

HIGH-RESOLUTION CT EXAMINATION OF TEMPORAL BONE : NORMAL ANATOMY AND INDICATIONS

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SUMMARY : *In this review, the anatomical and radiopathological imaging abilities and indications of high-resolution computed tomography examination of temporal bone are presented. Scanning technique is described, and diagnostic value is compared with other radiological diagnostic methods.*

Key Words : *Tomography, X-ray computed, Radiology of Temporal Bone.*

INTRODUCTION

The complicated anatomical structure of the middle and inner ear challenges the diagnostic ease in radiologic examinations of the temporal bone. Their tiny dimensions and close neighbourings of the structures limited the successful imaging facilities for long periods of time. Conventional radiologic procedures has been inadequate for diagnostic imaging but recently especially multidirectional tomography, high-resolution computed tomography (HRCT) and magnetic resonance imaging procedures has gained importance.

Thin section, high-resolution computed tomography with modern equipment gives excellent fine bony detail in addition to its capability of identifying soft tissue lesions located in inner-middle ear and mastoid. Due to these advantages HRCT has replaced multidirectional tomography completely in the radiologic evaluation of temporal bone diseases (Fritz et al. 1989; Shankar et al. 1989). Radiation dose exposed to skin and eye lens is also considerably less in HRCT compared to multidirectional tomography (Fritz et al. 1989). According to the re-

sults of studies comparing MRI and HRCT, CT is more useful in the evaluation of the osseous labyrinth, while MRI produces excellent images of the membranous labyrinth and related neural components (Jackler and Dillon, 1988). In the diagnosis of middle ear and mastoid diseases CT; in the diagnosis of cerebellopontine angle lesions and central neurotologic diseases MRI has the superiority of providing more useful information (Mafee et al. 1988),

In this study, we reviewed the technique of temporal bone CT scan, the cross-sectional CT scan anatomy and indications of temporal bone CT scanning.

EXAMINATION TECHNIQUE

The examinations described in this study are carried out in Radiology Department of Gazi University Medical Faculty by using GE CT9800 Quick/HILight detector computed tomography system on patients who were sent to radiology clinic with diagnosis of various temporal bone pathologies.

Axial plane is accepted to be the main examination plane for temporal bone CT scans and different gantry angulations are suggested for axial scans. In our examinations 90 degrees lateral scout view of head is obtained after the patient is placed on the axial headholder. On the scout view gantry angle is adjusted parallel to a line connecting superior orbital rim and the most inferior point of the occipital bone, and planes between external acoustic meatus and superior semicircular canal are examined. This angle corresponds to 20-25 degrees superior to the well-known anthropological base-line. Coronal plane examinations are performed routinely except to those patients who are excessively symptomatic not permitting to give position using coronal headholder. By using two examination planes, optimal evaluation of inner ear structures is possible. For coronal examinations patients are placed on the coronal headholder with their heads hyperextended and -20 degrees gantry angle is used. This position corresponds to 100-110 degrees superior to anthropological baseline. Both axial and coronal plane examinations are carried out with 1.5 mm. thick contiguous sections with standard resolution. Approximately 10-12 scans in axial and 9-10 scans in coronal examination are obtained. 18 cm. display field of view, 512x512 matrix size, and 360 degrees tube rotation are used. Spatial resolution and pixel size were both 0.35 mm. 120 kV, 100mA, and 4 second scan time are used in all indications.

The original images obtained at standard resolution are examined by using soft tissue windows for posterior fossa structures in the examination areas, cerebellopontine angles, and vascular structures. To see the fine bony detail, bone review algorithm views are obtained by using special reconstruction function of the computer. 16 cm. display field of view is used in reconstructions and pixel size decreased to 0.31mm. These images in bone resolution are examined separately for each side with 1.8 to 2.2 magnification factor by using wide windows. In order to view vascular structures and make differential diagnosis of tympanic cavity and cerebellopontine angle lesions 1.5-2 cc / Kg non-ionic radiographic contrast agent is injected to the patients. In some reports it is stated that the use of contrast agents is worthless in temporal bone examinations (Johnson et al. 1983), on the contrary, some authors recommend the use of contrast agents in all temporal bone examinations (Mikhael et al. 1987). In our opinion excluding the patients examined for congenital anomalies, contrast agents should be

applied to all patients without contraindication.

The use of direct sagittal examinations and sagittal or oblique reformations are suggested for better viewing of middle ear structures (Mafee et al. 1988).

CT ANATOMY OF TEMPORAL BONE

The anatomical structures revealed by using the described technique should be evaluated in succession starting from external auditory canal (Fig 1, 2).

Temporal bone is composed of tympanic, mastoid, squamous, petrous portions and the styloid process. Tympanic part forms the anterior and inferior walls of the bony external auditory canal. Mastoid part constitutes its posterior wall, confines posterior part of the tympanic cavity, and accommodates mastoid air cells. Squamous part makes up a part of the skull, and petrous part is a wedge shaped structure containing the inner ear structures. Mastoid bone containing mastoid air cells can be visualized easily both in axial and coronal planes. The development of mastoid air cells is variable, depending on heredity and early episodes of infection. The mucosal layer covering them is too thin to be visualized in CT examinations (Johnson et al. 1983). External auditory canal is composed of outer 1/3 cartilaginous and inner 2/3 bony structure. The bony part of the canal is formed by the tympanic bone anteriorly and inferiorly, the mastoid bone posteriorly, and the squamous bone superiorly. Normally in axial sections, in the anterolateral end of external auditory canal the edges of tympanic and squamous parts forms a streak which should not be misdiagnosed as a fracture line. The scutum projects inferomedially from the superior and medial end of the external canal. Tympanic membrane attaches to this point. The anterior and posterior walls of the external canal are seen on axial CT sections while coronal sections are required to evaluate its inferior and superior walls. On axial sections foramen ovale and foramen spinosum can be visualized next to eustachian tube opening in the most inferior sections of the external auditory canal.

Tympanic cavity is an air filled obliquely oriented space medial to the tympanic membrane and it can be evaluated both on axial and coronal scans. It is divided into epitympanum, mesotympanum and hypotympanum portions according to the level of the tympanic membrane. Epitympanum is connected to mastoid antrum by a narrow opening called aditus ad antrum. Eustachian tube opening is pre-

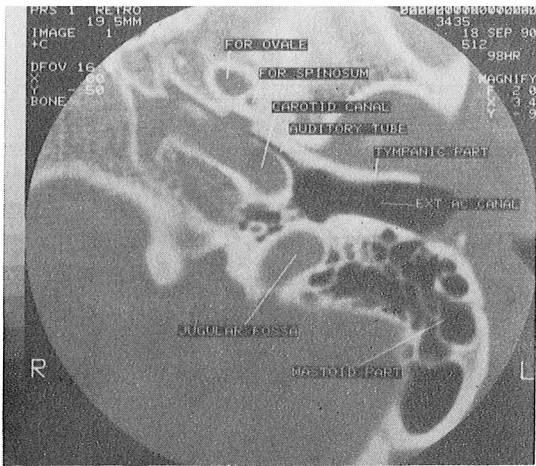


Fig. 1a

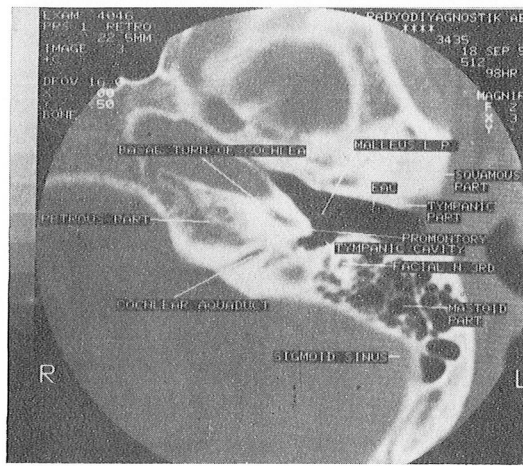


Fig. 1b

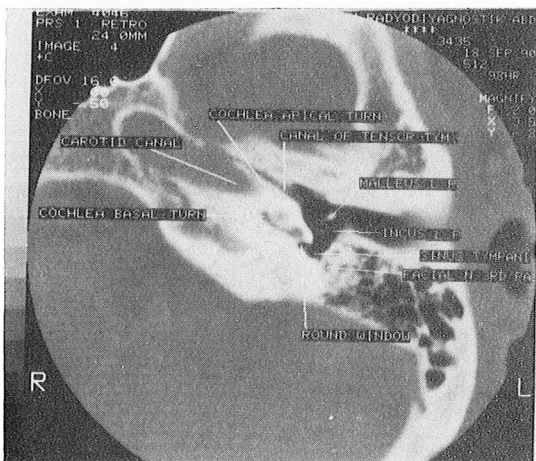


Fig. 1c

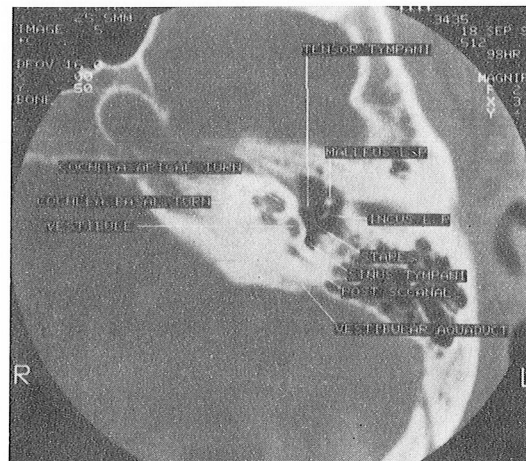


Fig. 1d

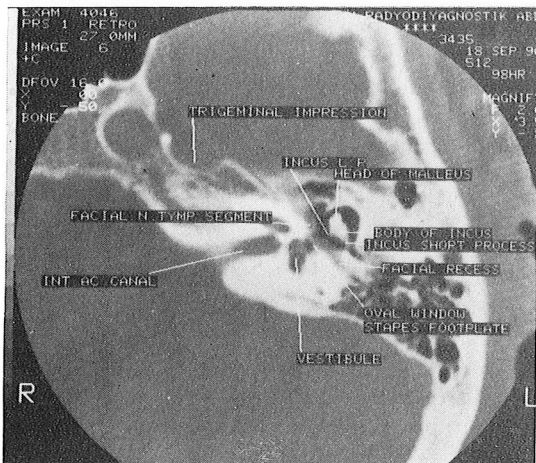


Fig. 1e

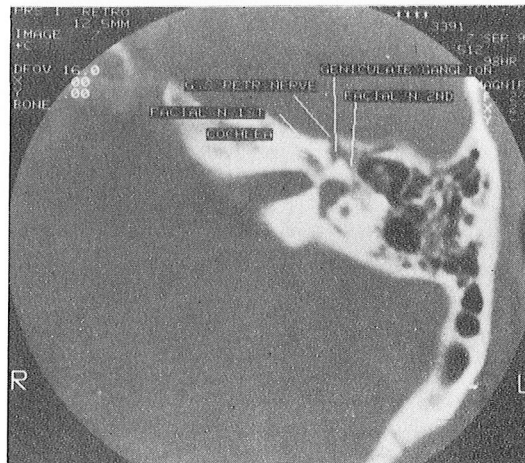


Fig. 1f

Fig. 1a - g : 1.5 mm. thick axial scans of left ear caudocranially.

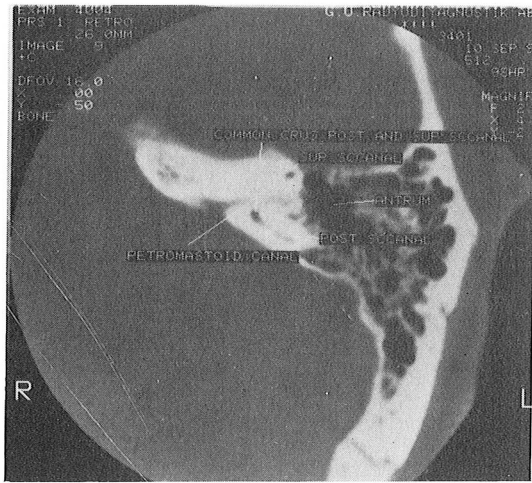


Fig. 1g

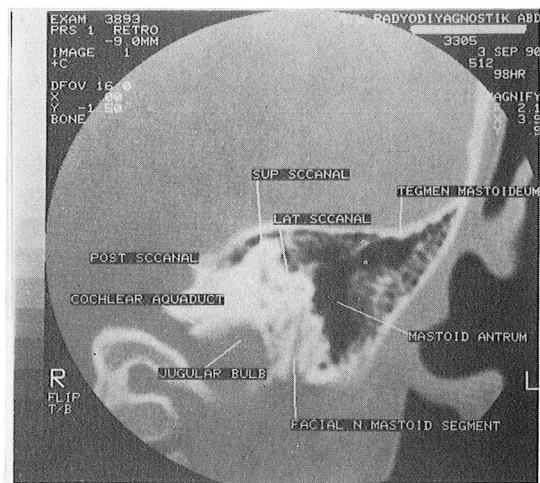


Fig. 2a

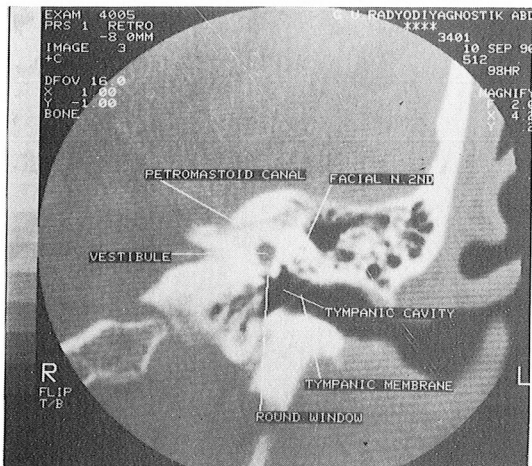


Fig. 2b

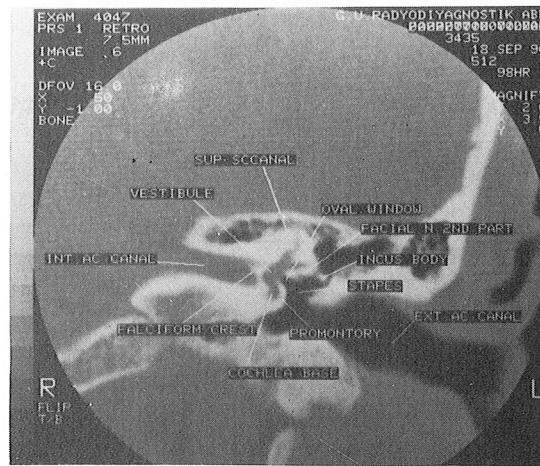


Fig. 2c

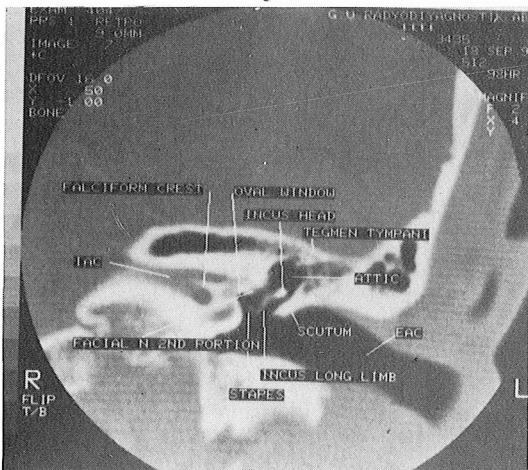


Fig. 2d

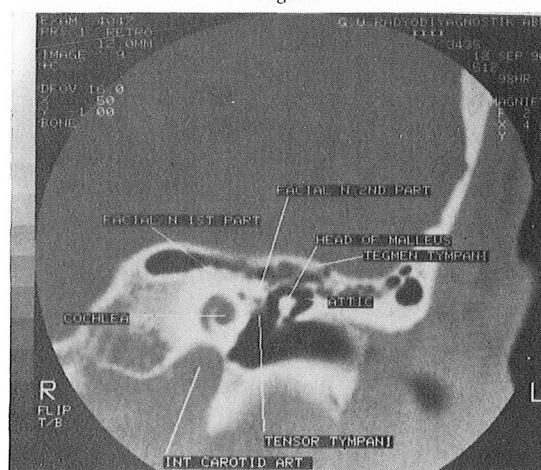


Fig. 2e

Fig. 2a - f : 1.5 mm. thick coronal scans of left ear posteroanteriorly.

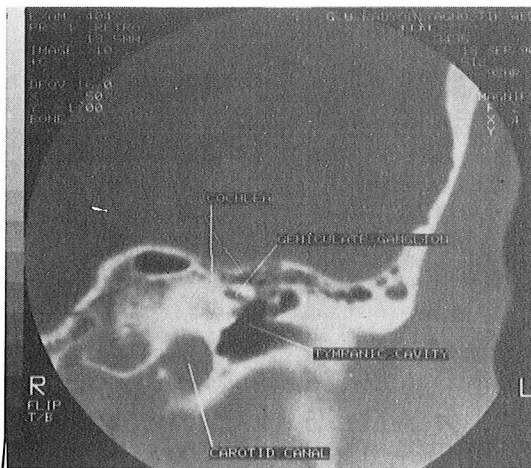


Fig. 2f

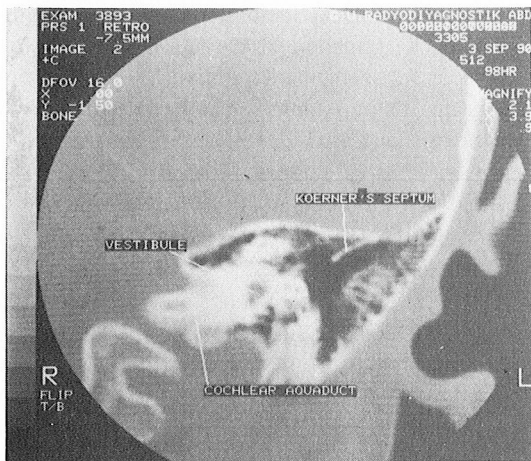


Fig. 3 : 1.5 mm. thick coronal section of left ear showing Koerner's septum.

present on the anteromedial wall of the hypotympanum. Middle ear is ventilated with the help of these two connections. Tympanic cavity contains ossicles which transmit sound from the tympanic membrane to the oval window. On axial sections the long processes of malleus and incus are visible as linear densities parallel to each other, malleus situated anteriorly and incus posteriorly. Stapes can also be imaged medially on the same section. Head of malleus and the body and short process of incus are observed on higher sections, and malleoincudal joint is seen as a lucent line. Some authors resemble the malleoincudal joint to an ice cream cone on axial sections and to an inverted teardrop on coronal sections (Chakeres and Weider, 1985).

Manubrium mallei is seen attached to the tympanic membrane on coronal sections, and the complete malleus with all of its components can be visualized in a single section. Short process of incus and stapes is visible posteriorly, and incudostapedi-

al joint can be seen which is an important landmark in the diagnosis of ossicular dislocation. Furthermore, oval (vestibular) window niche and position of stapes in it, is best visualized on coronal sections. Oval window and footplate of stapes can also be visualized on axial sections between horizontal facial canal and vestibule. Oblique reformations of axial images from oval window can be used for better imaging of stapes and visualization of both crura of stapes (Lee et al. 1989).

Tympanic membrane and lateral wall of epitympanic recess forms the lateral wall of tympanic cavity while cochlear promontory which is an important surgical landmark constitutes the medial wall. Round (cochlear) window can be seen behind the cochlear promontory on axial sections. It is just inferior to the vestibule on coronal scans.

Sinus tympani is one of the posterior wall structures of tympanic cavity, and together with cochlear promontory, it is very important in preoperative assessment of middle ear diseases (Hasso and Ledington, 1988). Sinus tympani is visualized between round window and facial recess on axial scans.

Tensor tympani muscle is situated on the anteromedial wall of the tympanic cavity above eustachian tube opening. Superiorly, tegmen tympani divides tympanic cavity and middle cranial fossa. It continues posteriorly over aditus, antrum, and mastoid, where it is named as tegmen mastoideum.

Tympanic cavity is connected to mastoid antrum, the largest one of the mastoid air cells, by a narrow passage called aditus ad antrum. On axial scans this connection can be visualized in a shape similar to. Periantral air cells are present around mastoid antrum. These cells normally are completely filled with air. The lateral wall of mastoid antrum has a trabecular margin named as Koerner's septum which is embryologic in origin. It attaches to tegmen mastoideum and extends to the anterior portion of the antrum. The development of Koerner's septum differs among people. Koerner's septum is demonstrated better on coronal sections, and it is important to know its position and development before planning middle ear operations (Fig 3).

Cochlea is visualized in the otic capsule just medial to cochlear promontory. It can be shown easily on both axial and coronal scans, containing approximately 2 1/2 to 2 3/4 turns arranged in a snail like configuration. Vestibule is located posterior and superior to cochlea. The three semisircular canals

are arranged perpendicular to each other, and they connect to the vestibule on each end. There are only five openings to the vestibule because limbs of posterior and superior semicircular canals combine to form a common crus. All of these structures form the bony labyrinth containing membranous labyrinth inside, which cannot be visualized with CT. Abnormalities and demineralization zones in the bony labyrinth can be evaluated both on axial and coronal scans.

Cochlear aqueduct is a narrow perilymphatic channel arising from basal turn of cochlea near the round window. It traverses the bone inferomedially to open into the subarachnoid space just anteromedial to the jugular fossa with a funnel-shaped configuration. Cochlear aqueduct is best visualized on coronal plane. In adults it is about 6-10 mm. in length. External opening of the canal is 2-5.3 mm. in width (Bhimani et al. 1984). Phelps (1986) reports that in 60 % of cases whole length of the cochlear aqueduct can be visualized with CT.

Vestibular aqueduct is the bony canal of the endolymphatic duct. It extends from the vestibule to an epidural space located on the posterior aspect of the petrous bone, lying medial to the inferior limb of the posterior semicircular canal. Its opening to the epidural space can be detected on coronal scans. In axial plane, vestibular aqueduct appears as a slit-like structure.

Petromastoid canal is a small bony canal carrying the subarcuate vessels, and it passes under the arch of the superior semicircular canal, terminating in cells around the mastoid antrum. It can be detected on both planes, and has been proposed as a route for a fistula or meningitis (Phelps, 1986).

Trigeminal impression comprising semilunar ganglion is visualized on the medial end of petrous apex which should not be misdiagnosed as an area of bony erosion.

Anterior and posterior walls of internal auditory canal are observed on axial scans while superior and inferior walls are viewed on coronal scans. A normal internal auditory canal can be in various configurations; the important point in evaluating internal auditory canal is bilateral symmetry and presence of destruction in the walls of the canal. Vestibulocochlear nerve, motor and sensory branches of facial nerve, labyrinthine artery and vein pass through internal auditory canal. The lateral end of the canal is unequally divided by the falciform

crest, which is located near the superior wall. The facial nerve, *nervus intermedius*, and branches of superior vestibular nerve enter into the otic capsule superior to the falciform crest. Inferior to the falciform crest several small openings are present for the cochlear nerve placed anteriorly and inferior vestibular nerve posteriorly. Extension of the superior and inferior vestibular nerve from the lateral end of the internal auditory canal to the vestibule can be shown on axial scans of most of the temporal bone CT examinations.

Facial nerve enters the temporal bone from the internal auditory canal, after following a complex route, leaves the temporal bone from the stylomastoid foramen toward the parotid gland. The intratemporal part of the facial nerve consists of labyrinthine (1.), tympanic (horizontal, 2.), and mastoid (vertical, 3.) segments respectively. After entering from the internal auditory canal, the labyrinthine segment runs anterolaterally with an angle of 45 degrees. This first segment is the narrowest and measures only 5 mm. in length (Shankar et al. 1989). Clinically the nerve is thought to be most vulnerable to an inflammatory process at this site (e.g. Bell's palsy). The first segment ends with the geniculate ganglion placed in the geniculate fossa. On axial sections geniculate ganglion is visualized as an inverted "V" shaped lucency whereas it is seen as two parallel placed circular lucency on coronal sections. On this point facial nerve forms its first genu, and anteriorly, the greater superficial petrosal nerve exits along the superior margin of the petrous bone to innervate the lacrimal gland through the ciliary ganglion (Chakeres and Capila, 1984). Bony canal of the greater superficial petrosal nerve should not be misdiagnosed as a fracture line on axial sections. After the first genu, the facial nerve enters the middle ear and continues as tympanic segment posterolaterally. Superiorly it is covered by dense cortical bone underlying the lateral semicircular canal, while inferiorly it is covered by only a thin bony shell. Many normal patients have dehiscences of the bony wall in this segment. On axial sections, the whole length of the tympanic segment of the facial nerve can be visualized in one section. On coronal scans, it can be seen as a soft-tissue density below lateral semicircular canal. On reaching the posterior wall of the tympanic cavity, facial nerve makes its 90 degrees second genu next to sinus tympani and pyramidal eminence, and it descends vertically to become the mastoid segment. Second genu of the facial nerve can be visualized on axial scans;

oblique reformations from the axial images may be helpful to demonstrate this structure completely. The mastoid segment is best seen on coronal plane. Two branches arise from this segment. The first branch close to the second genu is the stapedial nerve, the second branch is the chorda tympani.

Carotid canal of the internal carotid artery is anteroinferior to the temporal bone, and normally it is separated from the middle ear cavity by a bony covering. It can be recognized both on axial and coronal scans. Jugular foramen is bordered by temporal bone anteriorly and contains the jugular bulb, glossopharyngeal nerve, vagus nerve, spinal accessory nerve, and inferior petrosal sinus. Right jugular foramen is generally larger than the left due to venous asymmetry (Shaffer, 1985). The jugular fossa can have various size and configurations; it can be classified as high, middle and low-lying according to its position with regard to the basal turn of the cochlea (Wadin and Wilbrand, 1985). Normally, it is separated from the tympanic cavity by a bony covering. Dehiscence of this bone is important to evaluate preoperatively. Sigmoid sinus is another vascular structure demonstrated on axial sections.

DISCUSSION

Various examination planes, angles and section thicknesses have been used in temporal bone CT examinations. Today it is accepted that at least two examination planes have to be used to evaluate temporal bone structures optimally. Axial and coronal planes are agreed to be the basic examination planes; but it is also stated that direct sagittal examinations may be helpful to evaluate some temporal bone structures better (Mafee et al. 1988). Depending on our experience, we think that axial and coronal plane examinations with 1.5 mm. thick contiguous sections done routinely are sufficient for temporal bone CT examinations. By this technique, possible partial volume effect artefacts of thicker sections are avoided; furthermore, overlapping technique is very rarely needed for some special cases. Sagittal or oblique reformation images of the axial sections can be used whenever necessary, leaving no need for additional routine direct examination planes.

Because there are a variety of imaging techniques for evaluation of the temporal bone, it is essential to utilize the optimal examinations; in recent years a general consensus has been reached in the choice of imaging techniques of the temporal bone according to the suspected pathology. Considering the ease of

application, amount of radiation exposed to the eye, and the success in diagnosis, it is accepted that the use of high-resolution CT has completely replaced pluridirectional tomography (Fritz et al. 1989; Mikhael et al. 1987). The advantage of better spatial resolution of conventional tomography is no longer a factor effecting the diagnostic accuracy after the development of high-resolution CT scanners.

Magnetic Resonance Imaging (MRI) is proved to be another powerful diagnostic tool of radiology; and it is superior to CT in the diagnosis of most cerebellopontine angle lesions. On the other hand CT is superior to MRI in the diagnosis of middle ear and mastoid diseases. MRI is especially valuable in demonstration of small intracanalicular tumors. CT combined with gas cisternography is considered to be a useless invasive technique for the diagnosis of intracanalicular lesions after the clinical applications of MRI (Mikhael et al. 1987).

The indications of temporal bone CT examinations should be well understood before routine clinical applications of it. CT is not necessary in the evaluation of acute otitis media as it is well portrayed on conventional radiographies. However in the evaluation of chronic otitis media, cholesteatoma and malignant otitis externa patients, CT examination is indicated. The most reliable method of evaluating cholesteatomas is CT, which will demonstrate the soft tissue mass with homogeneous sharply defined borders, and demineralization of neighbouring bony structures. Some authors suggest the utilization of CT numbers (HU) in the diagnosis of cholesteatoma, while others report that the comparison of CT numbers has not proven to be helpful in this application (Hasso and Ledington, 1988).

Contrast enhanced CT scans are very valuable in showing the extension of the disease in late cases of malignant external otitis. High-resolution dynamic CT scan is the best method to show the hypervascularity of paragangliomas like glomus tympanicum and glomus jugulare tumors; also the extent of these tumors are well displayed with this technique.

In Meniere's disease, CT is employed to rule out other retrocochlear pathologies that may cause the same symptom complex. Congenital or acquired cerebrospinal fluid fistulas can be demonstrated in patients with similar labyrinthine irritation symptoms. Tegmen tympani, apical air cells, petromastoid canal, facial nerve canals should be care-

fully evaluated in CT examinations of patients with recurrent meningitis and symptoms and signs of CSF otorrhea or rhinorrhea. Hyrtl's fissure is another potential route for CSF fistula, which is caused by a failure of fusion of bone between cochlea and jugular bulb through which Arnold's nerve passes from posterior fossa to the middle ear (Phelps, 1986). The width of the cochlear aqueduct should also be evaluated in all patients with probable CSF fistula (Arenberg et al. 1984).

CT shows probable vascular anomalies, vascular tumors, and retrocochlear lesions in patients complaining of tinnitus. Infectious, neoplastic cystic, vascular lesions of petrous apex, retrocochlear mass lesions, vascular or non-vascular congenital anomalies are all among indications of high-resolution CT examinations. Ectopic internal carotid artery and bulging exposed jugular bulb in the middle ear could accurately be diagnosed by CT scans. Internal carotid artery aneurysm in the middle ear, persistent stapedia artery, hemangiomas of the middle ear, and varices of the tympanic membrane are other vascular anomalies of the middle ear which could be demonstrated by CT.

Radiological investigation is usually not indicated in Bell's palsy. CT examination should be applied in permanent or recurrent facial nerve paralysis (Wadin et al. 1987).

CT is the most successful method to demonstrate temporal bone fractures following trauma (Holland and Zawadki, 1984). Temporal bone fractures are classified into longitudinal, transverse, complex and atypical fractures according to the course of the fracture line and the structures affected. It is reported that approximately 50 % of all acutely traumatized patients with brain CT signs of hemotympanum were found to have clinically unsuspected temporal bone fractures on high-resolution CT (Schubiger et al. 1986).

Evaluation of patients with primary conductive hearing loss is the most clearcut indication for CT of the ossicles (Chakeres and Weider, 1985). The involvement of the ossicles in disease processes like trauma, cholesteatoma, tumor and congenital abnormalities can also be evaluated by high-resolution CT examination of the temporal bone. In our experience, axial and coronal plane examinations are sufficient for imaging of ossicular dislocations.

In otosclerosis patients in active otospongiosis phase, demineralization zones of the otic capsule can be shown with CT. On the other hand demonstration of the dense sclerotic bone formation phase of the disease by CT is controversial. Some investigators report that CT densitometric analysis is useful to detect this phase of the disease. CT density of normal otic capsule is measured to be between 1800-2050 Hounsfield Units (Willbrand, 1988). High-resolution CT makes it possible to evaluate the modifications of the oval window and the thickness of the footplate of the stapes. Some authors suggest the use of 0.5 mm. thick axial and coronal scans and oblique reformations from the level of vestibular window in the diagnosis of otosclerosis (Mafee et al. 1985). Postoperative CT examination following otosclerosis operations is very helpful showing probable complications like subluxation of the prosthesis, postoperative tympanic fibrosis, incus necrosis, and regrowth of otosclerotic bone. CT can also be employed to visualize the position of ossicular prosthesis postoperatively. The information provided by CT is also very useful in planning cochlear implantation operations (Harnsberger et al. 1987; Mueller et al. 1989).

The use of temporal bone CT examinations pre-surgically in any kind of operation of that region may be helpful to provide a preoperative picture of normal variants and avoidable surgical pitfalls (Curtin, 1988). High jugular fossa with dehiscent walls exposed to tympanic cavity, cochlear aqueduct with wide opening or a dehiscent facial canal in the tympanic cavity are some potential abnormalities which a surgeon can encounter very frequently in daily practice. Being aware of these kind of congenital variations preoperatively is very valuable for a surgeon in planning the surgical approach.

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