Imaging of the Temporal Bone

Fourth Edition
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Thieme
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To Mrs. Charles Zale Swartz.

—Joel D. Swartz

To Joel Swartz—your passion, persistence, pride, and patience made this important project happen.
To my family, immediate and extended—thanks for your love and support.

—Laurie A. Loevner
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Preface

Well, it wasn’t easy! But then again, very few things that are worthwhile come easily. Losing a renaissance man such as Ric Harnsberger as an editor/contributor would certainly be expected to make any task more difficult, but 10 years between editions was more than we could have possibly anticipated!

Production was complicated by a number of foreseeable and unforeseeable events and was not without high levels of drama and anxiety as well as an obligatory high-wire act. But after all is said and done, this story has a happy ending. We are very proud of this authoritative monograph.

Imaging of the Temporal Bone continues to evolve as a comprehensive reference book. The text has been rewritten and expanded throughout, the illustrations to a large extent have been replaced by more cutting edge high resolution CT and MR images, and the bibliography has been extensively updated. The index has been expanded as well and is now on par with other contemporary reference books. Our main focus is centered on the imaging specialist, but we continue to hope that our clinical colleagues find our contribution of interest and importance as well. The chapter organization remains identical to previous editions. If it’s not broken, why fix it?

This edition has substantially more contributors than the previous editions. This was necessitated by a number of factors, not the least of which are the exploding advances in imaging technology, as well as the increasing subspecialization within neuro-otology which results in certain facilities seeing specific types of cases more than others.

Comments from dedicated readers were the driving force behind many of the changes in this fourth edition. Foremost among these suggestions was the request for the introductory chapter to expand the “cookbook” approach to evaluating and imaging the temporal bone. Chapter 1 has accomplished that objective. Paul Caruso was the lead author and he and his colleagues Jennifer Smullen, Robert Liu, Mary Beth Cunane, and Hugh Curtin provided us with a highly detailed contribution useful to radiologists, otolaryngologists, and technologists alike. Paul was also very helpful by providing us with many images utilized in this book, especially those pertaining to normal anatomy and congenital malformations.

Our good friend, Doug Phillips, spearheaded an outstanding contribution on the facial nerve for Chapter 7 with a very tight deadline and we are deeply indebted to him and his coauthors George Hashisaki and Francis Veillon. Doug was also very helpful to us in procuring a number of images used in this book. The editors also wish to thank Lucianna Ramos Taboada, Maher Abu Eid, and Sophie Riehm for their outstanding contributions.

Mauricio Castillo is a productive neuroradiologist, author, editor, administrator, and friend who took time from his increasingly busy schedule along with lead author Valerie Jewells to produce Chapter 2 on the external auditory canal.

Tim Larson provided considerable help with the postoperative middle ear and mastoid in Chapter 3. His experience and support allowed us to successfully update and expand this important section.

Gul Moonis, Ann Kim, and clinical colleague and friend Douglas Bigelow did a wonderful job with the subject of vascular anatomy and tinnitus in Chapter 4, and our friend Christine Glastonbury provided an outstanding contribution on imaging the cerebellopontine angle and internal auditory canal in Chapter 8. We are also indebted to Deborah Shatzkes and Edwin Wang for their contribution to temporal bone trauma, Chapter 6.

We would like to take this opportunity to thank our superb medical illustrator, Lori Goldstein Motis, for many of the beautiful drawings found throughout this book. And an enormous thank you to the entire staff at Thieme...
for their support, patience, and hard work in completing this project. And last, but not least, we especially want to thank our families, spouses Nina and Steve, and children Matthew and Laura, Daniel, Chuck, Benjamin, and Alexander. Where would we be without you?

To the readership, we especially thank you for your continued support. We hope that you find the information and images that follow interesting and educational. We are greatly interested in any of our readers’ comments or suggestions. Please feel free to e-mail us at swartzjd@aol.com or laurieloevner@aol.com.

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This chapter on the technique for imaging the temporal bone is a practical “how to” written in two parts. In the first part, we explain how to image the temporal bone: how to run the hardware and obtain the images. We present the imaging modalities and technical parameters routinely used for imaging of the temporal bone. In addition, we provide guidelines for the technologist or radiologist as to how to determine which parameters to enter into the computed tomography (CT) or magnetic resonance imaging (MRI) scanner. In the second part, we explain how to read and report the results of temporal bone imaging studies. Here we provide a plan of action for the radiologist who, faced with a request for a temporal bone imaging study on a particular patient, must protocol the case, interpret the images, and report the findings in a way that answers the referring clinician’s questions. The major indications for imaging of the temporal bone are thus reviewed, and protocols, interpretive strategies, and template reports are provided for each of these indications.

Imaging Modalities and Technical Parameters

CT and MRI are primarily used for imaging of the temporal bone. We first present the standard technique and protocols most often used, then review the special considerations for both modalities. A brief overview of the roles of plain radiographs, ultrasound (US), positron emission tomography (PET), and PET/CT is given at the end of this section.

Computed Tomography

Routine Technique

The patient is placed supine in the gantry and positioned to place the lens of the eye as far as possible out of the path-way of the x-ray beam to minimize exposure to the lens. Gantry tilt may need to be avoided to facilitate image reconstruction and reformats. A lateral topogram is then performed. The scan excursion is plotted from the arcuate eminence (the summit of the temporal bone) through the mastoid tip.

The anatomy and pathology of the temporal bone involve small structures; resolution is thus highly important. Collimation is of optimal importance to achieve high resolution.

We routinely use a collimator of 0.6 mm and most commercially available units can be collimated to at least 1 mm. Collimation wider than 1 mm is not usually used, as the resolution is often insufficient.

For 40 to 64 detector scanners, the effective mAs (defined as the mA × the gantry cycle time/helical pitch) is adjusted according to the age and head size. Usually, it is 150 effective mAs (CTDIvol [volume CT dose index] 34 miligray [mGy]) for neonates, 200 effective mAs (CTDIvol 45 mGy) for children ages 1 to 10 years, 250 effective mAs (CTDIvol 57 mGy) for adolescents, and 320 (CTDIvol 72 mGy) for adults. The gantry cycle time is set at 1 cycle or gantry rotation/second. The kilovolt peak (kVp) is usually 120.

A helical mode is chosen. Although traditionally, some imagers maintain that nonhelical scans provide better resolution, it is our experience that the difference in resolution between nonhelical and helical acquisitions at thin collimation is not appreciable, and helical acquisitions allow for clearer coronal or oblique reformats and decrease susceptibility to motion artifact.

Intravenous (IV) contrast is usually of the low osmolar type; it is administered by power injector at standard doses of 1 mL/lb to a maximum of 80 to 100 mL for adults. IV contrast is used for the evaluation of vascular pathology (e.g., dissection, tumors) and may be considered for some types of infections such as coalescent mastoiditis or for the evaluation of abscesses. However, it is not routinely used to evaluate for otomastoiditis or hearing loss.

The raw data from each ear are separated and reconstructed into 0.6 mm (slice thickness) axial images in bone algorithm at a dual field of view (DFOV) of 100 mm that effectively magnifies the images. Then the 0.6 mm images for each ear are brought up on the CT scanner console, where the raw data are displayed in three orthogonal planes. The technologist scrolls through the sagittal data to find an image where the anterior and posterior limbs of the lateral semicircular canal are displayed in cross section (Fig. 1.1). An axial dataset is then made in a plane parallel to the lateral semicircular canal (LSCC). The technologist “connects the two dots” of the LSCC and...
Fig. 1.1 Making the standard axial and coronal computed tomography (CT) dataset. (A) Once the source data are brought up in the three-dimensional (3D) viewer on the scanner console, the sagittal images are scrolled through until a sagittal image through the anterior and posterior limbs (short white arrows) of the lateral semicircular canal (LSCC) are found. (B) A set of axial images is then generated with 0.1 mm overlap parallel to this plane. (C) If the axial reconstructions have been done correctly, the axial dataset should produce an image where the entire lateral semicircular canal is displayed and, as in (D,E), where the cochlear fossa, modiolus, and stapes footplate are clearly delineated.
Fig. 1.1 (Continued) (F) The coronal reconstructions are made in a similar fashion. Starting with the sagittal image in (A), a plane perpendicular to the LSCC is established, and the coronal reformats are made along this plane. (G) This technique should yield a set of coronal images where Prussak’s space (short white arrow) and (H) the facial nerve canal (short white arrow) are clearly delineated.
makes a 0.6 mm (image thickness) × 0.5 (distance between images) axial dataset in this plane parallel to the LSCC; 0.6 × 0.5 mm coronal images are made in a plane perpendicular to the axial images. The raw data are also reconstructed into 2 mm axial images in soft tissue algorithm to include both ears and the brain at 180–210 mm DFOV. This protocol generates seven sets of images, three for each ear—the source 0.6 mm images (in a variable axial plane), the 0.6 mm reformats in the axial plane parallel to the LSCC, the 0.6 mm reformats in the coronal plane, and a set of 2 mm axial images in soft tissue algorithm of the entire scan volume.

**Multidetector Computed Tomography Reformats**

Multidetector CT provides shorter acquisition times, a decrease in tube current load, and improved spatial resolution. Short acquisition is useful in temporal bone imaging to reduce motion artifact, particularly in children who require sedation or are imaged postprandially without pharmacologic sedation. Although the radiation dose with multidetector scanners in high-quality mode remains an issue compared with single detector scanners, the improved spatial resolution allows for high-quality reformats that essentially obviate the need for rescanning the patient in a second coronal plane.

Reformats may, moreover, be obtained in sagittal or oblique planes to improve the detection of pathology in specific clinical settings such as superior semicircular canal dehiscence (SSCD) as discussed below in the section Vertigo and Dizziness.

**Stenvers Reformat**

Similar to the method explained above, for making the standard axial and coronal images, the 0.6 mm raw data are brought up on the console viewer in three orthogonal planes: axial, coronal, and sagittal. As above, the technologist scrolls through the sagittal plane until a view of the SSC is obtained represented by the two “dots” of the anterior and posterior limbs (Fig. 1.2). The axial plane is then established by connecting the two dots. The technologist then scrolls through the axial dataset until an image of the summit of the SSC is viewed. The Pöschl reformats are then made by tracing a line parallel to the long axis of the summit of the SSC at 0.6 × 0.5 mm intervals. The line must be made as parallel as possible to the axis of the summit of the SSC. A slight obliquity may spuriously obscure a dehiscence by volume averaging with the temporal bone on either side of the summit of the SSC.

**Computed Tomography Arteriography and Computed Tomography Venography**

CT arteriography (CTA) or CT venography (CTV) of the temporal bone may be used to evaluate for tinnitus. At our institution, the standard CT protocol for temporal bone imaging is employed, but the injection rate is increased to 3 to 4 cc per second for CTA. A power injector is employed if a 22-gauge IV or larger is available.

**Radiation Dose Reduction Techniques and Considerations for Pediatric Patients**

Compared with most radiography procedures, CT exams deliver higher radiation dosages to patients. The quantity CTDIvol is used to describe the patient dose. CTDIvol represents the average dose in a given scan volume. When a scan is prescribed, the system displays the CTDIvol in mGy on the console. However, the dose displayed is not the true dose for the specific patient under examination. Instead, it is the dose value when the patient is replaced with an acrylic phantom while the same imaging parameters are used. The head phantom is a cylinder with a diameter of 16 cm and a height of 15 cm.

The effective dose E is used to assess the radiation detriment from partial-body as opposed to whole-body irradiation (e.g., irradiation of only the head or only the abdomen). The effective dose is a weighted sum of the doses to all exposed tissues. $E = \sum (w_i \times H_i)$, where $H_i$ is the equivalent dose to a specific tissue and $w_i$ is the weight factor representing the relative radiosensitivity of that tissue. The unit of effective dose is sievert (Sv). The effective dose for a typical CT exam of the temporal bone is ~1 mSv (i.e., 1/1000 Sv). In comparison, the average effective dose from cosmic rays, radioisotopes in the soil, radon, and so on, is ~3 mSv per year in the atmosphere.
United States. The effective dose can be estimated from the dose-length product (DLP = CTDIvol × scan length), which is also displayed on the CT scanner console. The effective dose for a head study in mSv is −0.0021 DLP (mGy cm).2

Radiation Risks  The biological effect of radiation is either deterministic or stochastic. The deterministic effect will not occur unless a threshold dose is exceeded. However, the stochastic effects may occur at any dose level, and the probability of occurrence increases with dose linearly according to the linear nonthreshold dose–response model.3

For CT of the temporal bone, the primary concern for deterministic effect is the dose to the lens. The minimum dose required to produce a progressive cataract is −2 Gy in a single exposure.4 If the lens is in the direct x-ray beam, the dose to the lens from CT of the temporal bone is in the range of 0.03 to 0.06 Gy, but it could be as high as 0.13 Gy. If the patient is positioned in such a way that the lens is outside the direct x-ray beam, the dose is in the order of 0.003 Gy.2 Although the typical dose to the lens from a single
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CT scan is much lower than the threshold value for a cataract, multiple nonoptimized scans in a short time with the lens in the x-ray beam can result in a lens dose close to the threshold. Every effort should be made to keep the lens outside a direct x-ray beam if it is possible.

Stochastic effects include carcinogenesis and the induction of genetic mutations. Children are inherently more sensitive to radiation because they have more dividing cells, and radiation acts on dividing cells. Also, children have more time to express a cancer than do adults.6

Factors Influencing the Patient Dose The CT scanning protocols should be optimized such that the quality of images is sufficient for diagnosis and the patient dose is kept as low as reasonably achievable (ALARA). To get the best balance of the image quality and patient dose, it is important to understand the effects of imaging parameters on the dose and imaging quality.

Patient dose depends on three factors: equipment-related factors, patient-related factors, and application-related factors.

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Fig. 1.3 How to make a Poschl reformat. (A) Once the source data are brought up in the three-dimensional viewer on the scanner console, the axial images are scrolled through until an image through the summit of the superior semicircular canal (SSC) is found. (B) The Poschl reformats are made in a plane perpendicular to the long axis of the SSC, and (C) should yield a view of the entire excursion of the SSC (short white arrows) from anterior to posterior.
Chapter 1 Temporal Bone Imaging Technique

The factors in the first group include x-ray beam filtration, x-ray beam collimation, system geometry, and detector efficiency. Although users do not have control of most of these factors, it is important to understand that the z-axis dose efficiency is reduced when the total x-ray beam width becomes very small for multidetector CT due to the need to keep the beam penumbra out of any detector row.

The dose is strongly dependent on patient size. If the same technique is used to image the heads of an average adult and a newborn, the dose to the newborn is significantly higher.

Imaging parameters such as kVp, mAs (the product of the tube current and the time in seconds per rotation), and pitch (the table travel per rotation divided by the total x-ray beam width) are selected by the operator.

If all other parameters are fixed, the patient dose is proportional to the effective mAs which is defined as the mAs (mA × seconds per rotation) divided by the pitch.

The dependency of dose to kVp is more complicated. In general, the dose increases as a power function of kVp (D ~ kVp^p) if all other parameters are fixed. The value of p is in the order of 2 to 3 depending on the type of scanner.

Image Quality  Image quality is characterized by spatial resolution, contrast resolution, image noise, and other quantities. It is difficult to use a single variable to characterize completely the quality of an image. However, in practice, image noise has been widely used to judge the CT image quality because the detectability of low-contrast objects is strongly dependent on the contrast-to-noise ratio. The standard deviation of a region of interest (ROI) in the image is usually used to represent the noise. In CT, for a given reconstruction kernel, the noise is primarily due to the fluctuation of the x-ray photons reaching the detector. The noise is approximately inversely proportional to the square root of the patient dose. To reduce the noise by a factor of 2, the dose must be increased by a factor of 4. In general, image quality is better when the patient dose is increased.

Strategy for Dose Reduction  To optimize the CT technique, the image quality required for the specific indication is assessed based on the radiologist’s experience. The imaging parameters are then selected based on the patient size and organ type under exam such that the required image quality is achieved, while the patient dose is kept as low as possible. Weight- or age-based pediatric protocols should be established and special attention should be paid to children under age 2 because their heads are small and under rapid development.

In general, the technologist and radiologist should keep in mind that

Dose = mA, time in seconds per rotation of the gantry, kVp^2, and 1/pitch

and adjust these parameters to reduce dose, while maintaining image quality.

Often these adjustments are done empirically, and the technique described above (see Routine Technique section) represents our experience with such adjustments.

Magnetic Resonance Imaging

Routine Technique

The standard MRI protocol for evaluation of the temporal bone in adults is detailed below for a 1.5T (Tesla) magnet.

The patient is placed in the supine position in the head coil.

Sagittal T1-weighted, axial T2-weighted, axial fluid attenuated inversion recovery (FLAIR), and axial diffusion weighted images (DWIs) are obtained through the whole brain.

Axial T1-weighted images are obtained through the temporal bone from the arcuate eminence through the mastoid tip using the following parameters: TR (time to repetition) = 300 milliseconds; TE (echo time) = 12 milliseconds; flip angle = 90 degrees; slice thickness = 3 mm; distance factor = 0.10; matrix = 192 × 256 (phase to frequency encoding steps); FOV = 180 mm; two acquisitions, one saturation, time = 3 minutes, 15 seconds.

Axial CISS (constructive interference in steady state; Siemens AG, Berlin/Munich, Germany) or 3D (three-dimensional) FIESTA (fast imaging employing steady-state acquisition; General Electric Healthcare, Waukesha, WI) images are obtained through the internal auditory canals and pons using the following parameters: TR = 12.25; TE = 5.9; flip angle = 70 degrees; one slab, slab thickness = 32 mm; effective thickness = 0.7 mm; number of partitions = 46; matrix = 230 × 512; FOV = 200; swap left (L) to right (R), no saturation, time = 4 minutes, 20 seconds.

Gadolinium is then administered.

Axial T1-weighted images are obtained through the whole brain.

Coronal T1-weighted images are obtained through the internal auditory canals using the following parameters: TR = 450 milliseconds; TE = 15 milliseconds; flip angle = 90 degrees; slice thickness = 2 mm; distance factor = 0.10; matrix = 192 × 256 (phase to frequency encoding steps); FOV = 170 mm; two acquisitions, swap L to R, one saturation, time = 4 minutes, 20 seconds for each set; total time = 8 minutes, 40 seconds.

Coronal T1-weighted images are obtained through the internal auditory canals using the following parameters: TR = 450 milliseconds; TE = 15 milliseconds; flip angle = 90 degrees, slice thickness = 3 mm, no gap, matrix = 192 × 256 (phase to frequency encoding steps); FOV = 170 mm, three acquisitions, swap L to R, one saturation, time = 4 minutes 22 seconds.