Temporal Bone CT: Anatomy, Technique, and Associated Pathophysiology

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After completing this article, the reader should be able to:
- Describe commonly used temporal bone computed tomography (CT) techniques.
- Discuss temporal bone anatomy and the auditory system.
- Describe commonly encountered temporal bone pathologies.
- Discuss the imaging appearance of various pathologies associated with structures displayed on temporal bone CT scans.
- Explain the role of CT and magnetic resonance imaging in evaluating temporal bone pathologies and auditory symptoms.

The structures of the temporal bone and ear can have normal variants and also are susceptible to a wide range of conditions including congenital and vascular anomalies, trauma, inflammatory conditions, and tumors. In addition, surgery can alter the appearance of the anatomy.

Computed tomography (CT) has transformed imaging of the temporal bone and the intricate structures of the ear. Advances in CT technology allow radiologic technologists to acquire high-resolution, volumetric data so that images can be reconstructed in any plane. Helical scans can help increase clarity and reduce motion artifact in some planes. The Stenvers and Pöschl projections are helpful for evaluating structures that are not seen as well on axial and coronal planes.

An understanding of temporal bone anatomy, normal variants, and common pathology of the structures housed in and around the temporal bone can help radiologic technologists better understand CT technique for assessment of these structures, along with the needs of patients undergoing CT examinations of the temporal bone and the physicians who evaluate and interpret the studies.

Temporal Bone Anatomy

A total of 22 bones make up the human skull. Of these, 14 are facial bones and 8 are cranial bones. The 8 cranial bones include the frontal, occipital, ethmoid, and sphenoid bones, along with 2 parietal bones and 2 temporal bones. Each temporal bone is located deep in the temple, along the side and base of the skull, and consists of 4 major parts: the squama temporalis, the petrous portion, the mastoid process, and the tympanic part. A fifth part, the styloid process, is a bony projection of the petrous portion where it joins the tympanic part (see Figure 1).

The squamous portion, or squama temporalis, is the anterior superior...
portion of the temporal bone. It makes up the largest portion of the temporal bone and is flat and scale-like. The sphenoid bone articulates with the anterior surface of the squama temporalis, and the parietal bone articulates with the lateral surface. The temporalis muscle attaches to the inferior portion of the squama temporalis.3,5

The petrous portion of the temporal bone houses the inner ear and is located at the base of the cranium. It is the hardest portion of the temporal bone. This portion of the temporal bone sometimes is referred to as the petromastoid portion and is divided into the anterior petrous part and the posterior mastoid part. Based on this division, the petrous part contains the inner ear structures. The mastoid part includes the mastoid process and mastoid air cells. The mastoid process serves as the attachment point for the sternocleidomastoid muscle, splenius capitis, and longissimus capitis muscles. The mastoid air cells are a series of connected cavities in the mastoid.3

The tympanic portion of the temporal bone lies anterior to the mastoid process and inferior to the squama temporalis. It surrounds the external acoustic meatus. At birth, the tympanic portion is separate from the other portions of the temporal bone. Ultimately, this independent tympanic bone fuses to the other portions of the temporal bone.3

**External Ear**

The external ear consists of both the auricle and the external auditory canal (see Figure 2). The auricle collects the sound, and the external auditory canal (also referred to as the external acoustic meatus) spans medially through the tympanic portion of the temporal bone to the tympanic membrane. The main function of the external auditory canal is to conduct the sound captured by the auricle to the tympanic membrane. The tympanic membrane is a thin, oval membrane that forms the medial end of the external auditory canal. It also forms the partition between the external ear and the middle ear.4,6

**Middle Ear**

The middle ear begins with an air-filled cavity that is located within the petrous portion of the temporal bone. This cavity is known as the tympanic cavity and is divided into 2 parts: the tympanic cavity proper and the epitympanic recess. The tympanic cavity is located just internal to the tympanic membrane, and the epitympanic recess is located superior to the tympanic membrane. It may be helpful to picture the middle ear as a 6-sided box with concave walls. In this scenario, the roof of the box is the tegmental wall and is formed by the tegmen tympani, a thin plate of temporal bone. The floor of the box is known as the jugular wall and is formed by a layer of bone that separates the superior bulb of the internal jugular vein from the tympanic cavity.

The lateral wall of the box is the membranous wall and is mostly formed by the tympanic membrane, though a small portion is formed by the bony wall of the epitympanic recess. The medial wall of the box is the labyrinthine wall; this wall divides the tympanic membrane and the inner ear. The anterior wall of the box is the carotid wall, and separates the tympanic cavity from the carotid canal. Finally, the posterior wall is known as the mastoid wall. The superior portion of this wall has a small opening that connects to the mastoid cells.4,6

The auditory ossicles are located within the tympanic cavity of the middle ear. There are a total of 3

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**Figure 1. Anatomical diagram of the temporal bone.**

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ossicles: the malleus, incus, and stapes. Essentially, the ossicles form a small “chain” that spans from the tympanic membrane to the oval window, which is an opening on the labyrinthine wall. The handle of the malleus is embedded in the tympanic membrane, and the malleus head articulates with the body of the incus in the epitympanic recess. This articulation forms the incudo-malleal joint, which typically resembles the shape of an ice cream cone on axial CT sections. The interior end of the incus articulates with the head of the stapes at the lenticular process. Finally, the base of the stapes fits into the oval window and is attached to its margins.\(^4,6\)

**Inner Ear**

The inner ear is deep within the petrous portion of the temporal bone. The bony labyrinth is contained in the dense otic capsule of the petrous portion of the temporal bone and contains the cochlea, the vestibule, and the semicircular canals. The bony labyrinth is a series of chambers and canals that contain a fluid called perilymph. The membranous labyrinth is a series of sacs and ducts suspended within the bony labyrinth; it contains a fluid called endolymph, a unique extracellular fluid in the body.\(^6\)

The cochlea is a spiral-shaped portion of the bony labyrinth involved with hearing. The spiral of the cochlea makes 2.5 to 3 turns around a bony core known as the modiolus. The vestibule of the bony labyrinth is approximately 5 mm in length and is bordered laterally by the oval window, anteriorly by the bony cochlea, and posteriorly by the semicircular canals. The semicircular canals and vestibule are necessary for accurate equilibrium and balance.\(^6\)

There are 3 semicircular canals: superior, inferior, and lateral. The semicircular canals are situated orthogonally to one another, and each expands at its base to form a structure known as the ampulla. As the head moves into different positions, the endolymph within the semicircular canals activates sensory hair cells, which then signal the brain via the vestibulocochlear nerve.\(^7\) The nerve provides information to the brain when the head is tilted or moved side to side or up and down. A structure known as the utricle connects with the ends of the semicircular canals. The hair cells in the utricle provide information to the brain about horizontal movement when the head is stationary (eg, when sitting in a moving subway train). The utricle connects to a structure known as the saccule. The sensory hair cells of the saccule also provide information to the brain regarding vertical acceleration when the head is stationary (eg, ascending in an elevator). Through these processes, the structures of the inner ear provide sensory information about movement to the brain.\(^4,6,7\)

The internal auditory canal (IAC), also referred to as the internal auditory meatus, is a narrow channel in the petrous bone. The lateral border of the IAC abuts the labyrinth, and its medial border opens to form the porus acusticus, which is an opening into the cranial cavity through which the cochlear, facial, and vestibular nerves extend. The lateral end of the IAC is known as the fundus. Within the fundus, the IAC is divided

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Figure 2. Anatomical diagram of the external and middle ear.
into superior and inferior parts by a transverse crest known as the *crista falciformis*. The superior part of the IAC is further divided into anterior and posterior parts by a vertical partition referred to as *Bill’s bar*. The anterosuperior portion houses the facial nerve, and the anteroinferior portion houses the cochlear nerve. The superoposterior portion houses the superior vestibular nerve, and the inferoposterior portion houses the inferior vestibular nerve (see Figure 3).4,6

**Temporal Bone CT Technique**

Temporal bone CT technique has evolved over the years with the advent of new technologies and software and can vary from one CT department to another. As with any CT examination, the radiologic technologist must consider the balance between radiation exposure to the patient and image quality. The optimal technique is the one that provides the highest quality image with the lowest dose to the patient. The technologist might need to adjust the technique based on patient-specific factors such as age and body habitus.

Initially, the technologist should instruct the patient to lie in a supine position in the gantry and maximize the distance between the lens of the patient’s eye and the x-ray beam to minimize radiation exposure to the eye lens. When placing patients in the supine position, it might be necessary to avoid gantry tilt to facilitate image postprocessing. After the lateral topogram is performed, the scan excursion should be plotted from the arcuate eminence, a rounded prominence on the superior portion of the petrous part, to the mastoid tip.2

Because of the small size of the anatomy and pathology of the temporal bone region, adequate collimation and high-resolution images are essential. The literature typically describes using collimation between 0.6 mm and 1.0 mm to obtain the desired resolution.1,2 Swartz and Loevner define effective mAs as \[\text{mA} \times \left(\frac{\text{gantry cycle time/helical pitch}}{\text{rotation}}\right)\].2 For temporal bone imaging on CT scanners with between 40 and 64 detectors, the authors recommend using 120 kVp, 1 gantry cycle (rotation) per second, and the effective mAs amounts (see Table).2

Swartz and Loevner make several other recommendations regarding the technique for performing and acquiring CT imaging of the temporal bone. The authors use helical scans to help reduce motion artifact. They also believe that helical acquisitions result in increased clarity in oblique and coronal reformats.2

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**Figure 3.** A. Anatomical diagram of the inner ear. B. A coronal computed tomography image shows: 1, external auditory canal; 2, mastoid air cells; 3, tegmen mastoideum; 4, tegmen tympani; 5, tympanic segment of the facial nerve; 6, labyrinthine segment of the facial nerve; 7, petrous apex; 8, basal turn of the cochlea; 9, interscalar septum; 10, middle turn of the cochlea; 11, carotic canal; 12, tendon of the tensor tympani; 13, lateral process of the malleus; 14, lateral malleal ligament; 15, malleus (head). Reprinted with permission from Juliano AF, Ginat DT, Moonis G. Imaging review of the temporal bone: part I. Anatomy and inflammatory and neoplastic processes. *Radiology*. 2013;269(1):17-33. http://pubs.rsna.org/doi/full/10.1148/radiol.13120733. Accessed June 10, 2014.
The decision to use intravenous (IV) contrast is based on suspected pathology. For example, when evaluating pathologies such as a tumor, vascular dissection, or certain infections, the use of IV contrast might be beneficial. However, when evaluating for hearing loss alone, IV contrast might not help determine a cause.

**Image Reconstruction**

Image reconstruction plays an important role in temporal bone CT scanning. Swartz and Loevner recommend initially reconstructing the raw imaging data into bone algorithm axial images. After reconstruction, the authors display the raw data on the CT scanner console in 3 orthogonal planes. Philips et al recommend reprocessing and reformating the axial sections into magnified axial and coronal images, displayed with overlap at 0.3-mm intervals.

Both Philips et al and Swartz and Loevner recommend performing image reconstructions in the Stenvers and Pöschl projections. The Stenvers projection encompasses the plane parallel to the long axis of the petrous bone. The Pöschl projection encompasses the plane perpendicular to the long axis of the petrous bone. These additional projections aid in the evaluation of middle and inner ear structures (see Figure 4). Use of contrast in CT of the temporal bone depends upon the patient’s symptoms.

**Associated Pathophysiology**

It is common to encounter structures on temporal bone CT scans that are not technically part of the temporal bone. For example, structures of the inner ear are seen on a temporal bone CT scan. This section discusses associated pathophysiology that might be encountered on a temporal bone CT scan.

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**Table**

<table>
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<th>Patient Age/Size</th>
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**Figure 4.** High-resolution multidetector CT of the temporal bone was performed with 0.625-mm slices and reformations of the semicircular canal (SSC) along the longitudinal axis (Pöschl projection) and transverse axis (Stenvers projection). To measure the extent of dehiscence, a straight line was drawn subtending the arc of the SSC and rounding to the nearest 0.5 mm in the Pöschl projection. In this patient, the petrous bone overlying the right SSC was eroded but without dehiscence, as seen on the Pöschl projection (A) and the Stenvers projection (B). However, there was dehiscence of the left SSC as seen on the Pöschl projection (C) (arrowhead) and the Stenvers projection (D) (arrow). Reprinted with permission from Yu A, Teich DL, Moonis G, Wong ET. Superior semicircular canal dehiscence in East Asian women with osteoporosis. BMC Ear Nose Throat Disord. 2012;12:8. doi:10.1186/1472-6815-12-8.

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**Normal Variants**

Some normal anatomical variants occur and must be considered when imaging temporal bone anatomy. Normal variants are important for physicians to recognize in making an accurate diagnosis and planning appropriate treatment because they can mimic disease or compromise the surgical approach.

**Cochlear Cleft**

Chadwell et al retrospectively examined temporal bone CT examinations from 100 children (ie, a total of 200 scans) without known sensorineural hearing loss. The researchers identified a small, nonosseous space in the otic capsule presenting as a C-shaped...
ribbon (lucency). Although the size of this variant was not consistent, the C shape is a consistent finding. The C-shaped lucency was observed parallel to the base turn of the cochlea, and its upper part was located inferior to the cochleariform process. The researchers named this variant the *cochlear cleft* (see Figure 5).

The study’s authors identified the cochlear cleft in 34% of the 200 temporal bones they reviewed and noted that it occurred with equal frequency on either side. The cochlear cleft can appear unilaterally or bilaterally and should not be confused with a fracture. The researchers were unsure of the exact cause of the cochlear cleft but hypothesized that it is either “a space between the endosteal and outer periosteal layers of the otic capsule or that it is closely related to the fissula ante fenestram.” The fissula ante fenestram is a minute slit in the labyrinthine anterior wall.

**Petromastoid Canal**

The petromastoid canal also is known as the *subarcuate canaliculus* or *subarcuate canal* (see Figure 6). It is an example of a bony fissure in the temporal bone that can be mistaken for a fracture. The petromastoid canal courses between the 2 limbs of the superior semicircular canal, connecting the mastoid antrum to the posterior cranial fossa. The subarcuate vein and artery pass through the petromastoid canal, and some dura mater extends into the canal. The extension of dura into the petromastoid canal makes the small opening a pathway for the intracranial spread of mastoid infection.

On CT images, the petromastoid canal appears as a thin, curvilinear lucency localized between the anterior and posterior portions of the superior semicircular canal. Although the petromastoid canal can vary in width, its diameter typically does not exceed that of the corresponding vestibular aqueduct. The petromastoid canal can be classified according to its width:

- **Type 1** – not visible.
- **Type 2** – a width less than 0.5 mm.
- **Type 3** – a width of 0.5 mm to 1.0 mm.
- **Type 4** – a width greater than 1 mm.

These common features of a petromastoid canal are important considerations when scanning and evaluating patients for possible temporal bone fracture.

**Cochlear Aqueduct**

The cochlear aqueduct is another example of a temporal bone structure that could be mistaken for

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**Figure 5.** Axial (A) and coronal (B) high-resolution CT images of the right temporal bone in a child with suspected left sensorineural hearing loss. The small lucency seen around the cochlea (arrow) on both images indicates a cochlear cleft, which is a normal variant. Images reprinted under the terms of the Creative Commons Attribution License granted by the original authors. Purohit B, Hermans R, Op de beeck K. Imaging in otosclerosis: a pictorial review [published online ahead of print February 9, 2014]. Insights Imaging. 2014;5(2):245-252. doi:10.1007/s13244-014-0313-9.
a fracture. The cochlear aqueduct is a channel that extends from the subarachnoid space to the basal turn of the cochlea. Therefore, infected cerebrospinal fluid can travel through the cochlear aqueduct into the internal ear. The cochlear aqueduct travels in a direction similar to that of the IAC. The singular canal also runs in a similar plane to the IAC, but can be distinguished from the cochlear aqueduct by noting that the cochlear aqueduct arises near the round window. In addition, the glossopharyngeal sulcus is seen just caudal to the cochlear aqueduct. A final way to determine whether a given CT lucency represents a fracture or the cochlear aqueduct is to look for a funnel shape becoming wider as it extends medially, which indicates a cochlear aqueduct.

**Surgical Difficulties**

Some anatomical variants that appear on a temporal bone CT scan can cause difficulties or complications during surgery. Two of these conditions are a high jugular bulb and bulging sigmoid sinus.

**Jugular Bulb Variants**

The location of the jugular bulb within the temporal bone varies. The lateral venous sinuses converge in the jugular bulb, which drains to the internal jugular vein (see Figure 7). Abnormalities of the jugular bulb are relatively common and several variants are encountered when imaging this structure. A high jugular bulb extends superiorly to the floor of the IAC. Patients might have one jugular bulb that extends more superiorly than the other, though it is not considered...
a high jugular bulb unless at least the uppermost portion, or roof, of the jugular bulb extends superior to the lower most portion, or floor, of the IAC. In one study, most (61%) high jugular bulbs were found in women. Usually, a high jugular bulb has an intact sigmoid plate. However, if there is a deficiency of the sigmoid plate, the jugular bulb could protrude into the middle ear because the sigmoid plate normally separates the jugular bulb from the tympanic cavity. If this occurs, it is called a dehiscent jugular bulb. If the sigmoid plate remains intact, but there is an extension of a portion of the jugular bulb into the deep temporal bone (behind the IAC), this might indicate the presence of a jugular bulb diverticulum.

Bulging Sigmoid Sinus

In some cases, the sigmoid sinus bulges anteriorly, protruding into the posterior mastoid. The presence of a bulging sigmoid sinus should be noted on CT images because if a mastoidectomy is performed, the patient is at increased risk for laceration of the sigmoid sinus.

Congenital Anomalies

There are many congenital anomalies that affect the appearance of temporal bone anatomy on CT images. Some of the most common congenital anomalies of the temporal bone, as well as the outer, middle, and inner ear, are described in this section.

Large Vestibular Aqueduct

With sensorineural hearing loss, sound waves are received by the inner ear, but structural abnormalities keep the information from reaching the brain. A large or enlarged vestibular aqueduct is a relatively common cause of sensorineural hearing loss. In fact, in individuals who have sensorineural hearing loss, the most common osseous anomaly is an enlarged vestibular aqueduct. As early as 1978, the phrase “large vestibular aqueduct syndrome” was used to describe the association between sensorineural hearing loss and an enlarged vestibular aqueduct. A vestibular aqueduct is considered enlarged if the midportion of the vestibular aqueduct has a caliber of 1.5 mm or greater. In addition, if the vestibular aqueduct has a larger diameter than the associated normal lateral semicircular canal, enlargement of the aqueduct may be indicated. A large vestibular aqueduct can occur in isolation or in combination with other malformations of the inner ear. For example, one study found a correlation between enlarged vestibular aqueducts and modiolar deficiency. This means identification of the bony modiolus might be impossible in patients with an enlarged vestibular aqueduct.

External Auditory Canal Atresia

The medial aspect of the external auditory canal is bony, and the lateral aspect is cartilaginous. During weeks 26 through 28 of the gestation period, the epithelial plug from the first brachial cleft begins to canalize, forming the lateral soft tissue portion of the external auditory canal. If this canalization fails, then congenital atresia of the external auditory canal occurs (see Figure 8). Congenital atresia of the external auditory canal encompasses a broad spectrum of conditions that can be either osseous, membranous, or mixed in nature. The prevalence of this condition has been described as 1 per 10 000 to 1 per 20 000, and the abnormalities can be either unilateral or bilateral, though unilateral occurrence is more common.

Because the external auditory canal is not developed in external auditory canal atresia, sound is unable to reach the tympanic membrane. Several radiographic features are noted in patients who have congenital atresia of the external auditory canal, the most obvious of which is the absent canal. Although the inner ear and IAC are typically normal, findings within the middle ear vary. Some radiographic findings, such as the volume of the middle ear, are of particular importance for surgical planning. A volume greater than 3 mm often is needed for successful surgery.

Middle ear findings are noted as appropriate on images of atresia cases, and physicians also review the ossicles. Although the incudomalleolar joint and incus usually are normal, the absence of a tympanic membrane usually results in a rudimentary handle of the malleus. The physician evaluates the stapes as well; an absent stapes should be replaced with a prosthetic. The inner ear’s round and oval windows also are evaluated, because each must be present for a successful surgery that allows the patient to hear. Finally, the locations of other structures (such as the internal carotid artery,
jugular bulb, and facial nerve) can cause surgical complications if the locations are abnormal.1,20

Cochlear Deformities

Many types of cochlear deformities can occur and are classified according to a variety of systems. A widely accepted classification scheme identifies cochlear deformities based on the timing of developmental arrest during gestation. Types of cochlear deformities include11:

- Complete labyrinthine aplasia, or Michel deformity.
- Cochlear aplasia.
- Common cavity deformities of the vestibule and cochlea.
- Cochlear hypoplasia.
- Incomplete partition and dilatation defects, such as Mondini dysplasia.

Historically, all cochlea partitioning abnormalities were referred to simply as Mondini malformations. However, some systems now classify these as either incomplete partition type 1 or incomplete partition type 2.1

In cases of labyrinthine aplasia, there is a complete absence of the vestibular structures and cochlea.12 The aplasia can be either unilateral or bilateral and usually is associated with IACs that have a smaller diameter than normal. The aplasia occurs as a result of developmental arrest in the third week of gestation.

Cochlear aplasia is characterized by an absent cochlea. The semicircular canals and vestibule are present, but they might be dilated, normal, or hypoplastic. The site at which the cochlea normally is located presents as dense otic bone (see Figure 9).12

In cases of common cavity deformity, the cochlea and vestibule are undifferentiated, forming a common, cystic cavity. The common cavity deformity occurs during the fourth week of gestation, when differentiation between the cochlea and vestibule has not yet occurred. A developmental arrest at this point results in no differentiation between the structures.

Incomplete partition type 1 abnormalities are slightly more differentiated than the common cavity deformity. This is because incomplete partition type 1 abnormalities occur as a result of developmental arrest in the fifth week of gestation. In cases of incomplete partition type 1 abnormalities, the cochlea and vestibule have normal dimensions, but the cochlea appears cystic, lacking a modiolus and cribriform area.1,17

Cochlear hypoplasia occurs with developmental arrest in the sixth week of gestation. The cochlea and vestibule are small, but are separated and differentiated from one another. The cochlea is seen projecting from the IAC, often appearing as a small bud.1,17

Figure 8. This curved CT reformatted image demonstrates an absent left external auditory canal, also known as external auditory atresia, and a normal right side. Reprinted with permission from Radiopaedia.org Web site. External auditory canal atresia. Goel A, Gaillard F. http://radiopaedia.org/articles/external-auditory-canal-atresia. Accessed August 22, 2014.
When developmental arrest occurs during the seventh week of gestation, the resulting abnormality is referred to as an incomplete partition type 2, or Mondini, deformity. In these cases, the cochlea is a normal size but has only 1.5 turns instead of the normal 2.5 to 3 turns. Although there is a normal basal turn of the cochlea, the middle and apical turns actually combine to form a cystic apex. With incomplete partition type 2 abnormalities, there usually is enlargement of the vestibule and vestibular aqueduct, and the semicircular canals are normal in size.\textsuperscript{1,17,22}

Lateral Semicircular Canal Malformation

Semicircular canal malformations are the most common congenital abnormality found in the inner ear.\textsuperscript{23,24} These malformations range in type and presentation and are associated with a common cavity to the inner ear structures or hypoplasia of the lateral semicircular canal. The specific nature of the abnormality or malformation depends on the point within embryological development that the insult occurs. During embryogenesis, the lateral semicircular canal is the last singular inner ear structure to form. This explains why the lateral semicircular canal is malformed more often than the other 2 semicircular canals.

Malformation of the lateral semicircular canal can be isolated or occur in conjunction with other anomalies and can range from being clinically insignificant to being associated with hearing loss and vertigo.\textsuperscript{23,24}

**CHARGE Syndrome**

Coloboma of the eye, heart defects, atresia of the choanae, retardation of growth or development, genital anomalies, and ear anomalies (CHARGE) syndrome is a genetic disorder seen in 1 of every 9000 to 10 000 births.\textsuperscript{25,26} Patients who have CHARGE syndrome have various combinations and severities of these conditions. More than 90\% of these patients have some form of outer ear abnormality, malformed ossicles, Mondini defect, or semicircular canal abnormality.\textsuperscript{24} The diagnosis of CHARGE syndrome relies on clinical findings and temporal bone imaging findings. Treatment of CHARGE syndrome is based on the patient’s specific symptoms and often requires a multidisciplinary approach.

**Trauma**

**Temporal Bone Fractures**

Temporal bone fractures usually occur as a result of blunt head injury. Patients with fractures have bleeding from the ear or skin discoloration similar to a bruise behind the ear, an indicator known as the Battle sign. If the fracture involves inner or middle ear structures, the patient has associated symptoms such as hearing loss, facial paralysis, and vertigo.\textsuperscript{27}

**Classification**

Historically, temporal bone fractures were described as either longitudinal or transverse based on the orientation of the fracture plane in relation to the long axis of the petrous bone. According to the historical temporal bone fracture classification scheme, 70\% to 90\% of temporal bone fractures are classified as longitudinal.\textsuperscript{24} Longitudinal temporal bone fractures typically arise from trauma to the temporoparietal portion of the skull. A longitudinal temporal bone fracture line runs parallel to the petrous bone’s long axis (see Figure 10).
The fracture line usually is seen anterior to the labyrinthine structures, near the middle cranial fossa and eustachian tube. In some cases, the fracture line can appear posterior to the labyrinth near the posterior cranial fossa and jugular foramen. Longitudinal fractures typically extend into the middle ear cavity, disrupting the ossicles and resulting in conductive hearing loss. These fractures frequently involve the facial nerve, and in 20% of cases the patient experiences facial paralysis.\textsuperscript{1,28}

According to the historical temporal bone fracture classification scheme, approximately 20% to 30% of temporal bone fractures are classified as transverse.\textsuperscript{29} Transverse temporal bone fractures typically occur from trauma to the frontal or occipital bones. The plane of these fractures runs anterior to posterior, perpendicular to the long axis of the petrous bone. The fracture plane commonly extends from the foramen magnum and jugular foramen to the middle cranial fossa (see Figure 11).\textsuperscript{1}

Transverse fractures might involve the otic capsule, commonly passing through the vestibular aqueduct.

Transverse temporal bone fractures can be subdivided further according to whether they pass medial or lateral to the arcuate eminence. Both of these subtypes can result in sensorineural hearing loss. The hearing loss can occur if the medial transverse fracture transects the cochlear nerve or the lateral transverse fracture transects the bony labyrinth. Transverse temporal bone fractures also can result in facial nerve palsy, vertigo, and vascular injury.\textsuperscript{1,29}

Several other classification schemes are commonly used and often are considered to be more clinically relevant than the historical classification scheme. For example, temporal bone fractures can be classified based on whether they involve or spare the otic capsule. The same is true regarding a fracture involving the petrous apex.\textsuperscript{1,27} A fracture with otic involvement is clinically relevant because it is much more likely to be associated with serious complications such as facial nerve paralysis, cerebral spinal fluid drainage, and sensorineural hearing loss. Temporal bone fractures can be complex, involving features of both transverse and longitudinal types.

Complications

Temporal bone fractures are commonly associated with hearing loss (sensorineural, conductive, or mixed).


Figure 11. A transverse fracture of the temporal bone involving the midportion of the vertical segment is seen as an axial cut of the right temporal bone. Image reprinted under the terms of the Creative Commons Attribution License granted by the original author. Yetiser S. Total facial nerve decompression for severe traumatic facial nerve paralysis: a review of 10 cases. Int J Otolaryngol. 2012;2012:607359. doi:10.1155/2012/607359.
Other complications also can occur. A fracture might disrupt the ossicular chain, with the incus being most prone to injury. The malleus and stapes have supportive ligaments that help stabilize the structures, making them more resistant to dislocation than the incus. The most common ossicular injuries are incudostapedial or malleoincudal subluxation, as well as dislocation of the incus or malleoincudal complex. Fractures of the stapes and malleus are much less common.

Temporal bone fractures also can lead to serious complications such as meningitis and acquired cholesteatomas, which essentially are cysts or sacs trapped within the temporal bone that are lined with squamous epithelium and filled with discarded skin debris. Treatment of temporal bone fractures and their associated comorbidities often is aimed at managing specific symptoms and complications. When patients have immediate facial nerve paralysis, surgery might be warranted, but in cases of delayed-onset or incomplete paralysis, conservative management usually results in symptom resolution.

**Vascular Anomalies**

**Aberrant Internal Carotid Artery**

An aberrant internal carotid artery is an anatomical variant in which there has been agenesis of the first embryonic segment (cervical portion) of the internal carotid artery (see Figure 12). Because of this, a collateral pathway forms from the ascending pharyngeal artery connecting to the horizontal portion of the internal carotid artery. The collateral vessels that course through the middle ear usually are small, but become enlarged in these cases. This results in an enlarged artery passing lateral to the cochlear promontory. On otoscopic examination, this artery might appear as a retrotympanic mass. Two vessels enlarge and form the aberrant internal carotid artery: the inferior tympanic artery and the caroticotympanic artery. These vessels join the petrous portion of the internal carotid artery at its horizontal segment.

An aberrant internal carotid artery is a rare clinical condition that often presents with nonspecific signs and symptoms such as hearing loss, pulsatile tinnitus, and a retrotympanic mass. Pulsatile tinnitus is a ringing or other sound in the ear that occurs in pulse with the heartbeat. An aberrant internal carotid artery can mimic other anomalies such as glomus tumors or other types of vascular lesions of the temporal bone. An aberrant internal carotid artery often is displayed with either CT scanning or angiography. CT demonstrates that the vertical segment of the carotid canal is either hypoplastic or completely absent. Furthermore, there could be an enlarged inferior tympanic canal that is traversed by a reduced caliber aberrant internal carotid artery.

Angiography might demonstrate that the ascending pharyngeal artery has an enlarged tympanic branch, marked lateral extension of the internal carotid artery, or that the internal carotid artery deviates more posterior and lateral than usual. Identifying this abnormality can prevent bleeding from a laceration of the aberrant artery during surgery. An aberrant internal carotid artery usually is managed conservatively, although surgery can be indicated if the benefits outweigh the risks.

**Dehiscent Jugular Bulb**

As previously mentioned, a high jugular bulb refers to situations in which the jugular bulb extends...
superiorly to the floor of the IAC. The sigmoid plate, a small, thin plate of bone that prevents the jugular bulb from protruding into the middle ear cavity, typically remains intact. The sigmoid plate can be seen only on CT scans; if it is deficient or absent, the jugular bulb protrudes into the middle ear cavity, becoming a dehiscent jugular bulb.\textsuperscript{33} Dehiscent jugular bulb is a known cause of pulsatile tinnitus.

If the ear is evaluated with an otoscope, a dehiscent jugular bulb presents as a blue mass behind a normal tympanic membrane. The mass also can become distended if ipsilateral jugular compression or Valsalva maneuvers are used.\textsuperscript{14} A retrospective study of 1010 patients with various ear symptoms examined the high-resolution CT scans of these patients’ temporal bones and found jugular bulb dehiscence in 153 (7.5%) of the patients.\textsuperscript{14} It is important to identify a dehiscent jugular bulb before a patient has a biopsy or middle ear surgery to prevent vascular compromise and bleeding. Preoperative evaluation, identification, and awareness of dehiscent jugular bulb can help to minimize morbidity and mortality.\textsuperscript{14} If the pulsatile tinnitus caused by a dehiscent jugular bulb is debilitating, surgical treatment is an option, but there is considerable risk involved.

**Persistent Stapedial Artery**

Persistent stapedial artery is a rare condition that affects only about 0.48% of the population but must be evaluated and identified before an individual has middle ear surgery.\textsuperscript{1,35} The stapedial artery typically is present early in fetal development, connecting the branches of the eventual internal and external carotid arteries. The stapedial artery arises from the hyoid artery during the first 4 to 5 weeks of fetal development and extends superiorly, passing through the mesenchymal primordium of the stapes to form the obturator foramen of the stapes.\textsuperscript{36} Ultimately, the branches of the stapedial artery develop into vessels that persist into adulthood. The stapedial artery usually degenerates during the tenth week of fetal development.\textsuperscript{37} If the stapedial artery does not degenerate and remains into infancy, it is called a persistent stapedial artery.

A persistent stapedial artery typically causes symptoms such as pulsatile tinnitus, conductive hearing loss, or sensorineural hearing loss. This anomaly can be associated with other inner ear anomalies such as an aberrant internal carotid artery. Several findings might be present in radiographs, including expansion of the tympanic segment of the facial nerve and an absent or hypoplastic ipsilateral foramen spinosum. Other reported findings are a soft tissue density crossing over the cochlear promontory in a linear formation and a small canaliculus arising from the petrous segment of the internal carotid artery.\textsuperscript{1,36}

**Inflammatory Conditions**

**Acute Otitis Media**

Acute otitis media is the most common inflammatory condition of the structures housed by the temporal bone and the childhood disease for which antibiotics are most commonly prescribed in the United States.\textsuperscript{1} Acute otitis media is a bacterial disease that occurs most often in infants and children. It usually is accompanied by an upper respiratory infection because of the spread of bacteria from the nose and nasopharynx to the middle ear.

Imaging is typically performed only if a patient with acute otitis media has a suspected complication. Clinical symptoms that can indicate a complication include postauricular erythema, edema, and tenderness. Complications can be either intracranial or intratemporal and might include radiologic findings of the middle ear, mastoid opacities, or air fluid levels. The **Box** lists several possible complications that should be considered when reviewing radiological studies of otitis media.\textsuperscript{1}

Coalescent mastoiditis, which involves the bone, has an imaging hallmark: the loss of the mastoid air cells’ internal bone septa from the opacification of fluid or

| Possible Complications of Acute Otitis Media\textsuperscript{1} |
|-------------------|-------------------|
| Coalescent mastoiditis |
| Bezold abscess |
| Dural sinus thrombosis |
| Subperiosteal abscess |
| Facial nerve involvement |
| Meningitis |
| Petrous apicitis |
| Labyrinthitis |
| Intracranial abscess and empyema |
soft tissue. This demonstrates the destruction of mastoid trabeculae. Bezold abscess presents with erosion of the mastoid tip. Because the abscess is located so close to the insertion of the digastric muscle, the infection can travel inferiorly along the fascial planes. Patients with the acute otitis media complication of dural sinus thrombosis might have fever, otalgia, papilledema, and headache. The presence of the thrombosis can be confirmed with contrast-enhanced CT.\textsuperscript{1,4}

**Chronic Otitis Media**

Chronic otitis media refers to chronic inflammation of the middle ear. When the infection involves the mastoid, it is called chronic otomastoiditis. The most common cause of chronic otitis media is long-standing dysfunction of the eustachian tubes, although perforation of the tympanic membrane can be a causative factor as well.\textsuperscript{1,4} Chronic otitis media can present with other imaging findings such as granulation tissue, effusion, cholesterol granuloma, and cholesteatoma.\textsuperscript{4}

**Cholesteatoma**

Cholesteatomas are cysts or sacs within the temporal bone, and they can be congenital or acquired.\textsuperscript{1,38} Congenital cholesteatomas are the third most common mass of the cerebellopontine angle, but only about 2% of cholesteatomas are congenital.\textsuperscript{4} A congenital cholesteatoma typically is located in the region of the petrous apex.\textsuperscript{39} The cyst commonly is seen just superior to the opening of the eustachian tube, in the anterior superior middle ear quadrant. It is believed that congenital cholesteatomas arise as a result of epithelial rests in the middle ear.\textsuperscript{4}

Acquired cholesteatomas represent 98% of cholesteatomas and can develop in the middle ear as a result of acute or chronic otitis media.\textsuperscript{1} According to the invagination theory, acquired cholesteatomas develop when a vacuum phenomenon is created in the middle ear because of eustachian tube malfunction. This causes a retraction pocket to form in the pars flaccida, the looser portion of the tympanic membrane.\textsuperscript{40} The pocket grows over time.\textsuperscript{4} The epithelial invasion theory proposes that a perforation in the tympanic membrane allows for the growth of keratinizing stratified squamous epithelium in the middle ear.\textsuperscript{4} Acquired cholesteatomas typically present in the pars flaccida but also can be seen in the pars tensa region, which makes up the bulk of the tympanic membrane.\textsuperscript{1,40}

Both the congenital and acquired cholesteatoma appear under otoscopic evaluation as a white, pearly mass. Cholesteatomas most often are evaluated with imaging by CT scanning, magnetic resonance (MR) scanning, or both, although CT is described in the literature as the modality of choice. Cholesteatomas typically display on CT scans as a region of soft-tissue attenuation that exerts mass effect and might have resulting bony erosion.\textsuperscript{41}

On CT, acquired pars flaccida cholesteatoma appears as a lobulated, expansile lesion in the Prussak space.\textsuperscript{42} The Prussak space is a component of the lateral epitympanic space. It is bounded laterally by the tympanic membrane, medially by the neck of the malleus, superiorly by the lateral malleolar ligament fold, and inferiorly by the short process of the malleus. There might be associated erosion and medial displacement of the ossicles.\textsuperscript{7} Lateral displacement of the ossicles, and therefore a more medial lesion, is seen in cases of pars tensa cholesteatoma. The soft-tissue attenuation of cholesteatomas can make it difficult to distinguish them from middle ear inflammation or infection on CT scans. In these cases, diffusion-weighted MR may be beneficial.\textsuperscript{1}

**Labyrinthitis**

Labyrinthitis refers to inflammation of the membranous labyrinth of the inner ear. The late stage of labyrinthitis, known as \textit{labyrinthitis ossificans}, represents a compromise of the vestibular system and cochlea due to the abnormal ossification of the bony labyrinth’s luminal spaces.\textsuperscript{4} Labyrinthitis can be caused by infection, trauma, or autoimmune problems and can be divided into 5 classes based on the following etiologies:\textsuperscript{43}

- Tympanogenic.
- Post-traumatic.
- Autoimmune.
- Meningogenic.
- Hematogenic.

Tympanogenic labyrinthitis is typically unilateral and results from the spread of infection or toxins into the inner ear from the middle ear via the oval or round window. Patients who have tympanogenic labyrinthitis...
typically present with vertigo or sensorineural hearing loss. Fluctuating hearing loss might indicate the presence of a perilymphatic fistula.43

Post-traumatic labyrinthitis usually presents with a perilymphatic fistula and a temporal bone fracture. Autoimmune labyrinthitis is rare and commonly associated with Takayasu arteritis.43

Meningogenic labyrinthitis occurs as a result of meningitis (usually bacterial) and typically presents bilaterally. It occurs more often in children than in adults and has been described as the most common cause of acquired deafness.43 Most likely, the infection spreads to the cochlea via the lateral aspect of the IAC. Cytomegalovirus infection also can cause meningogenic labyrinthitis in HIV-immunocompromised patients.43

Hematogenic labyrinthitis refers to the spread of infection to the inner ear via the blood. This is thought to be a common cause of labyrinthitis, but some sources debate whether these infections spread to the inner ear via the blood or directly from the middle ear. Examples of viruses that can commonly result in hematogenic labyrinthitis include measles, mumps, and syphilis.43

There are 3 radiologic stages of labyrinthitis: acute, fibrous, and labyrinthitis ossificans.1 During the acute stage, CT scans might appear normal, although MR images demonstrate enhancement of the labyrinth. During the fibrous stage, CT might still appear normal, and MR scans can demonstrate cochlear obstruction or loss of fluid signal intensity. Finally, during the labyrinthitis ossificans stage, ossification of the cochlea and bony labyrinth is displayed well on CT images.1,4

**Otospongiosis**

Otospongiosis is a condition that is difficult to classify and is not a true inflammatory condition. Specifically, otospongiosis is a disease that results in progressive hearing loss by affecting the otic capsule. It also is referred to as otosclerosis and affects women twice as often as men.1 Otospongiosis has been described as one of the leading causes of deafness in adults and usually presents when patients are in their fourth or fifth decades of life.44 A patient might demonstrate periods of remission of the hearing loss, or the hearing loss can flare and then rapidly recede. Pregnancy might exacerbate hearing loss in these patients. In cases of otospongiosis, the normally dense and ivory-like enchondral bone of the otic capsule is replaced by a spongier, highly vascular, and irregular bone. Otospongiosis can be divided into 2 subcategories: fenestral (stapedial) and retrofenestral (cochlear). The fenestral type is more common and involves the lateral wall of the bony labyrinth, including the facial nerve canal, promontory, and oval/bony windows (see Figure 13). Conductive hearing loss is associated with the fenestral type. The retrofenestral type more often involves the otic capsule and presents with sensorineural hearing loss.1,44

Thin-slice temporal bone CT is the preferred imaging method for evaluation of patients with suspected otospongiosis. Axial and coronal bone algorithm non-contrast scans provide sufficient information on early changes to the inner ear.44 During the active phase of the fenestral type of otospongiosis, bone demineralization or loss anterior to the oval window is evident. If the patient is in a phase of remission, however, this region appears sclerotic.44

In cases of retrofenestral otospongiosis, a foci of lucency appears that disrupts the border of the cochlear otic capsule. This can either be focal or affect the entire cochlea. When treatment is warranted in cases of fenestral otospongiosis, stapedectomy with a stapes prosthesis is the treatment of choice. A stapes prosthesis can be made of a variety of materials, such as polytetrafluoroethylene or steel. Once placed, the stapes prosthesis should be seen on a temporal bone CT scan in the oval window and connect well with the long process of the incus.

Tumors

Temporal bone tumors are relatively rare, and only about 200 new cases are identified in the United States each year. There are many types of temporal bone tumors, and some of the more common tumors are discussed here. Four common clinical presentations are suggestive of temporal bone lesions. The first is patients presenting with vertigo, sensorineural hearing loss, or tinnitus. The second is cranial neuropathy involving the jugular foramen or pulsatile tinnitus. Patients with temporal bone lesions also might have dysfunction of the peripheral facial nerve. Finally, a patient with a previously identified temporal bone tumor should be considered for a subsequent lesion.

Vestibular Schwannoma

A schwannoma is a benign, slowly growing tumor that arises from the nerve sheath and is composed of Schwann cells. Vestibular schwannoma is the most common temporal bone tumor affecting the cerebellopontine angle and IAC. The tumor also might be isolated to the facial nerve. Patients presenting with a schwannoma are typically 50 to 70 years old and might have sensorineural hearing loss, tinnitus, balance problems, or facial nerve paralysis symptoms. If a patient has bilateral vestibular schwannoma, neurofibromatosis type 2 should be considered.

Several radiographic features indicate vestibular schwannoma. Most of these tumors have an intracanalicular component, and if they grow large enough, will expand the porus acusticus. This widening of the IAC appears similar to a trumpet. The appearance of calcification or hemorrhage with these tumors is not common unless the tumor has been previously treated. Although small vestibular schwannomas are more solid, larger tumors can present with cystic degeneration. CT scans with contrast should be used to display the tumors, which still can be difficult to see, depending on the tumor’s size. On T1-weighted MR images, vestibular schwannoma appears hypointense or isointense to gray matter and hyperintense to cerebral spinal fluid. On T2-weighted MR images, vestibular schwannoma appears mildly heterogeneously hyperintense to gray matter (see Figure 14).

Vestibular schwannomas typically are slow growing, but for cases in which clinical symptoms are significant and the benefit outweighs the risk, surgery is a treatment option. Incidence of tumor recurrence following surgery is relatively low, ranging from 1% to 9%.

![Figure 14](image_url). This magnetization prepared rapid gradient echo magnetic resonance image shows a rounded vestibular schwannoma in the right cerebellopontine angle, with extension into the internal auditory meatus. Image reprinted under the terms of the Creative Commons Attribution-Noncommercial License 2.5 granted by the original author. Dahnert W. Radiology Review Manual. 5th edition. Lippincott, Williams & Wilkins; 2003. Credit: Laughlin Dawes, MB, BS, FRANZCR.)
Meningioma

The most common extra axial tumor of the central nervous system is the meningioma. Similar to vestibular schwannoma, meningioma also is seen in association with neurofibromatosis type 2. However, although meningioma is commonly seen at the cerebellopontine angle, the tumor rarely extends into the porus acusticus or IAC. If a meningioma extends into the IAC, it seldom expands the IAC or porus acusticus, and therefore rarely presents with the trumpeted IAC sign. Meningiomas also might extend into the middle cranial fossa, middle ear, and cavernous sinus. These tumors can occur elsewhere in the cranium.

Statistically, patients presenting with intracranial meningiomas are most likely to be women older than age 40. Meningioma is often an incidental finding, but if the tumors grow large enough, they can affect surrounding structures. The most common clinical presentations are headache, paresis, change in mental status, and focal neurological defects.

Meningiomas typically appear as broad-based, hemispherical masses along the posterior petrous wall. On a CT scan, meningioma might be calcified and appear isoattenuating or hyperattenuating next to brain parenchyma. They typically enhance homogeneously and might present with hyperostosis (excessive thickness or growth) of adjacent bone. On T1- and T2-weighted MR images, meningiomas appear isointense or hypointense compared with gray matter.

Physicians treat meningiomas with a combination of surgical excision and external-beam radiation therapy. The tumor recurrence rate varies substantially (6.9%-72.7%) depending on tumor grade.

Exostoses

An exostosis is a benign bone growth that extends outward from the surface of a bone. Several factors can trigger the growth of an exostosis, including a local irritant. Exposure to cold wind and water can lead to exostoses of the temporal bone. In fact, exostosis of the temporal bone is commonly referred to as “surfer’s ear.” Exostosis involving the external auditory canal is usually bilateral, multiple, and firmly attached. Exostosis can cause a severe narrowing of the external auditory canal, which can cause patients to have frequent ear infections as foreign debris is caught within the external auditory canal. If the exostoses are severe enough that treatment is warranted, surgery can be performed to remove them.

Paragangliomas

Paragangliomas are the second most common temporal bone tumors and the most common middle ear tumors. These tumors arise from paraganglia cells and can occur anywhere in the body where these cells are present. Paragangliomas also are referred to as glomus tumors. Paragangliomas in the temporal bone region originate from paraganglia that are located along the tympanic branch of either the auricular branch of the vagus nerve or the glossohypopharyngeal nerve. When the tumor arises from the glossohypopharyngeal nerve and is confined only to the tympanic cavity, it is called a glomus tympanicum. If the tumor involves the base of the skull and the jugular bulb, it is referred to as a glomus jugulare, regardless of its origin. Finally, tumors that involve both the jugular foramen and middle ear are called glomus jugulotympanicum tumors.

Paragangliomas of the head and neck are seen nearly 3 times more often in women than men and most often are found in patients 40 to 60 years old. Although these tumors are slow growing, if the paraganglioma involves the middle ear cavity, it might extend into the external ear as it grows. Patients might have pulsatile tinnitus, conductive deafness, cranial nerve palsies, or a retrotympanic mass. It is possible, although rare, for these tumors to undergo malignant transformation and metastasize. When indicated, treatment typically involves surgical excision, often with preoperative endovascular embolization to reduce bleeding. If the tumor is unresectable, radiation therapy can be used to provide palliative relief.

Generally, paragangliomas are highly vascular tumors. On radiographs, the tumors typically enhance markedly with contrast. These tumors often are associated with bone destruction, making CT a useful method for evaluation. The mass is better appreciated on MR images and often is characterized by a speckled appearance on both T1- and T2-weighted images.

Endolymphatic Sac Tumor

Endolymphatic sac tumors are rare masses that occur sporadically, although they rarely occur.
in association with von Hippel-Lindau disease. Endolymphatic sac tumors are locally invasive and typically seen along the posterior petrous apex and involve the vestibular aqueduct. These tumors cause local bone destruction as they grow, usually affecting the retrolabyrinthine petrous bone. Although endolymphatic sac tumors are aggressive locally, they do not metastasize. Still, detecting the tumor early can help prevent further hearing loss.¹⁴,⁵⁰

Most patients with endolymphatic sac tumors have some form of hearing loss, tinnitus, vertigo, aural fullness, or facial paresis. The average age of onset for clinical symptoms of this tumor is 22 years.⁵¹ The primary method of treatment for endolymphatic sac tumors is surgical resection. An adequate surgical margin is necessary to prevent tumor recurrence, even when doing so can compromise hearing conservation. Radiation therapy and Gamma-Knife radiosurgery have been described as adjunct treatment methods.⁵²,⁵³

Endolymphatic sac tumors have a standard CT appearance, displaying as a destructive process on the dorsal surface of the petrous portion of the temporal bone. The invaded bone commonly has a lytic, moth-eaten appearance. The lesions are hypervascular, and therefore will enhance with contrast. Central or posterior rim calcification might also be present.¹⁴,¹⁵,⁵¹

**Middle Ear Adenoma**

Middle ear adenoma is a benign tumor that arises from the mucosal cells of the middle ear. It is a rare tumor that presents with both neuroendocrine and epithelial properties, and also is called *adenomatous tumor of the mixed pattern type*. Middle ear adenomas usually are poorly vascularized.⁴,⁵⁴

Patients with middle ear adenomas most commonly have tinnitus, a sense of ear fullness, or unilateral hearing loss. These tumors occur equally in men and women, and the average patient age upon tumor diagnosis is 45 years old.⁴

The radiologic findings of these tumors are nonspecific. In fact, on CT the only finding might be a middle ear opacity. The lesion might or might not be embedded in the ossicles. In some instances, CT demonstrates a well-circumscribed, enhancing mass of soft-tissue attenuation. Unlike the endolymphatic sac tumor, a middle ear adenoma is not associated with bone erosion. Partly because the radiologic findings of middle ear adenomas are so nonspecific, definitive diagnosis is based on histologic and immunohistochemical examination upon surgical excision.⁴⁴

**Postoperative Ear**

The imaging appearance of the postoperative ear can vary substantially because of the number of past surgical procedures and potential anatomical changes. Some of the more common imaging findings are cochlear implantation, tympanostomy tubes, and mastoidectomy. Also of note is the surgical treatment of cholesteatoma.

A cochlear implant is an electronic device that is inserted surgically to stimulate functioning auditory nerves in the cochlea (see Figure 15). Unlike a hearing aid, which amplifies sound, cochlear implants give the patient additional auditory information. On preoperative temporal bone CT scans, a patient about to undergo cochlear implantation should have a well-pneumatized mastoid, no inflammation in the middle ear, and no calcification of the cochlea.⁴⁴ Typically, radiographs are sufficient for

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**Figure 15.** Illustration of a cochlear implant. National Institutes of Health (US). Public domain file.
evaluating the postoperative cochlear implant, particularly for evaluating extrusion and the number of inserted electrodes. CT scans can be used to evaluate the exact location of the electrodes. Electrodes that are well positioned have all of their channels in the cochlea and extend to the superior portion of the cochlea.

Tymanostomy tubes are inserted into the eustachian tube to facilitate drainage of middle ear fluid. This procedure is performed more often in infants and young children than in adults. The eustachian tube in children is more horizontal than in adults, which leads to fluid stasis and the increased likelihood of secondary infection. On CT images, the tympanostomy tubes should be seen within the expected location of the eustachian tubes. If a tympanostomy tube is seen lying in the external auditory canal, it is dislocated and might have been extruded by the tympanic membrane.

Mastoidectomy is a procedure performed for the treatment of several temporal bone pathologies, such as cholesteatoma or mastoiditis. There are 3 general types of mastoidectomy: simple, canal wall up, and canal wall down. In a simple mastoidectomy, the posterosuperior wall of the external auditory canal is preserved, but the lateral wall of the mastoid is removed. The canal wall up mastoidectomy is similar to the simple mastoidectomy, except that the Körner’s septum also is removed. The canal wall down mastoidectomy differs from the canal wall up mastoidectomy in that the posterosuperior wall of the external auditory canal also is removed.

**Conclusion**

Temporal bone CT scanning has changed over the years with the advent of new scanning technologies and postprocessing software. The future of temporal bone CT will continue to evolve in this fashion as well, improving with technological developments. Radiologic technologists should be familiar with common temporal bone CT scanning techniques, temporal bone anatomy, and temporal bone pathophysiology encountered most often to provide the highest-quality care to patients who have auditory and anatomic problems associated with the temporal bone area.

Although CT scanning technique might vary from one institution to another, technologists must consider the balance between radiation exposure to the patient and image quality. The optimal technique is the one that provides the highest quality image with the lowest dose to the patient. Technologists also should be familiar with patient positioning, slice thickness, when to use IV contrast, and image reconstruction methods to optimize image quality.

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**References**


Temporal Bone CT: Anatomy, Technique, and Associated Pathophysiology

1. The largest portion of the temporal bone is the ________ portion.
   a. petrous
   b. tympanic
   c. mastoid
   d. squamous

2. The ________ portion of the temporal bone houses the inner ear and is located at the base of the cranium.
   a. petrous
   b. tympanic
   c. mastoid
   d. squamous

3. The thin, ovular membrane that forms the medial end of the external auditory canal is the:
   a. auricle.
   b. external acoustic meatus.
   c. tympanic membrane.
   d. tragus.

4. Which of the following are auditory ossicles?
   1. malleus
   2. incus
   3. stapes
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

5. For temporal bone computed tomography (CT) scans, the patient should initially be placed in the supine position in the gantry.
   a. true
   b. false

6. According to the article, the range of collimation for temporal bone scans should be between ________ mm and ________ mm to obtain the desired resolution.
   a. 0.0; 0.5
   b. 0.6; 1.0
   c. 1.1; 1.5
   d. 1.6; 2.0
7. The Stenvers projection encompasses the plane ______ to the long axis of the ______ bone.
   a. perpendicular; petrous
   b. parallel; petrous
   c. perpendicular; parietal
   d. parallel; parietal

8. Researchers identified a normal anatomical variant that is represented as a small, nonosseous space in the otic capsule and appears as a C-shaped ribbon and named it:
   a. the cochleariform process.
   b. Bill’s bar.
   c. the fissula ante fenestram.
   d. the cochlear cleft.

9. The petromastoid canal, which can be mistaken for a fracture, can vary in width, but its diameter typically does not exceed that of the corresponding:
   a. superior semicircular canal.
   b. vestibular aqueduct.
   c. subarcuate vein.
   d. crista falciformis.

10. A channel that extends from the subarachnoid space to the basal turn of the cochlea and can be mistaken for a fracture is the:
    a. cochlear cleft.
    b. cochlear aqueduct.
    c. petromastoid canal.
    d. high jugular bulb.

11. Which of the following statements is true regarding the jugular bulb?
    a. The location of the jugular bulb within the temporal bone is constant.
    b. If the jugular bulb is more superior on one side, it will be equally superior on the other side.
    c. Usually, a high jugular bulb has an intact sigmoid plate.
    d. Most high jugular bulbs are found in men.

12. The most common osseous anomaly in individuals who have sensorineural hearing loss is a(n):
    a. epithelial plug.
    b. bulging sigmoid sinus.
    c. enlarged vestibular aqueduct.
    d. external auditory canal atresia.

13. Cochlear deformities typically occur:
    a. as a result of developmental arrest during gestation.
    b. when trauma occurs during an infant’s delivery.
    c. as a result of chronic otitis media.
    d. as a natural part of aging.

14. The most common congenital abnormality found in the inner ear is:
    a. CHARGE syndrome.
    b. semicircular canal malformation.
    c. Michel deformity.
    d. Mondini dysplasia.

15. According to the historical temporal bone fracture classification scheme, most temporal bone fractures are what type?
    a. longitudinal
    b. transverse
    c. oblique
    d. mixed

16. Transverse fractures of the temporal bone can result in:
    1. sensorineural hearing loss.
    2. vertigo.
    3. facial nerve palsy.
    a. 1 and 2
    b. 1 and 3
    c. 2 and 3
    d. 1, 2, and 3

continued on next page
17. According to the article, an aberrant internal carotid artery often is displayed on:
   1. CT scanning.
   2. ultrasonography.
   3. angiography.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

18. The ______ artery usually degenerates during the tenth week of fetal development but might persist and cause symptoms such as pulsatile tinnitus and hearing loss.
   a. internal carotid
   b. external carotid
   c. stapedial
   d. hyoid

19. The most common inflammatory condition of the structures housed by the temporal bone is:
   a. acute otitis media.
   b. chronic otitis media.
   c. cholesteatoma.
   d. labyrinthitis.

20. Imaging of patients with acute otitis media typically is performed:
   a. in all cases.
   b. only when there is a suspected complication.
   c. in cases involving adult patients.
   d. under no clinical circumstances.

21. Which of the following statements is not true regarding cholesteatomas?
   a. They are essentially cysts or sacs.
   b. Most are acquired.
   c. When congenital, they usually appear in the region of the petrous apex.
   d. The masses are easily distinguished from middle ear infections on CT scans.

22. ______ labyrinthitis usually presents with both perilymphatic fistula and temporal bone fracture.
   a. Tympanogenic
   b. Post-traumatic
   c. Autoimmune
   d. Meningogenic

23. Pathophysiological findings are displayed well on CT during the ______ stage of labyrinthitis.
   a. asymptomatic
   b. acute
   c. fibrous
   d. labyrinthitis ossificans

24. Which of the following temporal bone CT techniques assists with imaging suspected otospongiosis?
   1. thin-slice scans
   2. axial bone algorithm noncontrast scans
   3. coronal bone algorithm noncontrast scans
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

25. The appearance of calcification or hemorrhage is a common radiographic feature of vestibular schwannomas.
   a. true
   b. false

26. Endolymphatic sac tumors tend to:
   a. cause local bone destruction as they grow.
   b. show little local growth or aggressiveness.
   c. metastasize early in development.
   d. metastasize if not detected early.

continued on next page
27. ______ is typically sufficient for imaging evaluation of a postoperative cochlear implant.
   a. CT
   b. Magnetic resonance imaging
   c. Ultrasonography
   d. Radiography

28. A tympanostomy tube is inserted into the ear to facilitate:
   a. easier implantation of hearing devices.
   b. support of a fractured temporal bone.
   c. drainage of middle ear fluid.
   d. insertion of a stapes prosthesis.