Middle and Inner Ear: Improved Depiction with Multiplanar Reconstruction of Volumetric CT Data¹

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Many anatomic structures of the middle and inner ear are not optimally depicted at computed tomography (CT) with image reconstruction in the standard axial and coronal planes. Recent advances in multidetector CT, including the development of scanners with 32 detector rows, allow the acquisition of isotropic voxels that can be reconstructed in any plane of section. This technique gives radiologists the opportunity to visualize the anatomic structures of the middle and inner ear (the ossicular chain, stapedial footplate–oval window complex, round window, cochlea, vestibular aqueduct, and bones of the superior semicircular canal and facial nerve canal) in greater detail and may help increase the accuracy of CT for the diagnosis of diseases of the middle and inner ear.

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Introduction

Since the advent of computed tomography (CT), the physical limitations of gantry angle and patient positioning have restricted the plane of imaging in temporal bone to the standard axial and coronal orientations. However, most anatomic structures of the middle and inner ear are not optimally depicted in these planes. In the days of temporal bone polytomography, complex oblique projections were often obtained to better visualize some of these structures. Recent advances in multidetector CT technology allow the acquisition of volumetric data with isotropic voxels that permit image reconstruction in any plane of section. Our purpose in this article is to demonstrate the utility of oblique planes of reconstruction for achieving optimal depiction of clinically relevant temporal bone anatomy and pathologic change.

Abbreviation: CHARGE = coloboma of the eye, heart defect, atresia of the choanae, and renal, genital, and ear abnormalities

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Multidetector CT Technique

CT examinations of the temporal bone are performed at our institution by using a multidetector scanner (Sensation 64; Siemens, Malvern, Pa). The scanner is equipped with 32 rows of detectors, but the use of an oscillating focal spot produces the effect of scanning with 64 detector rows. Scanning is performed in the standard axial plane with helical technique (120 kV, 350 mA, pitch of 0.85, rotation time of 1 second, section thickness of 0.6 mm, matrix of 512 × 512). The subject’s head is placed in a neutral position, without chin tilt, to approximate the Reid base line. The image data set is reconstructed to a 70-mm field of view, with an individual voxel size...
of $0.6 \times 0.6 \times 0.6$ mm. The images included in this article were reconstructed at a standard vendor workstation (Wizard; Siemens). The time required for multiplanar reconstruction of the CT image data set was 2–3 minutes per reconstruction. Each reconstruction was tailored to depict a structure of common clinical interest: the ossicular chain, the stapedial footplate-oval window region, the round window, the cochlea, the vestibular aqueduct, or the bony canals of the superior semicircular duct and the facial nerve. The anatomic location and orientation of the structures to be evaluated were confirmed on images in three orthogonal (axial, coronal, and sagittal) planes of reference. Oblique planes of section were defined to optimally depict the given structure. The approximate angle of obliquity required to achieve optimal depiction of each area of interest is listed in the Table. Examples of disease were obtained from the first 100 cases acquired with this 64-section CT system.

**Malleus and Incus**

The long axes of the malleus and incus are not optimally depicted at the conventional temporal bone CT examination, which consists of the acquisition of axial and coronal sections. The manubrium of the malleus and the long process of the incus are angled posteriorly and medially as they course from superior to inferior anatomic points. Oblique coronal planes located along the long axes of these structures provide the best depiction of the malleus (Fig 1a–c) and of the incus and incudostapedial joint (Fig 2a–c). The oblique sagittal plane also allows visualization of the long axes of both the malleus and incus and provides an alternative to the axial plane for assessment of the incudomalleolar joint (Fig 3a–3c).
Figure 3. Double-oblique sagittal view of the left malleus and incus. (a, b) Orthogonal axial (a) and coronal (b) reference images show the plane of reconstruction (white line). (c) Double-oblique sagittal image shows the molar tooth–like appearance of the incudal body (IB), incudomalleal joint (IMJ), malleal manubrium (MM), and incudal long process (ILP). (d) Double-oblique sagittal image in another patient shows a missing cusp of the molar tooth (arrow), a finding that indicates the complete erosion of the incus by a cholesteatoma, as was proved at surgery.

Figure 4. Double-oblique axial view of the stapes at the oval window. (a, b) Orthogonal coronal (a) and sagittal (b) reference images show the plane of reconstruction (white line). Obliquity in two planes was required to optimally profile both the stapes and oval window. (c) Double-oblique axial view shows a normal stapes, including the stapedial anterior crus (SAC), posterior crus (SPC), and footplate (SFP), at the level of the oval window. (d) Double-oblique axial image in a child with CHARGE syndrome shows a unipolar left stapes (arrow). (e) Double-oblique axial view in another patient shows a remote temporal bone fracture with foreshortening of the posterior crus (arrow), subluxation of the footplate (white arrowhead), and posttraumatic ossification of the vestibule (black arrowhead).
Stapedial Footplate–Oval Window Complex

Although true coronal images in a standard two-plane examination often provide the best depiction of the oval window, the orthogonal axial images are not oriented properly to depict the oval window or the footplate and crura of the stapes. Inspection of the relative positions of the stapedial crura in the sagittal plane (Fig 4b) demonstrates that the anterior crus is located inferiorly to the posterior crus, a position that requires an oblique axial plane of reconstruction to depict both crura on a single image. In the coronal plane, the superior margins of the oval window and stapedial footplate are lateral to the inferior margins, a position that necessitates the use of a second axial oblique plane of section to depict these structures (Fig 4a). These relationships help explain why standard axial images often do not adequately represent the oval window. A double-oblique orientation of the axial reconstruction plane enables the optimal display of both the crura and the stapedial footplate at the oval window (Fig 4c). An oblique sagittal reconstruction is useful for confirming the presence of both crura just lateral to the footplate at the level of the oval window (Fig 5a–5c). The combination of oblique axial (long-axis) and oblique sagittal (short-axis) reconstructions may aid in the evaluation of congenital anomalies such as unipolar stapes, which is commonly seen in children who have the so-called CHARGE syndrome (with associated coloboma of the eye, heart defect, atresia of the choanae, and renal, genital, and ear abnormalities) (Fig 4d) (1). The combination also may be helpful for evaluating stapedial fracture dislocation (Fig 4e) and stapes fixation in the setting of conductive hearing loss (Fig 5d).

Reconstruction in this plane re-creates the polytomographic lateral view of the malleus and incus, in which the combined structures resemble a molar tooth. These reconstruction planes also may be helpful for delineating ossicular erosions in the clinical setting of cholesteatoma (Figs 1d, 2d, 3d) or traumatic dislocation. Congenital anomalies of the ossicular chain and oval window may be depicted in these planes as well (Fig 3e, 3f).

Figure 5. Oblique sagittal view of the stapes immediately lateral to the oval window. (a, b) Orthogonal axial (a) and coronal (b) reference images show the plane of reconstruction (white line). (c) Double-oblique sagittal image shows normal anatomy of the stapedial posterior crus (SPC), stapedial anterior crus (SAC), and cochlear promontory (CP). (d) Double-oblique sagittal image in a patient with congenital conductive hearing loss depicts congenital fixation of the stapedial posterior crus to the cochlear promontory (arrow). The synostosis was lysed at surgery, and stapedial ossiculoplasty was performed, with resultant restoration of normal conductive hearing.
Figure 6. Single-oblique sagittal view of the round window. (a) Orthogonal axial reference image shows the plane of reconstruction (white line) through the round window. (b) Single-oblique sagittal image provides a profile of the normal round window (RW) within the round window niche and shows its location in relation to the carotid canal (CC), labyrinthine segment of the facial nerve canal (FN), sinus tympani (ST), and superior vestibular nerve canal (SVN). (c) Single oblique sagittal reconstruction in a patient with fenestral and retrofenestral otospongiosis shows a lucent halo (arrow) that surrounds the bony labyrinth and similarly lucent otospongiotic plaques (arrowheads) in the round window niche.

Figure 7. Double-oblique coronal short-axis view of the cochlea. (a, b) Orthogonal axial (a) and sagittal (b) reference images show parallel planes of reconstruction (white lines) along the short axis of the cochlea. Note the inferior tilt of the cochlea on b. (c–e) Consecutive double-oblique coronal images provide en face views of normal anatomy of the apical turn (AT) (c), middle turn (MT) (d), and basal turn (BT) (e) of the cochlea (Mo = modiolus). (f) Double-oblique coronal image in another patient shows posttraumatic ossification of the basal turn of the right cochlea (arrow), a sequela of remote trauma, with persistent lucency of the fracture lines (arrowheads) through the superior and lateral walls of the labyrinth.
Round Window
The round window opens posteriorly from the basal turn of the cochlea into the round window niche. This anatomic feature may be clearly depicted on images in the axial plane (Fig 6a); however, its clear depiction in the coronal plane is not possible, because of the orientation of the structure. As an adjunct to images in the axial plane, therefore, oblique sagittal reconstructions are optimal for depicting the opening of the round window into the niche (Fig 6b). The oblique sagittal view may be particularly helpful for detecting the plaque formation that occurs in fenestral otospongiosis (Fig 6c).

Cochlea
The long axis of the cochlea is tilted inferiorly and laterally and thus is not optimally depicted on standard axial or coronal images. Evaluation of the apical, middle, and basal turns may be aided by oblique angulation of the plane of section to parallel the short (Fig 7a, 7b) and long (Fig 8a, 8b) axes of the cochlea and thereby achieve optimal depiction of all three cochlear turns.

In addition, the aperture of the cochlear nerve (Fig 8c) and the integrity of the modiolus (Figs 7e, 8c) can be further assessed on images in the same oblique planes. The presence of a normal cochlear nerve aperture may be a useful indirect indicator of an intact cochlear nerve (2). The modiolus, which accommodates the branches of the cochlear nerve and appears cribriform at microscopic examination, has CT attenuation lower than that of the rest of the bony labyrinth (Fig 8c). A small and hyperattenuating modiolus presumably indicates either the absence or the marked hypoplasia of the cochlear nerve (Fig 8d).

Semicircular Canals
The superior semicircular canal is oriented at an angle of approximately 90° to the long axis of the temporal bone. Orthogonal coronal images usually suffice for the assessment of the integrity of the bony roof of the canal. However, in individuals in whom this covering of bone is thin, problems with volume averaging effects at the anterior and posterior edges of the superior semicircular canal arch could cause confusion regarding the integrity of the bone. Oblique sagittal reconstructions in the same plane as the long axis of the canal (Fig 9a) can help eliminate problems with volume averaging (Fig 9b).
In the setting of Tullio syndrome (a condition that is characterized by vertigo, is precipitated by loud sounds, and is secondary to a bone defect in the roof of the superior semicircular canal), dehiscence of the bone can be confirmed at CT prior to surgical repair (Fig 9c) (3).

Vestibular Aqueduct
The vestibular aqueduct, which contains the endolymphatic duct and part of the endolymphatic sac, proceeds superiorly from the posterior surface of the petrous bone and then curves to enter the posteromedial vestibule just anterior to the common crus. The vestibular aqueduct has a triangular shape that has been compared to that of a Christmas tree (4). The course of the duct in relation to the common crus may be best depicted on images in the sagittal plane (Fig 10a, 10b). The use of this plane of reconstruction can aid in the diagnosis of dilated vestibular aqueduct syndrome, the most common bony labyrinth anomaly observed in patients with a profound sensorineural hearing loss (Fig 10c) (5).

Facial Nerve Canal
The tympanic segment of the facial nerve proceeds from the geniculate ganglion posteriorly and laterally beneath the lateral semicircular canal. At the second genu, the nerve enters the mastoid segment of the canal, after which it courses inferiorly through the canal and exits at the stylomastoid foramen. With image reconstruction in an oblique sagittal plane, the entire length of the tympanic and mastoid segments can be depicted on a single image (Fig 11a–11c). The use of this plane of reconstruction can aid in the diagnosis of facial nerve anomalies (Fig 11d) and fractures that transect the facial nerve canal (Fig 11e).

Historical and Clinical Context
Temporal bone imaging became a specialized area of radiologic study with the advent of polytomography during the late 1950s and early 1960s. The recommended tube angulation for examinations of the temporal bone depended on the anatomic region of greatest clinical interest, but the standard examination comprised frontal (coronal) and lateral (sagittal) projections (6). Supplemental projections were developed to show certain structures to better advantage. The Stenvers view, a long-axis projection of the petrous portion of the temporal bone, was used to depict the round window and posterior semicircular canal, as well as other structures (7). The Poschl view, a short-axis view of the petrous pyramid, was used to optimally visualize the superior semicircular canal, anterior wall of the cochlea, and vestibular aqueduct (8,9). With the advent of CT, the restrictions imposed by limitations in gantry angle defined the axial and coronal planes as the standard views. Attempts in the early 1980s to incorporate sagittal imaging into the routine examination...
Figure 10. Single-oblique sagittal view through the vestibular aqueduct. (a) Orthogonal axial reference image shows the plane of reconstruction (white line), which includes the medial wall of the vestibule and the vestibular aqueduct. (b) Single-oblique sagittal image shows the spatial orientation of the normal vestibular aqueduct (VA), which enters the vestibule just anterior and medial to the opening of the common crus (CC). (c) Single-oblique sagittal image in a patient with profound sensorineural hearing loss shows a dilated vestibular aqueduct (arrow).

Figure 11. Double-oblique sagittal view of the facial nerve canal. (a, b) Orthogonal axial (a) and coronal (b) reference images show the plane of reconstruction (white line). (c) Double-oblique sagittal image shows normal anatomy of the tympanic (FNt) and mastoid (FNm) segments of the facial nerve canal, the lateral semicircular canal (LSC), and the tensor tympani (TT) muscle. (d) Double-oblique sagittal image in a child with CHARGE syndrome shows the inferior location of an aberrant tympanic segment of the facial nerve canal (arrow) and the absence of the lateral semicircular canal, which should appear immediately superior to the facial nerve canal. (e) Double-oblique sagittal image in another patient shows a remote complex temporal bone fracture (arrow) that transects the tympanic facial nerve canal (arrowhead).
were not widely successful, because of difficulties in patient positioning and requirements for modifying the standard head holder (10,11).

The advent of multidetector CT with submillimeter section thickness provided the opportunity to replace direct coronal scanning with coronal reconstruction of image data from axial scanning (12). The 64-section CT technology employed in this study allows the acquisition of a data set that consists of isotropic voxels. Reconstructions in any plane are thus possible without a significant loss in resolution. This capability should lead to a reassessment of the optimal imaging planes for the depiction of temporal bone. Mafee et al (10) advocated the use of direct sagittal imaging because it allows the depiction of the relevant anatomy along a plane of section that more closely approximates the surgical plane of exposure and, thus, has greater clinical utility to the surgeon.

We found that sagittal reconstructions with slightly different degrees of axial and coronal obliquity are useful for evaluating all of the structures included in this study, except the oval window. Reconstructions in the plane parallel to the long axis of the petrous bone (Stenvers projections) are useful for obtaining short-axis views of the cochlea (Fig 7), vestibular aqueduct (Fig 10), facial nerve canal (Fig 11), round window (Fig 6), and incudomallear joint (Fig 3). Reconstructions in the plane parallel to the short axis of the petrous pyramid (Poschl projections) are useful to optimally depict the superior semicircular canal (Fig 9) and the long axis of the cochlea (Fig 8). It is important to note that optimal depiction of a given structure often requires an oblique orientation with regard to more than one reference plane (Table).

Summary

Imaging in nonorthogonal planes was advocated decades ago by pioneers in temporal bone polytomography. The recent development of volumetric CT technology gives radiologists the opportunity to evaluate more completely and more accurately the anatomic structures of the middle and inner ear. This article demonstrates the utility of multiplanar reconstructions of volumetric CT image data acquired with a scanner with 32 detector rows (64 effective sections) for depiction of normal anatomy and pathologic states in the temporal bone. The technique described helps overcome the limitations long imposed by restrictions in gantry angle and patient positioning and may help improve diagnostic accuracy. Further studies are needed to determine whether the use of oblique planes of reconstruction can improve the accuracy of CT for the detection and characterization of diseases of the middle and inner ear.

References

Teaching Points for Middle and Inner Ear: Improved Depiction with Multiplanar Reconstruction of Volumetric CT Data

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