue to the cholesteatoma may simulate a chemodectoma.

External auditory canal mass: squamous cell carcinoma

The major tumor to consider is squamous cell carcinoma, which produces destruction of the cartilage and bone of the external canal. Differentiation from external otitis must be made clinically.

Petrous bone masses

Hemangioma. Primary hemangioma of bone produces a thickened, sclerotic, and pock-marked petrous bone, typically the tegmen. This diffuse thickening is characteristic (Curtin et al, 1987; Lo et al, 1989). It is usually not as extensive or as homogeneous as fibrous dysplasia, nor are there the multiple phases seen with Paget's disease.

Cholesterol granuloma. Cholesterol granuloma usually involves the petrous apex, resulting from obstruction of air cells with secondary deposition of cholesterol crystals and granulomatous material, vascular proliferation, and hemorrhage. On CT there is a well-circumscribed expansile lesion of the petrous apex without enhancement (Fig. 150-13, A), simulating epidermoid (Gacek, 1980; Lo et al, 1984). The MRI characteristics, however, differ from epidermoid in that the lesion is bright on the T1-weighted image because of the presence of cholesterol and methemoglobin products, and the lesion remains bright on the T2-weighted sequence (Figs. 150-13, B and C). There is hypointense rim representing either the expanded bone or hemosiderin (Greenberg et al, 1988; Latack et al, 1985a).

Primary malignant bone tumors. A variety of sarcomas arise in the petrous bone, such as osteogenic sarcoma or fibrosarcoma. They are characterized by aggressive bone destruction without other evidence of more diffuse disease to suggest metastatic tumor (Bird et al, 1983).

Metastasis. Metastatic tumor may involve the petrous and peripetrous regions, producing bone destruction.

Histiocytosis X. The petrous bone is a common location for involvement with histiocytosis X in the child. Aggressive bone destruction may be seen. The diagnosis can be suggested by the presence of bone destruction in both the petrous bone and orbital/retroorbital regions (Latchaw et al, 1990a).

Chordoma. Clival chordoma may extend laterally to involve the contiguous petrous apex. The tumor is slow growing, and calcification may be present. The MRI and CT characteristics may be present. The MRI and CT characteristics, along with enhancement patterns, are nonspecific (Brown et al, 1990; Latchaw et al, 1990b).

Congenital anomalies

Hypoplasia/atresia of external and middle ear cavities

Congenital anomalies of the external canal are usually accompanied by anomalies of the middle ear (Fig. 150-14) but not always (Fig. 150-15). They result in varying degrees of conductive hearing loss, deformity of the auricle, and facial weakness. Multiprojectional CT scanning with sagittal and coronal reformatted imaging is essential for evaluation. CT can differentiate external canal atresia from stenosis and can distinguish bony and soft tissue components. It can demonstrate the thickness of the atresia plate, the degree of mastoid pneumatization, the extent of development and aeration of the middle ear cleft, the presence and configuration of the ossicles and their attachment to the atresia plate, the location and course of the fallopian canal and facial nerve (Figs. 150-14 and 150-15), and the presence of any associated maldevelopment of the inner ear structures. Generally, the bony labyrinth is normal, although in approximately 25% of cases there may be an anomaly (Nager and Levin, 1980; Swartz and Faerber, 1985).

Anomalies of bony labyrinth

The majority of patients presenting with congenital sensorineural hearing loss have abnormalities not detectable on CT or MRI. Occasionally, there may be an anomaly of the inner ear. The Mondini malformation is characterized by a decrease in the number of turns within the cochlea. The classic Mondini malformation has a cystlike space representing the cochlea (Figs. 150-16 and 150-17), although there is a wide spectrum of Mondini malformations, with only subtle variations reported. Enlargement of the vestibule (Fig. 150-17, B) or semicircular canals is a frequent concomitant feature. The Michel malformation is aplasia of the bony labyrinth with no visible cochlea or vestibule and only a tiny internal auditory canal carrying the seventh cranial nerve (Jensen, 1974; Mafee et al, 1984). It is a very rare malformation occurring either spontaneously or secondary to thalidomide ingestion.

Diseases of vascular origin

The most common presentation of a lesion of vascular origin is pulsatile tinnitus. The evaluation of pulsatile tinnitus has been difficult because of the multitude of possible etiologies and available tests. Remly et al (1990) have recently developed an algorithmic approach to this patient population that has simplified the radiographic evaluation. It is based on the type of bruit present, objective versus subjective, and the findings at otoscopy.

High-resolution computed tomography (HRCT) is the initial study in all patients having otoscopic evidence of a vascular retrotymppanic mass. HRCT can distinguish the normal middle ear from vascular variants, including the aberrant internal carotid artery and a high jugular bulb, and from tumor such as a chemodectoma.

Normal otoscopy and both objective and subjective tinnitus should lead directly to angiography to exclude lesions such as dural arteriovenous malformation (AVM) or fibromuscular dysplasia of the carotid artery. Normal otoscopy and only subjective tinnitus should have HRCT first. If normal, angiography can be performed to definitely exclude AVM. Twenty percent of patients with pulsatile tinnitus and normal otoscopy did not have a

radiographic abnormality in the study by Remly et al (1990).

Arteriovenous malformations

The most common form of arteriovenous malformation (AVM) producing pulsatile tinnitus is the dural AVM, which most likely is secondary to transverse or sigmoid sinus or jugular bulb occlusion resulting in an opening of arteriovenous connections supplied by dural arteries. The dural sinus occlusive disease may recanalize, although it is still visible in many patients at angiography (Houser et al, 1979). These lesions may produce only a mild subjective bruit, but the bruit may increase and become so disturbing that suicide is contemplated. This lesion is notoriously difficult to treat and frequently persists or recurs whatever the treatment modality. Embolization is considered to be the primary form of treatment at this time. Embolization is generally withheld unless symptoms are moderate to severe. Treatment usually requires initial occlusion of arteries feeders using a liquid tissue adhesive since particulate embolization only leads to recanalization. Occlusion of the affected dural sinus with metallic coils or a tissue adhesive in addition to arterial embolization is frequently necessary to produce a significant reduction in flow (Halbach et al, 1990).

Vascular loop

Small arteries or veins coursing across the seventh/eighth cranial nerve complex, particularly near the porus acusticus, may be productive of pulsatile tinnitus. These crossing vessels may be seen on either air CT cisternography (Fig. 150-18) (Esfahani and Dolan, 1989) or on enhanced MRI with thin sections (Fig. 150-19). The etiology, diagnosis, and treatment of this disorder are controversial. Some investigators advocate separating the vessels from the nerves by a strip of Teflon, similar to the vascular decompressive procedures performed on other cranial nerves (Jannetta, 1979).

Aneurysm

An aneurysm of the anterior inferior cerebellar artery is a rare lesion. More common are larger aneurysms of the vertebral and basilar arteries, but these usually produce brain stem and cranial nerve compressions beyond simple pulsatile tinnitus.

Fibromuscular dysplasia of internal carotid artery

Fibromuscular dysplasia (FMD) produces a weblike constrictions of the internal carotid artery leading to turbulence of blood flow through the carotid artery, which is perceived as pulsatile tinnitus. CT and MRI are not capable of visualizing this lesion, and angiography is necessary. Balloon angioplasty may be curative (Hasso et al, 1981; Starr et al, 1981).

Aberrant internal carotid artery

The aberrant internal carotid artery represents a congenital posterolateral position of the internal carotid artery, with the bony septum between the carotid canal and the middle ear cavity missing (Fig. 150-20). CT scanning is diagnostic of this anomaly (Swartz et al, 1985). Commonly there is also an aberrant stapedia artery giving rise to the middle meningeal artery, with aplasia of the foramen spinosum on that side. A bluish red mass is seen through

the tympanic membrane and must be differentiated from a high jugular bulb or a glomus tympanicum tumor (Swartz et al, 1985). Biopsy by the unsuspecting otologist may be disastrous, requiring embolic occlusion of the carotid artery as a life-saving measure (Reilly et al, 1983).

High jugular bulb

A high jugular bulb is a common congenital anomaly, usually seen incidentally on the CT scan (Fig. 150-21). Occasionally, the bulb may erode the thin membrane of bone separating the jugular fossa from the middle ear cavity, with a bluish mass presenting in the middle ear cavity. Again, differentiation from other lesions by CT is necessary so that biopsy is avoided (Llogy et al, 1979).

Ischemia/infarction of cerebral tissue

Ischemia/infarction caused by vascular insufficiency leads to abnormalities of the brain stem, cerebellum, and cerebral hemispheres. MRI is superior to CT scanning in the diagnosis of these lesions. Although T1-weighted sequences may show subtle low-intensity abnormalities, the long TR, long TE sequences show areas of hyperintensity (Fig. 150-22) (Hecht et al, 1990). In the right context, differentiation between ischemic changes and demyelinating disease may be made.

Miscellaneous diseases

Ménière's disease

The etiology of Ménière's disease remains controversial. Procedures on the endolymphatic sac and vestibular aqueduct are advocated by many. Evaluation of the size and configuration of the vestibular aqueduct received attention in the past, but correlation between these radiographic findings and the patient's symptoms and operative outcome has been inconclusive (Dreisbach et al, 1983). CT scanning in the preoperative patient is useful, however, for evaluation of the thickness and pneumatization of the mastoid, the size and relationship of the sigmoid sinus and jugular bulb to the vestibular aqueduct, and the presence of other anatomic variants (Fig. 150-23) (Dreisbach et al, 1983). The patient should receive a preoperative gadolinium-enhanced MRI to exclude schwannoma as a cause of the symptoms.

Demyelinating disease

Plaques of multiple sclerosis (MS) may occur within the cerebellum and brain stem, producing disorders of balance simulating primary diseases of the petrous bone. MRI is the procedure of choice for the diagnosis of demyelinating disease. The long TR, long TE sequence demonstrates focal areas of hyperintensity within the brain stem, cerebellum, cerebellar peduncles, and cerebral hemispheres. Particularly characteristic are the presence of plaques within the brachium pontis and the corpus callosum. Lesions in these locations are not typical of ischemic disease. Correlation with CSF chemical studies is necessary.

Otosclerosis

Otosclerosis is a disease of unknown etiology usually occurring in families, beginning in adolescence and progressing with age. Two forms are recognized, the fenestral form producing conductive hearing loss, and the cochlear form producing sensorineural hearing loss.

The fenestral form is characterized by a decrease in the lucency of the oval window niche seen on the high-resolution CT scan (Fig. 150-24). Thickness of the bony promontory is present in more advanced cases. It should be emphasized that these findings are subtle at best, requiring very high-resolution CT with the bone algorithm (Swartz et al, 1984).

The cochlear form decreases sharpness of the margins of the cochlear lucency, particularly the basal turn (Fig. 150-24). Progression over time leads to a progressive increase in the intensity of the normally lucent cochlear turns (Fig. 150-24) (Mafee et al, 1985b).

An important role of CT is in the evaluation of the position of a prosthesis following stapedectomy in a patient who has a change in conductive hearing. The metallic piston device and Teflon prosthesis can be well demonstrated by CT (Fig. 150-25), whereas the most common device, the 35-gauge wire, can be difficult to demonstrate (Swartz et al, 1986).

Presurgical planning for cochlear implant

CT scanning is essential before undertaking cochlear implantation. It allows assessment of the size and anatomy of the hypotympanum and of the round window niche necessary to perform the procedure successfully (Fig. 150-26) (Dreisbach and Balkany, 1988).