Chapter 2: Radiology of the ear

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The petrous temporal bone is a complex structure containing important tiny bony objects such as the crura of the stapes and canals such as the vestibular aqueduct, which are less than 1 mm in diameter. These are close to the limits of resolution by imaging techniques. Good spatial resolution to allow adequate demonstration of these bony structures in the middle and inner ears has been an important requirement of radiographic equipment for many years. Spatial and density resolution are discussed in Volume 1, Chapter 17.

The major disadvantage of plain films is caused by overlap of structures which makes interpretation difficult. Historically, a great range of views has been described to try to overcome this problem. These specialized projections have now been almost entirely superseded by sectional imaging techniques, and only a few standard projections are required in practice.

Plain X-ray examination

The author rarely uses any plain film views other than the first four basic projections. The two that show both sides on one film are standard skull views with the field size reduced.

Lateral view

Since the temporal bones are symmetrically placed, a true lateral view results in superimposition of the two sides; it is therefore necessary to angle the incident ray, or alternatively the skull, in order to prevent this. The greater the tilt, the more the attic (epitympanic recess) and antrum will be thrown clear of the mass of bone around the labyrinth, but this is offset by increased distortion. As shown in Figure 2.a, the lateral projection of the petromastoid is obtained by placing the head in a true lateral position and angling the tube caudally 15°, thus preventing superimposition of the mastoid processes. The incident beam is centred 5 cm above the uppermost external auditory meatus. The angled lateral view results in superimposition of the petrous bone on the mastoid process and similarly of the internal and external auditory canals (Figures 2.1b and c). The view allows assessment of the degree of pneumatization of the mastoid, the state of translucence of the air cells and the position of the sigmoid sinus and its relation to the tegmen tympani. The attic, aditus and mastoid antrum are also visible. Erosion of the attico-antral region and of the bony bridge formed by the outer attic wall can be shown, but only when this is extensive.

Oblique posteroanterior (Stenvers’) view

In this view, the whole length of the petrous bone is demonstrated by placing it parallel to the X-ray film with the incident ray passing at right angles. When a ‘skull-table’ is used, the patient sits erect facing the film. With the radiographic baseline horizontal, the sagittal plane of the skull is rotated through 35° and tilted 15° away from the side to be examined (Figure 2.2a). The incident ray is inclined at an angle of 12° cranially and is centred on a point 2 cm medial to the tip of the mastoid process. A radiograph of Stenvers’
position should demonstrate the petrous tip and internal auditory meatus, the semicircular canals (superior and lateral), the middle ear cleft, the mastoid antrum and the mastoid process (Figures 2.2b and c). Erosion of the petrous tip and widening of the internal auditory (acoustic) meatus may be shown on this projection, although these changes are generally better demonstrated by tomography.

**Submentovertical (axial or base) view**

This is an important item in the X-ray examination of the ear, and no study by plain radiography is complete without it. In the classical position, the baseline is parallel to the film, and the incident beam centred at a point midway between the angles of the mandible. If the centring point is too far anterior or the head insufficiently extended, the angle of the jaw is projected over the middle ear and obscures it. To avoid this, a centring point slightly lower than that used in the classical position is recommended (Figure 2.3a). The radiograph demonstrates the middle ear, the external and internal auditory meatus and the bony eustachian canal (Figures 2.3b and c). This plain view of the middle ear provides the best plain X-ray assessment of its air content, the degree of translucence, and of the ossicular chain. The malleus and incus may be clearly visible; the cochlea should also be identified.

**Half-axial (Towne's) view**

The reversed Towne's view (Figure 2.4a) should be used whenever possible because of the large radiation dose to the eyes in the classical position. The internal auditory meatus, most of the labyrinth and middle ear are shown, together with enlargement and erosion of the attic and antrum (Figures 2.4b and c).

**Periorbital view**

This is the best view of the internal auditory meatus if tomography is unavailable and should be carried out in the posteroanterior position to avoid radiation to the eyes. The orbitomeatal line is at right angles to the film. The tube is angled 5-10° caudally, centring between the orbits (Figure 2.5a). The petrous pyramids and internal auditory meatus are thus projected through the orbits (Figure 2.5b).

**Jugular foramen view**

A symmetrical bilateral projection showing the margins of the jugular fossa can be obtained with the patient lying supine with the head extended so that the baseline is at 45° to the table top (Figure 2.6). This view is needed when a glomus jugulare tumour is suspected.

**Conventional tomography**

Although linear tomography is still used for the examination of the petromastoid, it is generally less satisfactory than complex motion tomography using a hypocycloidal or spiral movement of the X-ray tube. This gives even blurring of structures outside the plane of the section and cuts approximately 1 mm thick. Good technique and limitation of radiation to the
eyes by use of shields or the prone position are necessary. Rigorous beam collimation will both reduce radiation dose and improve definition. The technical factors are discussed in Volume 1, Chapter 17.

**Coronal sections**

These are taken with the orbitomeatal line at right angles to the film and table-top. For routine examination, tomographs are obtained at 2-mm separation of the sections. These should cover the full extent of the labyrinth from the apical turn of the cochlea to the posterior semicircular canal and allow comparison between the two sides. Four or five films are usually sufficient to show the internal auditory meatus, labyrinth, oval window (fenestra vestibuli), ossicles and the descending portion of the facial nerve.

There are two sections in the coronal plane that are important and must be recognized; these pass through the centre of the cochlea and vestibule respectively (Figure 2.7). The cochlear cut shows the modiolus or central bony spiral as a 'curl', while above the cochlea is the pit for the geniculate ganglion of the facial nerve. The ossicle shown in the middle ear cavity is the malleus. The vestibular cut, 3 or 4 mm posteriorly, shows the oval window and also the full length of the internal auditory meatus. The ossicle is the incus and sometimes the stapes may be demonstrated. The outer attic wall, which also forms the roof of the deep part of the bony external auditory meatus is, because of its appearance, called 'the spur'. The carotid canal and jugular fossa are shown in the cochlear and vestibular cuts respectively, below the labyrinth.

In the author's opinion polytomography in the coronal plane, especially the vestibular cut, provides the most satisfactory demonstration of the state of the bony margins of the internal auditory meatus. A two- or three-film examination, using lead shields on the patient's eye, provides one of the quickest, cheapest and most reliable screening examinations in the search for an acoustic neuroma. Lateral tomography can help to confirm whether any widening of 2 mm or more, shown on the coronal sections, is the result of expansion by a neuroma or merely asymmetry.

**Lateral tomography**

For sections in the sagittal plane, the head is placed in the true lateral position; they are made at 2-mm intervals through the petrous pyramid, middle ear and external auditory meatus, depending on the site of the pathological change. The labyrinth is not well visualized, but an appropriate section through the middle ear will demonstrate the bodies of the malleus and incus (Figure 2.8) as well as the descending portion of the facial nerve. Tomography of the middle ear in the true lateral position results in an image of the malleus and incus which has been likened to the appearance of a 'molar tooth'. The head of the malleus and the body of the incus combine to represent the crown of the tooth, the handle of the malleus forms the anterior root and the long process of the incus, the posterior root. The crown should normally appear as a solid shadow; any disruption of this image either in the form of separation of its two components, or their misalignment, indicates a dislocation. Divarication of the roots of the image also indicates displacement of the incus. A lateral projection is used to assess the cross-sectional appearances of the internal auditory meatus and any erosion of its posterior wall.
Lateral tomography is particularly important because of the difficulties encountered with computerized tomographic (CT) scanning in the sagittal plane. Such CT images must be obtained either with the patient in an uncomfortable position or by reformatting from axial slices when much spatial resolution is lost; this is the result of intrinsic distortion and partial volume averaging, as well as motion which may occur not only during scanning but also during the interscan time. Sagittal sections through the jugular fossa and carotid canal are a most important part of the examination to differentiate glomus tumours and other vascular masses and anomalies in the middle ear (Phelps and Lloyd, 1986). A smoothly outlined jugular fossa with an intact spur or crest of bone separating it from the carotid canal (Figure 2.9) virtually excludes a glomus jugular tumour, but not a glomus tympanicum or high jugular bulb (see below).

Another important structure best demonstrated by lateral tomography is the vestibular aqueduct. The rather variable course of the vestibular aqueduct means that further sections in a slightly off-lateral position may be required (Stahle and Wilbrand, 1974). This usually means elevating the chin of the patient about 20° if the underside temporal bone is being examined. The key to the correct level for identifying the vestibular aqueduct is the crus commune of the superior and posterior semicircular canals (Figure 2.10). Stahle and Wilbrand (1974) reported that Ménière's disease is often associated with absence of periaqueductal pneumatization. They classified periaqueductal pneumatization into three types:

1. large air cells
2. small air cells
3. absence of periaqueductal pneumatization.

They found that 75% of patients with Ménière's disease are type 3. More recently Valvassori and Dobben (1984) and Arenberg et al (1984) have discussed the demonstration of the vestibular aqueduct by both tomography and CT. In practice, these techniques appear to be of value only in the preoperative assessment for endolymphatic sac surgery, particularly for showing the position of the jugular bulb and sigmoid sinus. A high jugular bulb with diverticulum may even cause endolymphatic hydrops by compressing the endolymphatic duct (Jahrsdoerfer, Cail and Cantrell, 1981). (See the section on vascular anomalies.)

**Modified coronal section tomography**

**Zonography (see Figure 2.5)**

As an alternative to the evaluation of the internal auditory meatus by coronal hypocycloidal tomography, thick section tomography or zonography using a circular motion of the tube can be employed. Usually two or three zonograms suffice to give adequate visualization of the internal auditory meatus on both sides. The result is, in effect, a superior version of the periorbital view described in the section on plain X-ray technique.

**Semi-axial or Guillen projection (Figure 2.11)**

Another modification of tomography in the true coronal plane is the position corresponding to the Guillen projection on plain X-ray. The middle ear cavity, and in
particular its medial wall, incline medially as they run forward to the eustachian tube. Consequently, for optimal demonstration of the important region of the oval window and promontory, 15° of rotation from the coronal plane are necessary. In order to achieve this, the head is turned from the coronal plane 15° towards the side to be tomographed. The small canal containing the second part of the facial nerve is demonstrated in cross-section below the lateral semicircular canal on this view. The appearance of the section differs little from that of similar coronal section and, consequently, the author rarely uses this projection. Its main drawback is that both petrous bones need to be tomographed separately.

For full evaluation of the cochlea it is necessary to demonstrate the individual coils. To do this, the long axis of the modiolus or central bony spur must be in the plane of the section. Two projections fulfil this condition: the base and the axial-pyramidal. For the latter, the head is turned 45° towards the side to be examined.

**Computerized tomography**

The ability of CT to show intracranial lesions was its first and most important contribution to diagnostic imaging. For the otologist, the premier role of CT is the demonstration of intracranial complications of suppurative ear disease, such as brain abscess, and the intracranial extension of tumours of the petrous temporal bone, such as glomus and acoustic neuroma. Normal brain scan techniques with contrast enhancement are required. Since the introduction of high resolution thin-section computerized tomography, it has become the optimum technique for the study of the temporal bone. The bony portions of the petromastoid are depicted with approximately the same resolution as with complex motion tomography, but the better contrast, freedom from spurious shadows, and fewer problems with soft tissue silhouetting, make the pictures much easier for the non-expert to interpret, as well as being much easier to reproduce as illustrations (see Volume 1, Chapter 17). It is, however, the ability of CT to depict the soft tissue components within and adjacent to the temporal bone that has provided the major advance. Contrast enhancement of masses may be helpful in the diagnosis but, generally, tissue characterization in the middle ear particularly has been disappointing and relies on the anatomical configuration and situation of the mass. Thus, a profound knowledge of temporal bone anatomy is mandatory for the interpretation of these sectional images.

Although many planes, equivalent to those formerly described for conventional tomography, are advocated by some European authorities (Zonneveld et al, 1984), these must add enormously to cost, patient irradiation and examination time. In most institutions, only sections in the axial (base or horizontal) plane supplemented by frontal views in the coronal plane are used. Section thickness may vary between 1.5 and 5.0 mm, depending on the machine and a wide window setting should be used; contiguous sections cover the whole temporal bone. Sections at 1 mm intervals are not normally required unless reformatting in other planes is envisaged.

There are two important sections in the axial plane which may be labelled the cochlear and vestibular cuts. The cochlear cut shows the individual coils and is equivalent to the mid-modiolar section of the histologists. The vestibular cut shows the vestibule and lateral semicircular canal as a ‘signet ring’ (Figure 2.12). The posterior semicircular canal is an
important landmark for the surgeon operating on an acoustic neuroma. Lower sections in the axial plane show the whole length of the basal coil, the hook and round window niche (Figure 2.13). Below the basal turn, lie the carotid canal and jugular fossa with a crest of bone between them (Figure 2.14). The head of malleus and body and short process of incus, as well as the joint space are best visualized in the vestibular cut, while their long processes are seen in lower sections. The crura of the stapes may sometimes be seen in the cochlear cut.

Axial scans are followed by sections made with the patient's head extended as near as possible in the true coronal plane, and for this a machine with a tilting gantry is a distinct advantage. Once again, the two most important sections may be labelled the cochlear and vestibular cuts. In the coronal plane, the cochlear cut does not show the individual coils as well as the axial plane but depicts the central bony spiral as a small 'curl'. The vestibular cut, about 4 mm posteriorly, shows the oval window and the lateral and superior semicircular canals. The malleus is demonstrated in the cochlear cut and the incus in the vestibular cut. The carotid canal and jugular fossa are also shown in the cochlear and vestibular cuts respectively.

Two further sections behind the vestibular cut are important. Immediately behind the incudo-stapedial region, the pyramidal eminence lies between the facial recess and sinus tympani and appears as a small blob of bone (Figure 2.15). The cochlear aqueduct is found at this level but usually only the wider medial part can be identified. Further back still, the descending part of the facial nerve canal can be seen (Figure 2.16). The internal auditory meatus is best seen in the vestibular cut in either axial or coronal planes.

**Air meatography - the demonstration of the contents of the internal auditory meatus and cerebellopontine angle**

Cost and limitations on scan time in the UK mean screening large numbers of patients for an acoustic neuroma using conventional radiography and tomography. Polytomography provides a quick, cheap assessment of the bony margins of the internal auditory meatus, but an equivalent demonstration is given by axial or coronal high resolution CT and all tumours larger than 1.5 cm should be demonstrable in the cerebellopontine angle by an enhanced posterior fossa brain scan. Nevertheless, to show the normal contents of the internal auditory meatus and angle and to demonstrate a small acoustic neuroma confined to the internal auditory meatus or extending only slightly into the cerebellopontine angle, introduction of an intrathecal contrast agent is necessary. At present, this is also the only certain way to exclude a small tumour.

Air-CT meatography is a simple and effective procedure, which the author believes causes no more morbidity or unpleasantness for the patient than a simple lumbar puncture. It is usually carried out on an outpatient basis. The technique is described below.

The patient lies on his side on the scanner table with the ear to be examined uppermost; a lumbar puncture is performed and cerebrospinal fluid sent for differential protein estimation. The patient is positioned at a sufficient spinal gradient to allow 3 mL of air introduced via the cannula to pass into the cervical region. After 2 minutes, the head is elevated, momentarily, to allow the air to pass through the foramen magnum and into the
cerebellopontine angle. The first section is made at the level of the internal auditory meatus and if air is demonstrated in the meatus, then the examination is terminated (Figure 2.17).

The seventh and eighth cranial nerves and the loop of the anterior inferior cerebellar artery can usually be recognized (Figure 2.18). Air may enter the medial aperture of the cochlear aqueduct - a feature of negligible importance so long as this is not thought by the observer to be the porus of the internal auditory meatus.

Other intrathecal contrast agents are rarely used in otoradiology. Large extra-axial masses in the posterior cranial fossa are not satisfactorily demonstrated by air CT studies, and if not clearly defined on the enhanced CT scan and magnetic resonance (MR) is not available, they are best outlined by positive intrathecal enhancing agents such as Iopamidol (Niopam), which can show the relation of the tumour to the brainstem. An example of this is cholesteatoma of congenital origin in the cerebellopontine angle (Figure 2.19).

**Magnetic resonance**

Bone produces a negligible signal on MR scans and so both the bone of the petromastoid and the air in the middle ear cleft and mastoid cell system appear as black areas on the scan, devoid of any bone detail so well demonstrated by tomography and high resolution CT. Thus, only soft tissue structures within the petrous temporal bone are imaged and this can be an advantage for the demonstration of the cranial nerves passing through the skull base, as the nerve itself will be shown, not the canal in which it lies. However, these techniques are still being developed and really need the application of surface coils to improve the definition. In contrast to the non-signal of compact bone, marrow spaces, which are very variable in extent but occur mostly in the petrous apex, give an intense signal because of their large fat content.

So far MR has been used almost solely in otology for the demonstration of an acoustic neuroma. Superior density resolution without contrast enhancement, absence of artefacts, and the potential for three-plane imaging mean that MR is already beginning to replace CT for the demonstration of masses in the posterior cranial fossa. Intra-axial masses are particularly well shown (see Volume 1, Chapter 17). It is also possible to show a small acoustic tumour within the internal meatus (Figure 2.20 and see Figures 21.13c and d), and MR may well eventually replace both the enhanced posterior fossa CT scans and the air-CT meatogram. Paramagnetic agents have been used to enhance these tumours in the same way that iodine-containing substances are given intravenously with CT. The response has been variable and the possibilities for tissue characterization are still being assessed (Curati et al, 1986).

Similarly, it is hoped that a high intensity signal (long $T_2$) in $T_2$ weighted images, characteristic of cholesteatoma, may make it possible to differentiate this from fluid, cholesterol granuloma and other causes of soft tissue opacification.

**Angiography**

Carotid or vertebral angiograms are usually of diagnostic value only in glomus jugulare tumours but may be required to show the vascular supply and the relation of other lesions, particularly a neuroma or meningioma (see Volume 1, Chapter 17). A carotid
angioogram may be used to demonstrate the very rare abnormal course of the internal carotid artery through the middle ear. Digital vascular imaging and therapeutic embolization techniques are considered briefly in Volume 1, Chapter 17.

Retrograde jugulography has been advocated to diagnose and show the extent of small glomus tumours of the jugular bulb. In the author's opinion, however, this examination is nearly always superfluous if good quality pictures are obtained with subtraction angiography. Rarely is jugulography required to confirm a high jugular bulb and diverticulum. Such vascular anomalies can usually be sufficiently well demonstrated by non-invasive techniques (see below).

Demonstration of the facial nerve canal

The facial nerve runs a complicated course through the temporal bone. From the lateral end of the internal auditory meatus to the stylomastoid foramen, the facial canal is divided into three parts, corresponding to their directions (see Figures 24.3, 24.4 and 24.5). These are difficult to demonstrate with conventional radiography and the Stenvers' view, which may show the descending part, is probably the only projection of value.

Labyrinthine part

Starting at the anterosuperior aspect of the lateral end of the internal auditory meatus, this short segment swings anteriorly above the cochlea to the pit for the geniculate ganglion, where the nerve turns sharply backwards to become the second part. This short length of canal may be shown by axial CT (see Figure 2.17), but the sulcus for the geniculate ganglion is well demonstrated in coronal sections (see Figures 2.7 and 2.12).

Tympanic part

From the geniculate ganglion to the second bend, the nerve runs backwards above the oval window and below the lateral semicircular canal which overhangs it. It is surrounded by a thin bony sheath which may be dehiscent. Its course is somewhat oblique (Figure 2.21) and the bony canal is, therefore, best seen in cross-section on the semi-axial projection (see Figure 2.11).

Mastoid or descending part

The third part of the nerve runs downwards from the second bend at the level of the pyramidal eminence to the stylomastoid foramen. Its length is partly dependent on the shape of the temporal bone and partly on the extent of pneumatization of the mastoid. Its width varies considerably. The bony canal is best demonstrated by coronal section and lateral tomograms, and CT (see Figures 2.8 and 2.16). Recognition is easy where the nerve passes through solid bone, but may be difficult where there is much pneumatization. In children with congenital ear lesions, it is important not to confuse the facial nerve canal with other dehiscences such as the tympanomastoid fissure.
Choice of investigation by imaging techniques

There are no 'routine' investigations of the temporal bone; all should be undertaken to try to solve a problem in diagnosis or to define the extent of a lesion. Our commonest examination is the study of the internal auditory meatus in patients with symptoms and signs of eighth nerve dysfunction who might have an acoustic neuroma. Examination by complex motion tomography is preferred and such coronal sections usually comprise the initial temporal bone investigation. Most centres would use a few plain film projections.

High resolution CT is now established as the most useful and versatile procedure for showing bone detail in the petrous pyramid, soft tissue abnormalities in the middle ear and extension of disease into the cranial cavity. It is supplanting all other imaging modalities and restricting the use of angiography. However, the extensive use of CT for almost all lesions of the petromastoid seems excessive, on grounds of cost and radiation dose to the patient. If the eyes are rigorously avoided, the good beam collimation of CT results in a corneal dose almost as low as polytomography with eyeshields. However, 20-25 slices, which included the orbits, were found to result in a considerable dose of radiation (12-15 cGy) using the most recent machine of a major manufacturer (see Volume 1, Chapter 17).

Otitis media is essentially a clinical diagnosis. Radiology shows only non-specific opacity of the middle ear cleft and is rarely required. It may however be useful for showing evidence of bone erosion in mastoiditis or alternatively for confirming that the air cells are indeed air containing. Similarly, the diagnosis of an acquired cholesteatoma with attic perforation is clinical, the treatment is surgical exploration, and radiology largely irrelevant, although it is now being claimed that cholesteatomata as small as 3 mm in size can be diagnosed much earlier by the use of CT (Schwartz, 1984). For cholesteatoma behind an intact eardrum, radiology is as important as it is for vascular masses in the middle ear cavity (see below). The demonstration of rarefaction of the labyrinthine capsule is sometimes useful to confirm the presence of otospongiosis.

A brief review of imaging techniques in some of these pathological processes is given below.

Congenital malformations

Congenital malformations of the inner, middle and external ear almost always present in childhood and are considered in Volume 6 (see Figures 25.4 and 25.5). This does not, however, apply to vascular anomalies which are usually discovered in late childhood or adulthood. The differential diagnosis of these vascular anomalies and their distinction from vascular neoplasms, especially glomus tumours is almost entirely dependent upon radiology (Phelps and Lloyd, 1986).

Vascular anomalies

Angiography has been considered the definitive investigation and in many cases is mandatory when there appears to be a vascular mass behind the eardrum. Exceedingly rare abnormalities are a persistent stapedial artery or an aneurysm of the internal carotid artery (Glasscock et al, 1980; Moffat and O'Connor, 1980). These can only be recognized by
angiography. This discussion concerns aberrations in position of the internal carotid artery and jugular bulb.

The anatomy of the jugular bulb is variable, the right usually being larger than the left. Not infrequently, it extends above the inferior rim of the bony annulus, with or without a bony covering. The anatomy has been comprehensively reviewed by Graham (1974), who quoted dissections by other authors showing the jugular bulb extending above the inferior rim of the annulus in 6% of specimens, and a similar percentage showing dehiscence in the bony floor of the middle ear cavity.

When the jugular bulb is small, it is separated from the floor of the middle ear by a comparatively thick layer of bone, which is usually compact, but may contain air cells. Anteriorly the bulb is in relationship with the internal carotid artery. A spur or crest of bone separates the jugular fossa from the carotid canal at the skull base (see Figure 2.9). When the jugular bulb is very large, it can extend up into the mesotympanum with a thin bony covering, which can easily be damaged at surgery (Figure 2.22). When there is dehiscence of this bony covering the exposed jugular bulb is at even greater risk. The soft tissue mass of a dehiscent jugular bulb cannot be adequately shown by conventional and tomographic imaging, but is well shown by CT, especially in the coronal plane, and by retrograde jugular venography (Figure 2.23).

Another aspect of the large jugular bulb is encroachment on inner ear structures. The internal auditory meatus, vestibular aqueduct and posterior semicircular canal may be affected, especially if there is an associated diverticulum from the bulb (Phelps and Lloyd, 1983b).

Aberrations in the course of the internal carotid artery through the petrous temporal bone are extremely rare. Normally the artery ascends vertically, medial and anterior to the middle ear cavity before bending sharply anterior and medially below the eustachian tube and cochlea; it then passes through the foramen lacerum into the cranial cavity. A thin bony septum separates the artery from the hypotympanum (see Figure 2.12). There is said to be dehiscence in 1% of people (Glasscock et al, 1980), but the true incidence is probably much less than this. If the ascending part of the artery is more posteriorly placed than usual with a very acute bend, it is more likely to be dehiscent (Figure 2.24), although the spur between the carotid and the jugular bulb remains intact. In more severe aberrations, a soft tissue mass will be shown in the middle ear by CT (Figure 2.25), but the important differentiating feature on coronal CT is absence of the normal carotid canal and a laterally and more posteriorly placed vertical canal (Figure 2.26). These features need to be confirmed by angiography and no attempt at surgical interference should be made (Figure 2.27).

Differential diagnosis

Enlargement of the jugular fossa may be demonstrated on plain X-ray by a transoral view or an undertilted submentovertical projection. It may also be demonstrated on coronal hypocycloidal tomography, but lateral hypocycloidal tomography is the more important projection at this stage of the investigation and will demonstrate either a high jugular bulb, or enlargement of the jugular fossa in an anterior direction, when it is likely that the jugular bulb will encroach on the middle ear. However, the best method of demonstrating this
anomaly is by high resolution CT scan when the jugular bulb can be seen as a rounded or dome-shaped opacity encroaching upon the middle ear space (Figure 2.28). High resolution CT in the axial plane will also show both the enlargement of the jugular bulb and the integrity of the cortex at the margin of the jugular fossa. This allows a distinction to be made between a large jugular bulb and the enlargement that takes place in the presence of a glomus jugulare tumour. In the anomaly of an aberrant carotid artery, it can be shown from angiographic studies that the vessel lies both more lateral than normal and more posteriorly. In this way, it may come to lie under the promontory in the middle ear, sometimes producing a small indentation. CT is again the definitive investigation since it is possible to show both the soft tissue mass of the vessel in the middle ear and also the abnormal course of the carotid canal.

Trauma

The value of radiology for injuries involving the petrous temporal bone may be summarized:

(1) to confirm the presence of a fracture line
(2) to show the site of injury to the facial nerve
(3) to demonstrate and confirm the pathway of a cerebrospinal fluid fistula
(4) to show foreign bodies
(5) in the late management of persistent conductive deafness ossicular dislocations may be shown.

The radiological investigation should relate to and depend upon the clinical picture. To demonstrate a fracture, the X-ray beam must be in or close to the plane of the fracture line and several projections in different planes are necessary. Tomography or high resolution CT will show more fractures than will plain films and are valuable for demonstrating more precisely their path and extent. The examination needs to be performed in at least two planes.

Although fractures of the petrous temporal bone follow no set pattern, they are usually classified with reference to the long axis of the petrous pyramid as longitudinal or transverse (see Figure 24.5).

The fracture line in the commoner longitudinal type is in the long axis of the petrous bone and, typically, it extends from the squama across the superior aspect of the bony external auditory meatus and through the tegmen (Figure 2.29). The fracture line then passes in front of or behind the labyrinth (see also Figure 7.2).

Anterior longitudinal fractures usually involve the horizontal portion of the facial nerve canal in the region of the geniculate ganglion (Figure 2.30). Posterior fractures involving the vertical portion of the canal or the posterior genu then proceed either along the roof of the eustachian tube or to one of the nearby foramina (the foramen lacerum, jugular foramen or internal auditory meatus).

Longitudinal fractures are best shown by axial CT when the whole length of the fracture line can be shown, and by lateral tomography or reformatted lateral CT. The reformatting technique is particularly well suited to the demonstration of longitudinal fractures.
when the cross-sectional reconstruction can be made precisely in the plane of the fracture shown on the axial views.

Transverse fractures run at right angles to the long axis of the petrous bone. As classically described, this type of fracture affects the pyramid, with the fracture line passing across the labyrinth or internal auditory meatus. It produces facial palsy and sensorineural deafness which may be complete and permanent. Some fractures, however, pass laterally to the pyramid, through the middle ear or external meatus and, because they are in the same plane, should strictly be classified as 'transverse', although the conductive deafness and other features make them very similar to the longitudinal type.

Transverse fractures are also best demonstrated by axial CT but they can usually be shown also by simple plain film views in the periorbital or Stenvers' projections (Figure 2.31). Coronal CT sections will show the fluid level of a cerebrospinal fluid fistula.

**Ossicular dislocations**

When a head injury is followed by conductive deafness, it is most commonly the result of a simple haemotympanum or a traumatic rupture of the drum. However, if hearing loss remains after the drumhead has healed, then disruption of the ossicular chain must be suspected.

Unfortunately, the commonest dislocation, namely of the incudostapedial joint, cannot be satisfactorily demonstrated by tomographic methods. Displacement of the incus, rarely the malleus, and separation of the incudomalleolar joint can be demonstrated by axial and coronal tomograms or high resolution CT (Figure 2.32). Loss of the normal 'molar tooth' sign on the lateral tomograms is another important sign of major ossicular displacement (see above).

**Inflammatory disease**

Acute otitis media and its complications are essentially diseases of childhood, and are considered in Volume 6 (see also Figure 9.3).

Chronic suppurative otitis media is usually described as:

1. the non-cholesteatomatous tubotympanic type in which radiology has a negligible role
2. the attico-antral type with cholesteatoma.

Adhesive otitis media involves the development of adhesions and tympanosclerosis, that is calcification in areas of hyaline degeneration. The only importance of tympanosclerosis, from an imaging point of view, is to be aware of its existence to avoid misinterpretation of plaques of calcification in the middle ear.
Radiology of complications of middle ear infection

These may follow any form of middle ear infection but, most commonly, acute mastoiditis and cholesteatomatous chronic suppurative otitis media.

Labyrinthitis

The symptoms of vertigo in the presence of acute or chronic suppurative otitis media indicate the presence of labyrinthitis due to involvement of the labyrinthine fluids in the inflammatory process. Spread of the infection to the labyrinth may be via the intact oval window, the round window membrane or via an erosion in the labyrinth capsule, the latter being usually produced by a cholesteatoma. Radiology is likely to be informative only in cholesteatomatous disease, where the most common abnormality is an erosion of the bony capsule of the lateral semicircular canal, demonstrable on a Stenvers' projection, coronal section tomography or CT. Suppurative labyrinthitis can also result from spread of infection from the blood stream or meninges. Following an episode of purulent labyrinthitis, which results in total destruction of the membranous labyrinth, the bony labyrinth may become filled with granulation tissue which often undergoes varying degrees of ossification. This so-called 'labyrinthitis obliterans' is, primarily, a histopathological diagnosis but the ossification is readily detectable by tomography (see Figures 17.2, 25.2 and 25.3).

Partial obliteration of the bony labyrinth is probably a characteristic tomographic feature with a clear-cut margin seen between the parts obliterated by bone and portions seemingly unaffected. This appearance distinguishes post-suppurative labyrinthitis obliterans from advanced otosclerosis, in which the bone encroachment is much more diffuse.

Intracranial complications

These comprise one or more of the following extradural abscess, subdural abscess, temporal lobe abscess, cerebellar abscess, meningitis and hydrocephalus. Suspicion of their presence is par excellence the indication for computerized tomography in acute or chronic suppurative otitis media.

The radiological diagnosis of brain abscess is based on the demonstration of a localized area of low attenuation and, after injection of contrast medium, a surrounding area of high attenuation. Distortion or displacement of the ventricles may be present if the lesion is large. Serial CT scans allow the development of a lesion to be monitored and give warning of incipient rupture into ventricle, or they may be used to assess postoperative progress of the cavity. It is important to remember that up to 15% of brain abscesses or otitic origin are multiple. Occasionally, an abscess which is clinically silent may be demonstrated.

Extradural and subdural collections of pus may show a peripheral rim of low attenuation and contrast enhancement. Not infrequently, however, extradural abscesses are very shallow and not well demonstrated by computerized tomography, unless by chance a tomographic section passes through the centre of the pathological area.
Tuberculous otitis media in adults most commonly occurs in association with advanced pulmonary tuberculosis, but in children it may occur in isolation. Extensive ragged destruction in the mastoid and middle ear rather than sclerosis is a typical radiographic feature.

**Malignant otitis externa**

Malignant otitis externa is a rare condition in which an otitis externa, usually due to Pseudomonas infection in a diabetic patient, spreads wide, leading to osteomyelitis of the temporal bone cranial nerve lesions according to the precise area of spread may also occur and occasionally death (Prasad, 1976).

Radiologically there is a typical appearance of rarefaction of the bone spreading symmetrically and centrifugally from the external auditory meatus. In an analysis of nine cases of diabetic malignant otitis externa, Mendez et al (1979) found that when there was a unilateral facial paralysis or a jugular foramen syndrome, bone destruction was always demonstrable. Five cases had evidence of jugular fossa destruction, but only one had a jugular foramen syndrome. Retrograde jugular venography confirmed the presence of high degree of venous obstruction at the jugular bulb.

A good demonstration of the extent of the disease is given by CT (*Figure 2.33*), but probably more important are isotope studies to show the degree of activity of the infective process (Mendez et al, 1979). Nevertheless, early diagnosis is essential as prognosis seems to be related directly to the stage that the disease has reached at the onset of treatment (Mills, 1986).

**Cholesteatoma**

The aetiology of this characteristic epidermoid cyst containing keratin is not fully understood. Two types are recognized, although they do not differ histologically.

1. Congenital cholesteatoma originating from ectodermal cell rests. This may arise in any of the cranial bones, the petrous temporal being the most commonly affected, or within the cranial cavity.

2. Acquired cholesteatoma, in which there is ingrowth of the surface epithelium of the tympanic membrane.

In the vast majority the diagnosis is readily made on clinical grounds.

**Congenital cholesteatoma**

Congenital cholesteatoma may arise anywhere within the petrous temporal bone but may be conveniently classified into:

1. Cholesteatoma of the cerebellopontine angle

2. Cholesteatoma arising deep within the petrous pyramid
(3) cholesteatoma arising in the jugular fossa region

(4) congenital cholesteatoma of the middle ear cleft.

Classically, these lesions present in middle age with severe sensorineural deafness and facial spasm or weakness. This involvement of the facial nerve is a characteristic feature.

Cholesteatoma is the third most common tumour of the cerebellopontine angle, after acoustic neuroma and meningioma. The brain scan shows an area of low attenuation (see Figure 2.19).

In the petrous pyramid

A large erosion is usually evident on plain films in a patient with cholesteatoma of the pyramid or petrous apex. Tomograms show a clearly defined 'punched out' area of bone destruction. The clear-cut margins may be scalloped and the labyrinth is destroyed by a 'steam roller' effect, although individual coils of the cochlea and the modiolus may be identified after invasion of the cochlea has taken place. There may be thinning and elevation of the superior petrous ridge (Valvassori, 1974) (Figure 2.34). A CT scan will demonstrate a non-enhancing mass of low attenuation, and high-resolution CT demonstrates the characteristic expansile cyst-like lesion (Figure 2.35). The congenital cholesteatoma occurring in an extensively pneumatized pyramid can be difficult to diagnose radiologically.

In the jugular fossa

A cholesteatoma arising in the region of the jugular fossa or skull base may mimic a glomus tumour, both radiologically and clinically. Although the destruction may be extensive, it is usually less ragged than that caused by a glomus tumour. A CT scan should differentiate between the two lesions, if intravenous contrast enhancement is used, but angiography will be decisive.

In the middle ear and mastoid

It is uncertain what proportion of the much more common cholesteatomata arising in the attico-antral region have a congenital origin but the percentage is probably small and they are, ultimately, indistinguishable from acquired cholesteatoma.

There are two criteria which help to distinguish a cholesteatoma of the middle ear cleft which ha a congenital rather than an acquired origin. These are:

(1) an intact eardrum with no evidence of a previous perforation

(2) an intact spur.

Acquired cholesteatoma

The vast majority of cholesteatomata arise from either the pars flaccida or the posterior segment of the tympanic membrane. From here they extend into any part of the tympanic
cavity and backwards into the mastoid antrum and air cells. There is associated erosion of the walls of the middle ear cleft.

The most important single plain radiographic projection in the management of typical cholesteatoma is the lateral view, with the incident beam tilted 20° caudally. This will show the extent of pneumatization and erosion of the outer attic wall. The other mastoid projections will only demonstrate large erosions. Pneumatization is usually poor or absent and the mastoid sclerotic, but cholesteatoma may be encountered, with minimal bone destruction, in an extensive air-cell system.

Tomography in the coronal plane was formerly the optimum method for demonstrating small cholesteatomata in the attic and antrum. The tomographic evaluation of cholesteatoma is based mainly on the detection of bone erosion (Figure 2.36).

In the attic the following signs indicate the presence of a cholesteatomata:

1. destruction of the lateral spur of bone formed by the junction of the lateral boundary of the attic and the roof of the external auditory canal
2. bone destruction of the lateral attic wall
3. destruction of the ossicles
4. erosion of the medial attic wall. This is a less common sign, but may lead to involvement of the facial canal or a labyrinthine fistula. It should be noted that the presence of a fistula can only be confidently predicted if the lesion is present on two or more slices.

Similar erosive changes can be discerned on coronal CT, but its ability to depict precisely small soft tissue masses in the middle ear makes CT the best overall method of imaging cholesteatoma. Acquired cholesteatomata are diagnosed on CT by the presence of a non-dependent homogeneous soft tissue mass in an appropriate location (Schwartz, 1984). It is important to remember that CT imaging is unable to distinguish the soft tissues of a cholesteatomata from polyps, granulation tissue mucosa, cholesterol cysts or fluid, by tissue characterization (Figure 2.37).

If a lesion is adequately assessed clinically, and a versatile surgical technique applied in the treatment, then radiological assessment is necessary only in those cases with unusual clinical features, for example suspicion of intracranial complications, facial palsy, positive fistula sign, and severe sensorineural deafness or disease in an only hearing ear.

A cholesteatoma may not, however, always be apparent on first inspection. House and Sheehy (1980) reported 41 cases of cholesteatoma with an intact eardrum (3.7% of their series). Cholesteatomata may also be associated with a central type of perforation. Such a true perforation is usually a feature of the safe tubotympanic type of disease, but it may also result from breakdown of a retraction pocket with the resultant isolation of squamous epithelium in the middle ear. Often polyps and granulation tissue obscure both types of disease. Invasion of the labyrinth by a cholesteatoma is not necessarily immediately associated with a dead ear, presumably due to a sealing off of the disease process. When there is a small fistula present
in a semicircular canal, a piece of cholesteatoma matrix may be left over the defect in the hope of preserving the remaining cochlear function. In these circumstances, tomographic demonstration of the site of invasion of the labyrinthine capsule provides useful preoperative information (Figure 2.38).

Preservation of cochlear function in the labyrinth invaded by cholesteatoma, first described by Phelps in 1969, is now a well-recognized, though unusual phenomenon. Bagger-Sjobach and Phelps (1985) recently reviewed reported cases of this phenomenon and added three more (Figure 2.39).

To summarize, therefore, the radiological demonstration of cholesteatoma affecting the petrous temporal bone depends on the anatomical site and configuration of a soft tissue mass in the middle ear or petrous pyramid producing characteristic clear-cut bone erosion. These features are well shown by CT but tissue characterization has been unsatisfactory. Magnetic resonance does not demonstrate the bony features and very limited experience suggests tissue characterization may not be much more satisfactory (Figure 2.40). The differing MR signal seen with cholesteatomata appears to be related to the variable amounts of fat found in these lesions (Latack et al, 1985).

**Tumours of the middle ear and petrous temporal bone**

Tumours may involve the middle ear, the mastoid and the petrous parts of the temporal bone - primarily, metastatically or by extension from adjacent sites such as the postnasal space, external auditory meatus, parotid gland or even from structures within the cranial cavity. Acoustic neuroma is the most common tumour to erode the temporal bone, but it is most unusual for this to cause any radiologic abnormality other than expansion of the internal auditory meatus. Primary neoplasms of the middle ear region are extremely rare, the most common being the glomus jugulare tumour (benign) and squamous cell carcinoma (malignant).

**Benign neoplasms**

A compact osteoma appears as a well-defined usually single, although occasionally lobulated, bony mass of high density. Cancellous osteomata are more rare and present as a less dense, defined mass. They occur in the following situations:

(1) external auditory canal - where they are asymptomatic unless they become large enough to cause obstruction, with consequent hearing loss or retention of wax and skin debris

(2) squama of the temporal bone - where they cause a hard bulge above and behind the pinna

(3) mastoid - where they are asymptomatic unless encroaching upon the facial nerve canal, causing paralysis

(4) petrous pyramid - where they can occur in the region of the porus of the internal auditory meatus (Beale and Phelps, 1986)
(5) middle ear - where they may impinge upon the ossicular chain, causing a conductive hearing loss (*Figure 2.41*).

**Glomus tumours**

Sometimes called chemodectoma or paraganglioma, these arise from small structures called glomus bodies. The tumours are usually classified as glomus jugulare, vagale or tympanicum, depending on the site of origin. The glomus tympanicum may be entirely confined to the middle ear cavity but, usually, the tumour has reached such a size by the time of presentation that it is difficult to determine exactly where in the base of the skull or upper part of the neck, it has arisen.

The glomus jugulare tumours located in the jugular bulb has ready access to various parts of the temporal bone and the foramina at the base of the skull, since they spread along the lines of least resistance. Intracranial extension, therefore, can be along the carotid artery, through cranial nerve foramina, into the nasopharynx, intravascularly into the sigmoid sinus and superior petrosal sinus, through the tempore bone air-cell system to the petrous apex, or retrofacially into the mastoid process (*see Figure 23.1*).

Classically, large tumours demonstrate ragged erosion of the base of the skull in the region of the jugular fossa and posteroinferior aspect of the petrous pyramid, with extension into the mastoid and adjacent occipital bone (*Figure 2.42*).

The first radiographic indication of a glomus jugulare tumour is an abnormality of the jugular foramen and fossa. The lateral (vascular) part of the fossa will be affected rather than the medial (nervous) part. The two fossae are rarely symmetrical and expansion may be difficult to assess. It is most important, therefore, to look for evidence of bone erosion of the margins of the foramen (*see Figure 2.6*). More extensive lesions show a ragged and irregular outline; this is more clearly defined than the erosion produced by an infiltrating lesion such as a carcinoma but not as smooth as the margin of a congenital cholesteatoma or neuroma.

Computerized tomography is superior to plain films, not only for assessment of the extent of bone destruction, but also for demonstrating the presence of a mass in the middle ear cavity. Minor erosion of the walls of the cavity and, especially, the promontory, by small glomus tympanicum tumours may also be shown. Tomography or CT will demonstrate the presence or absence of the floor of the middle ear cavity, an important point when trying to decide whether a mass behind the eardrum is coming from the jugular bulb. The initial radiological investigation for a suspected glomus tumour should include routine views of the skull and mastoid, together with a special view of the jugular foramen and coronal section tomograms. Further assessment can then be made by tomography in other planes, especially the lateral (*Figure 2.43*), by axial and coronal CT, and by arteriography and jugular venography. The role of these special investigations will now be considered in more detail.

Computerized tomography is the investigation of choice. It is used to show both the intracranial extent of a glomus tumour and its downward extension into the neck. The intracranial tumour is well demonstrated on the enhanced scan (*Figure 2.44*). In the soft tissues, glomus tumours do not show marked contrast enhancement except in the early
vascular phase. In this respect, their behaviour is similar to that of a juvenile angiofibroma and one explanation would seem to be that there is little tumour tissue present, much of its volume being made up of vascular spaces. There is, therefore, little extravasation of contrast medium into the extracellular spaces. Demonstration of the tumour requires scanning immediately after a bolus injection or, better still, during continuous infusion. 'Dynamic CT' is a more scientific way of showing the characteristic immediate enhancement followed by rapid 'wash-out' of contrast (see Volume 1, Chapter 17).

High resolution CT may be used to show both the soft-tissue mass of the tumour and the bone erosion on a single scan and, in the axial view, this is now the optimum method for showing the forward extension from the jugular fossa into the middle ear cleft and external auditory meatus (Figure 2.45). (See also Volume 1, Figure 17.8).

For glomus tympanicum tumours originating in the middle ear, high-resolution CT is even more valuable diagnostically and is now the method of choice (Phelps and Lloyd, 1983a). In conjunction with the characteristic clinical signs, the appearance of a soft-tissue mass arising from the promontory (Figure 2.46) is virtually diagnostic of tympanic body tumour; the discrete nature of the mass and the absence of involvement of the jugular fossa serve to distinguish it from the glomus jugulare tumour, especially if air can be demonstrated between the mass and the intact floor of the middle ear (Figure 2.47; see also Figure 23.2b-c).

**Arteriography**

Digital vascular imaging will confirm the presence of all but the smallest glomus tumours. Arteriography is almost always necessary to demonstrate the extent of these tumours and their complete vascularization, as well as their not infrequent multiplicity. The angiographic appearance is nearly always characteristic (Figure 2.48; see also Figure 23.3) with large vascular spaces, arteriovenous connections and dense homogeneous tumour staining. The blood supply is principally from the ascending pharyngeal artery which is the first branch of the external carotid. Other collaterals from both external and internal carotid systems develop as the tumour enlarges and eventually there may be an additional supply from the vertebral system. The initial injection, therefore should be into the common carotid artery with subsequent selective catheterization and vertebral injection as required. Subtraction films are necessary.

Recently, percutaneous catheter embolization has been used for large tumours. Embolization aims at blocking the vascular bed of the tumour, causing thrombosis and preventing the establishment of collateral channels as long as obliteration of the vascular bed is maintained. Selective angiography of the external carotid artery is an indispensable prerequisite to embolization. The vessels feeding the tumour are identified. The catheter should be advanced as close as possible to the lesion before emboli are introduced. This will reduce the chances of reflux of emboli back into the carotid bifurcation where stray emboli may enter the internal carotid artery (see Figure 23.4).
Jugular venography

Adequate demonstration of the jugular bulb is often obtained in the venous phase of the arteriogram. However, a better demonstration of the jugular bulb and a glomus tumour invading it, may be obtained by retrograde catheterization of the internal jugular vein in the neck (Figure 2.49). Where there is extensive involvement of this system, the upper and lower limits of the tumour may be ascertained by the two types of venography, that is run-off phase of the arteriogram for the upper end, and retrograde jugulography for the lower.

To summarize, therefore, the most important diagnostic feature for glomus jugulare tumours is the demonstration by plain films or CT of ragged erosion and loss of the normal cortical margin of jugular foramen. Loss of the normal crest of bone between the carotid canal and the jugular fossa on lateral views is a particularly good sign of a jugulare tumour (see Figure 2.43). Angiography with subtraction is mandatory for the confirmation of glomus jugulare tumours and an aberrant carotid artery; may not be necessary for a small tympanicum tumour confined to the promontory; and should not be necessary for a high jugular bulb. Magnetic resonance, which shows no bone detail, has little to offer, as the flowing blood in these vascular lesions will appear as black areas of no signal.

Neuroma

Neuromata, more correctly called schwannomata, may arise from any of the cranial nerves but have a peculiar tendency to occur in the vestibular components of the eighth nerve within the internal auditory meatus. They are the commonest tumour of the petrous temporal bone.

Neuromata of the facial nerve are slow-growing rare tumours which may arise on any part of the facial nerve, and although they usually present with facial palsy, this is not always a feature.

Radiological diagnosis depends on the demonstration of localized erosion or expansion in the course of the facial nerve canal. The lesions are usually rounded or somewhat elongated (Figure 2.50). The whole length of the canal should be examined and an air meatogram is usually indicated to show the proximal limit of the tumour, either in the internal auditory meatus or cerebellopontine angle. The region of the geniculate ganglion is often involved (Latack et al, 1983) and so the pit for the geniculate ganglion above the cochlea should be carefully assessed on the coronal CT cochlear cut for any erosion. Facial neuromata arising in the internal auditory meatus are virtually indistinguishable from acoustic tumours.

Acoustic neuromata

Most acoustic neuromata arise in the lateral one-third of the internal auditory meatus. Tumour growth takes place medially following the line of least resistance and causes remodelling and expansion of the internal auditory meatus. Extension out through the porus into the cerebellopontine angle then occurs.

A battery of clinical tests is available for the detection of acoustic neuromata but none is completely reliable nor indicates the size of the lesion. Radiological studies are therefore
the definitive investigation for demonstrating or excluding the presence of a tumour on the eighth nerve. However, while most authorities agree with the desirability of demonstrating small tumours a few millimetres in size, the decision of whether or not surgical removal is indicated becomes difficult, given the tumour's variable rate of growth. This decision will depend to a large extent on the age of the patient.

Traditionally there has been great reliance placed on the demonstration of the bony margins of the internal auditory meatus. Where limitations of scan time and cost preclude the investigation by CT of patients with minimal symptoms and signs, plain films or polytomography still provide a valuable screening examination (see above). Computerized tomography provides the means of imaging all acoustic neuromata large and small but, unfortunately, not without the use of intravenous and intrathecal contrast agents.

The ability of magnetic resonance to distinguish brain tissue and tumours from cerebrospinal fluid makes it the potential investigation of choice for identifying all acoustic neuromata both large and small (see Figure 2.20). It is the only modality which will define the lateral and the medial extent of a small lesion confined to the internal auditory meatus. However, the time seems far distant when all patients with mild sensorineural deafness and some unsteadiness will have an MR scan to exclude an acoustic neuroma (see also Figures 21.3 and 21.13).

**Bone studies**

The classic criteria of abnormality in the internal auditory meatus as shown by tomography (Valvassori, 1969) are still applicable:

(1) erosion of the cortical line surrounding the lumen of the canal seen in the lateral tomograms

(2) widening of 2 mm or more of any portion of the internal auditory meatus when compared with the corresponding segment of the opposite canal

(3) shortening of the posterior wall of the canal at least 3 mm in comparison with the opposite side

(4) demonstration of the crista falciformis running closer to the inferior than to the superior wall. The crista should normally be located at or above the midpoint of the vertical diameter of the canal.

Lateral tomographic views obtain a better assessment of the degree of expansion.

A less common but more pathognomonic appearance of the internal auditory meatus occurs when there is irregular and pronounced destruction of the walls of the meatus (Figure 2.51). Why a minority of neuromata should produce this type of bone erosion instead of the more usual expansion of the internal auditory meatus, is unknown.
Computerized tomography with intravenous contrast

Acoustic neuromata show variable attenuation. In about 50% this is similar to that of normal brain but may be more, less, or mixed. However, almost all acoustic neuromata show some degree of contrast enhancement and should appear on the scan if they are of sufficient size (Figure 2.52). Indirect signs, such as displacement of the brainstem and fourth ventricle, obliteration and widening of the cisterns and ventricular dilatation from obstructive hydrocephalus, indicate the presence of a space-occupying lesion. Improvements in scanner technology have lessened the problem of posterior-fossa artefacts caused by the dense bone of the petrous pyramids. Typically, acoustic neuromata are round or lobulated, often with non-homogenous areas of enhancement. Areas of low attenuation may be due to cystic change within the tumour (see Figure 21.12).

Modern scanners should show almost all neuromata in the angle larger than 1.5 cm and often give a convincing demonstration of smaller lesions.

Air CT meatography

Pitfalls with air studies and their interpretation are usually due to incomplete filling of the internal auditory meatus or partial volume averaging on the sections (see Volume 1, Chapter 17). Unless a filling defect with a convex medial margin can be reliably and repeatedly demonstrated, a firm diagnosis of a neuroma should not be made, as failure to fill fully the internal auditory meatus with air may be due to the 'tomato ketchup effect', with air not completely replacing cerebrospinal fluid. This is a particular problem with a normal or narrow internal auditory meatus. The examination should be repeated after repositioning and shaking the patient's head. Examining the other side may help. Excessive pneumatization around the internal auditory meatus may make expansion of the meatus difficult to demonstrate on plain films, and tomography or CT give a better assessment. Pneumatization can also be a problem with air studies in deciding which is air already present in the air cells, and which is that introduced intrathecally (Figure 2.53). Usually the appearances of small acoustic neuromata are characteristic (Figures 2.54 and see Figure 2.18).

Other tumours within the cerebellopontine angle

Acoustic neuromata account for 90% of tumours within the cerebellopontine angle. The differential diagnosis of large tumours is primarily the differentiation of masses in the posterior cranial fossa (see Figure 21.14).

Meningioma

Meningiomas are the next most common neoplasms that occur in the cerebellopontine angle. Several differentiating features have been described. Unlike acoustic neuromata, meningiomas often calcify. Acoustic neuromata expand mainly posteriorly and medially and rarely have a broad attachment to the petrous bone. Meningioma may be oval, which is unusual with acoustic tumours; surrounding oedema is said to occur more often with acoustic neuromata. Changes in the internal auditory meatus are rare with meningioma and frequent with neuromata. Dense homogeneous enhancement, a smooth outline (Figure 2.55)
and sometimes, hyperostosis of the petrous ridge, are other features of a meningioma in the posterior fossa, although bony changes occur less often than when they arise in the region of the sphenoid ridge.

**Cholesteatoma**

Cholesteatoma occurs in the angle or, more anteriorly, alongside the petrous apex. Non-enhancement of the lesion and low or even negative attenuation values, are characteristic features (*see above*).

**Glioma**

Gliomata, or large glomus jugulare tumours from below, may appear as enhancing masses in the region of the cerebellopontine angle. The pattern of bone erosion of the petrous pyramid will, however, suggest an extrinsic mass.

**Neuroma**

Neuromata arising from the trigeminal nerve or from the ninth, tenth and eleventh nerves in the jugular fossa, may also extent up into the cerebellopontine angle. Neuromata of the last four cranial nerves involve the jugular foramen and cause expansion. It is usually impossible to determine the exact nerve of origin of these tumours at surgery, since the mass generally envelops them all. Radiologically, these tumours of the lower cranial nerves need to be differentiated from both glomus jugulare tumours and from acoustic neuromata. They differ, radiologically, from glomus jugulare tumours in three respects: the contour of the bone is smooth and well defined with a neuroma, but poorly defined and irregular when the jugular fossa is expanded by a glomus tumour; a neuroma does not usually erode into the middle ear; and expansion of the hypoglossal canal is almost pathognomonic of a neuroma of the twelfth cranial nerve.

**Malignant neoplasms**

Carcinoma arising in the cartilaginous auditory meatus tends to spread into the parotid gland and the postauricular sulcus, whereas a tumour arising from the deep bony meatus may perforate the eardrum at an early stage. It is, therefore, often impossible to assess the exact site of origin of the tumour or to decide whether it has arisen from the deep meatus or the middle ear cleft (*Figure 2.56*).

The diagnosis of carcinoma in the mastoid is usually made while performing a mastoidectomy in an effort to control presumed chronic mastoiditis, since preceding chronic ear infection is to be expected in at least 40% of patients (Phelps and Lloyd, 1981). Sclerosis of the mastoid and clouding of the cells are therefore radiological signs of little value, but the presence of ragged erosion, usually extensive or in an unusual site, suggests neoplastic change (*Figure 2.57*). An important sign, on the lateral mastoid view, is erosion of the articular fossa of the temporomandibular joint. This was present on the initial radiographs in 30% of the author's cases. Much better demonstration of erosion of the bony external auditory meatus and back of the temporomandibular joint was given by lateral tomograms.
The hard avascular bone of the labyrinthine capsule is relatively unaffected by carcinoma, and erosion of the capsule with direct invasion of the inner ear is a late radiological feature only present with extensive surrounding bone destruction. There are two important modes of spread of carcinoma of the middle ear (Figure 2.58; see also Figures 2.21 and 2.22). First, the tumour extends anteriorly and penetrates the bony septum separating the middle ear cavity from the carotid artery. It then spreads around the artery and extends down around the eustachian tube towards the postnasal space. Erosion of the carotid septum margins of the bony eustachian tube and even soft-tissue extension of the tumour anteriorly can be demonstrated by CT. Second, the tumour may spread upwards through the tegmen tympani and backwards through the mastoid air cells, then through the thin plate of bone forming the posterior wall of the petrous pyramid and underlying the lateral sinus. Erosion of these thin bony structures may also be demonstrated radiologically.

**Otosclerosis and bone dysplasias**

The otic capsule forming the bony labyrinth of the inner ear is composed of hard, poorly vascularized, endochondral bone which is metabolically inert and therefore relatively unaffected by systemic bone diseases. Widespread bone disorders such as Paget's disease, hyperparathyroidism, rickets, osteogenesis imperfecta and fibrous dysplasia, may eventually affect the labyrinthine capsule causing sensorineural deafness, but the periosteal bone forming the remainder of the petrous temporal bone and base of skull is affected first in these disease. The rare congenital dysplasias which are present at birth or appear during childhood are considered in Volume 6. Otosclerosis, the most common bone disorder causing deafness, affects only the labyrinthine capsule.

**Otosclerosis**

Otosclerosis is a localized disease of the bony labyrinth in which new bone, initially spongy and later denser, replaces the endochondral bone of the otic capsule and may cause ankylosis of the footplate of the stapes. The French term 'otospongiose' is more descriptive.

This immature woven bone of increased thickness, vascularity and cellularity has a lower radiographic density than that of the otic capsule. The focus becomes less active and more sclerotic with increasing maturity (and probably, also as a result of fluoride therapy).

Tomographic or CT demonstration of otosclerotic bone deposits depends mainly on the distortion of the normal clear-cut outline of the labyrinthine capsule. Otosclerotic foci must be large enough - 1 mm in diameter or more - to become radiographically visible. The normal labyrinthine capsule is the most dense bone in the body. It cannot become more radiopaque but, eventually, only thicker by apposition of otosclerotic bone.

Fenestral otosclerosis is essentially a clinical diagnosis based on the audiometric findings and only when severe will narrowing or obliteration of the oval window niche be shown. Follow-up of patients after stapedectomy will be of more value to show displacement of a prosthesis (Figure 2.59).

Similarly, tomography can be used to show the position of a prosthetic cochlear implant (Figure 2.60). Such metallic objects cannot be demonstrated satisfactorily by CT.
Capsular otosclerosis, or more particularly otospongiosis of the bony cochlea, will appear as areas of rarefaction around the coils (Figure 2.61). In theory, CT with its improved density resolution should be better able to depict these areas of bone rarefaction, but in practice they have been demonstrated equally well by CT and polytomography (see also Figures 14.27a and b).

**Paget's disease (osteitis deformans)**

The radiological appearance of the petrous pyramids is pathognomonic (Figure 2.62). The periosteal bone is affected first and the extensive demineralization that occurs makes the labyrinthine capsule stand out more clearly than normal in the initial stage, osteoporosis circumscripta (see Figure 15.5). When the labyrinthine capsule becomes involved, the affected parts become almost impossible to identify, as they are replaced by amorphous bone (see Figure 15.6). The remaining unaffected parts of the labyrinth may give the impression of floating in this grey, featureless, homogeneous, pagetoid bone. The medial ends of the petrous pyramids become tilted upwards due to bone softening and platybasia. Secondary degenerative changes in the cochlear duct seem to be the main cause of the deafness rather than narrowing of the internal auditory meatus. The margins of the meatus become difficult or impossible to define on the tomograms when surrounded by pagetoid bone. Finally, all recognizable features of the inner ear may be lost as progressive sclerosis occurs (see Figure 15.7). The cause of the conductive component of the deafness seems to be involvement of the ossicles rather than stapedial ankylosis.

**Fibrous dysplasia**

Although monostotic fibrous dysplasia is not infrequently found affecting the facial bones, only a handful of cases have been reported in the petrous temporal region. These usually present with conductive deafness caused by a bony mass obstructing or occluding the external auditory meatus. Fibrous dysplasia of the petrous pyramid rather than the external ear is even rarer (Figure 2.63).

Although fibrous dysplasia, like Paget's disease, causes expansion of bone and affects the periosteal bone of the skull base rather than the labyrinthine capsule, the radiological differentiation is usually not difficult. Fibrous dysplasia occurs in a younger age group and the distinctive 'ground glass' appearance of fibrous dysplasia is unlike pagetoid bone (see Figures 15.8 and 15.9).

**Primary basilar impression (craniocervical dysplasia)**

Primary basilar impression is the upward displacement of the skull base and upper cervical vertebrae into the cranial vault. It is a radiological diagnosis based upon Chamberlain's supposition that all parts of the axis and atlas lie caudad to the base of the skull. Elies and Plester (1980) suggested that such craniocervical dysplasia may result in a symptom-complex that in itself presents as a differential diagnosis from Ménière's disease. They were able to display radiological evidence of primary basilar impression in 16% of patients presenting with non-specific dizziness and sensorineural deafness.
Chamberlain's distance is the perpendicular length between the tip of the odontoid peg and a straight line (Chamberlain's line) drawn from the dorsal margin of the hard palate to the dorsal tip of the foramen magnum (Figure 2.64). Chamberlain's distance was considered positive if the odontoid peg was cephalad to Chamberlain's line, and negative if it was caudal. Kane, O'Connor and Morrison (1982) using this measurement showed a proclivity to basilar impression in patients with Ménière's disease.

Secondary basilar impression may occur as a result of bone-softening pathologies, for example Paget's disease; the anterolateral impression is best measured by Bull's angle (Bull, Nixon and Pratt, 1955).

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