Imaging of Temporal Bone Trauma

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KEYWORDS

• Temporal bone fracture • Trauma • Ossicular injury • Hearing loss • Facial nerve
• Cerebrospinal fluid leak • Pneumolabyrinth • Perilymphatic fistula

KEY POINTS

- Multidetector temporal bone computed tomography examinations should be performed in patients with a clinical or radiographic suspicion of temporal bone fracture.
- Categorization of temporal bone fractures should include a descriptor for fracture direction, the presence or absence of labyrinthine involvement, and the segment of temporal bone involved.
- It is important to identify associated complications related to temporal bone trauma that will guide management. Complications include injury to the tympanic membrane, ossicular chain, vestibulocochlear apparatus, facial nerve, tegmen, carotid canal, and venous system.

INTRODUCTION

The temporal bone is at risk for injury in the setting of high-impact craniofacial trauma occurring in 3% to 22% of patients with trauma with skull fractures (**Table 1**).[1–3] Motor vehicle collisions, assaults, and falls are the most common mechanisms of injury.[4–6] Most patients with temporal bone trauma sustain unilateral injury, occurring in 80% to 90% of cases.[5,7,8] Multidetector computed tomography (CT) has revolutionized the ability to evaluate the intricate anatomy of the temporal bone, enabling clinicians to detect fractures and complications related to temporal bone trauma. An understanding of temporal bone anatomy is crucial in evaluating patients with trauma for temporal bone injury; this is beyond the scope of this article, but discussed in detail by Davidson.[9]

TEMPORAL BONE IMAGING

Patients presenting to the emergency department with significant head trauma should undergo initial evaluation with a noncontrast CT examination of the head. Careful scrutiny of the temporal bone on head CT is necessary to detect primary and secondary signs of temporal bone injury. External auditory canal opacification, otomastoid opacification, air within the temporomandibular joint, ectopic intracranial air adjacent to the temporal bone, and pneumolabyrinth in the setting of trauma should raise the suspicion of an associated temporal bone fracture (**Fig. 1**). Patients with temporal bone trauma often sustain concomitant intracranial injury, which often necessitates more emergent management. Once life-threatening injuries are addressed, further characterization of temporal bone fracture patterns and associated complications should be performed using a checklist approach (**Boxes 1** and **2**). A dedicated temporal bone CT examination should be considered in those patients with clinical findings worrisome for temporal bone injury as well as those patients in whom a temporal bone fracture is suspected on imaging of the head, cervical spine, or maxillofacial region.

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Table 1
Complications of temporal bone trauma based on symptoms

Symptom	Associated Imaging Finding
CHL	Tympanic membrane perforation Hemotympanum Ossicular injury (suspected in patients with persistent ABG of >30 dB for longer than 6 wk)
SNHL	Injury of the bony labyrinth Injury of the internal auditory canal Brainstem/nerve root entry zone injury Pneumolabyrinth
Vertigo	Injury of the bony labyrinth Injury of the internal auditory canal Brainstem/nerve root entry zone injury Pneumolabyrinth
Perilymphatic fistula (combination of vertigo, CHL, SNHL, possible otorrhea)	Fracture/dislocation of the stapes footplate-oval window Fracture that traverses the round window Unexplained middle ear fluid Pneumolabyrinth
Otorrhea	CSF leak related to fracture of the tegmen Violation of the stapes footplate-oval window Violation of the round window
Facial nerve weakness	Fracture, bony spicule, or hemorrhage that involves the facial nerve canal

Abbreviations: ABG, air bone gap; CHL, conductive hearing loss; CSF, cerebrospinal fluid; SNHL, sensorineural hearing loss.

The advent of multidetector CT has enabled the radiologist to critically evaluate the temporal bone in patients with trauma because of extremely fast acquisition times, very thin slices, and the ability to create multiplanar reconstructions. Axial images should be acquired using sub–1-mm slice thickness and a small field of view (<10 cm). Multiplanar reconstructions in the coronal plane, Stenvers view (oblique coronal orientation parallel to the petrous ridge), and Pöschl view (oblique coronal orientation perpendicular to the petrous ridge) can be generated for additional evaluation and cross-referencing.

FRACTURE CLASSIFICATION

Traditional Classification: Longitudinal and Transverse

In the past, temporal bone fractures were classified based on the orientation of the fracture plane with respect to the long axis of the petrous portion of the temporal bone (**Figs. 2** and **3**).[5,6,10] Fractures were characterized as longitudinal if parallel to the petrous pyramid and transverse if perpendicular to the petrous ridge (see **Figs. 2** and **3**).[6] A mixed subtype was subsequently incorporated into this scheme if there were components of both fracture planes. This classification scheme, based on fracture direction, was devised from cadaveric studies and has been scrutinized for clinical usefulness.[1,6,8] Longitudinal fractures occur more frequently, ranging from 50% to 80%.[6–8] Transverse fractures are less common and have been reported to occur in 10% to 20% of cases.[6–8] Some clinicians think that classifying fractures as longitudinal or transverse based on axial imaging is arbitrary, because most fractures are more complex in 3 dimensions.[5] A mixed or oblique subtype has been reported to occur in approximately 10% to 75% of cases.[1,5–8] The broad range seen with the mixed and oblique fracture subtypes in part reflects differences in definitions used between studies.

Alternative Classification Schemes

Subsequent studies have shown that other classification schemes that incorporate involvement of the labyrinthine structures may offer more clinical usefulness, potentially predicting those patients at higher risk for long-term sensorineural hearing loss (SNHL), intracranial injury, vascular injury, and facial nerve paralysis.[1,4] The otic capsule (bony labyrinth) is involved in a small minority of patients, occurring in only approximately 2% to 7% of cases in patients with temporal bone fracture (see **Figs. 2** and **3**).[1,4,8,11] However, the associated

Fig. 1. Indirect signs of temporal bone fracture. Axial temporal bone CT images of 4 patients (*A–D*) show indirect signs of temporal bone fractures. Intracranial air (*A*, *arrows*) can be seen if the temporal bone fracture communicates with the intracranial cavity. Air within the temporomandibular joint (*B*, *arrows*) is often seen if the temporal bone fracture involves the tympanic ring. Pneumolabyrinth (*C*, *solid arrows*) can be seen if the fracture extends through the otic capsule (*C*, *dashed arrow*) or if there is dislocation of the stapediovestibular joint. Opacification of the mastoid air cells (*D*, *solid white arrows*) or external auditory canal (*D*, *dashed white arrow*) in the setting of trauma should raise the suspicion of an underlying temporal bone fracture involving the mastoid or tympanic ring (*D*, *black arrow*) respectively.

Box 1
Indirect signs of temporal bone fracture

Intracranial air adjacent to the temporal bone
Air within the temporomandibular joint
Pneumolabyrinth
Opacification of the mastoid air cells
Opacification of the external auditory canal

morbidity in patients with intralabyrinthine fractures is greater than if the otic capsule is spared.[1,8] A significant force is needed to fracture the strong bony labyrinth compared with the other weaker segments of the temporal bone. Therefore, patients with an intralabyrinthine fracture are more likely to sustain greater traumatic forces and proportionally more severe complications.

In 2004, Ishman and Friedland[8] proposed a new classification system based on the segment of

Box 2
Temporal bone trauma checklist

- Location and direction of temporal bone fracture
- Violation of otic capsule: cochlea, vestibule, semicircular canals, vestibular aqueduct
- Ossicular integrity: malleus, incus, stapes
- Facial nerve canal: internal auditory canal, fallopian canal, geniculate fossa, tympanic, mastoid
- Tegmen: tympani, mastoideum
- Vascular: carotid canal (petrous, cavernous), venous sinus (transverse, sigmoid, jugular bulb)

temporal bone involved categorizing fractures as petrous or nonpetrous. In this location-specific classification system, a stronger correlation between petrous-type fractures and the presence of SNHL, facial nerve injury, and cerebrospinal fluid (CSF) leak was identified. Table 2 summarizes the recent literature on temporal bone classification systems. Therefore, a combined approach incorporating a descriptor for direction (longitudinal, transverse, oblique, or mixed), temporal bone location, as well involvement of the bony labyrinth is advocated in that it provides information on the overall fracture pattern with additional more clinically relevant details that better anticipate associated complications. It is the identification of complications related to temporal bone trauma more than the categorization of fracture patterns that dictates how patients are managed.[12]

COMPLICATIONS

Associated complications of temporal bone trauma include injury to the tympanic membrane, ossicular chain, facial nerve, cochlea, vestibule, tegmen, and vascular structures. Patients with temporal bone trauma may present with a myriad of clinical symptoms including conductive hearing loss (CHL), SNHL, facial paralysis, CSF leak, meningitis, vertigo, and intracranial hemorrhage.

Hearing Loss

The most common complication following temporal bone trauma is hearing loss, which is found in approximately 24% to 81% of patients with temporal bone trauma.[1,4,7,11] Hearing loss may be categorized as conductive, sensorineural, or mixed. CHL results from a disorder within the external or middle ear and affects air conduction, with preserved bone conduction on audiometry. SNHL affects both air and bone conduction and implies involvement of the otic capsule or cochlear nerve.

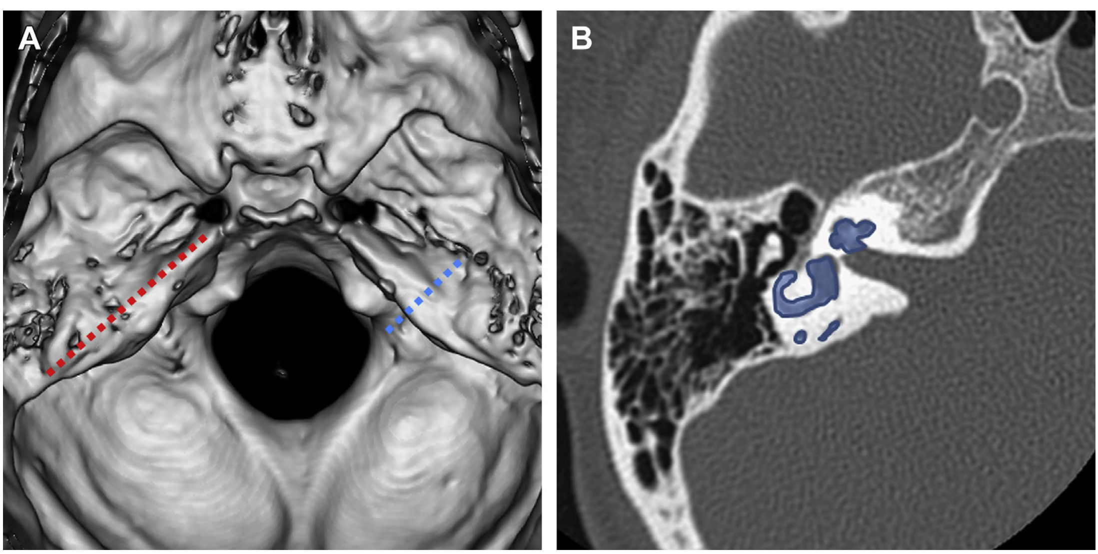

Fig. 2. Classification of temporal bone fractures. Three-dimensional (3D) volume -rendered CT image of the skull base (*A*) shows the trajectory of a longitudinal fracture of the right temporal bone (*A, red dashed line*) and a transverse fracture of the left temporal bone (*A, blue dashed line*). A fracture is categorized as mixed if both transverse and longitudinal fracture planes are present. Axial CT image of the temporal bone in a normal patient shows the normal anatomy of the bony labyrinth (*B*). An otic capsule–violating fracture may involve the cochlea, vestibule, semicircular canals, or vestibular aqueduct (*B, outlined in blue*).

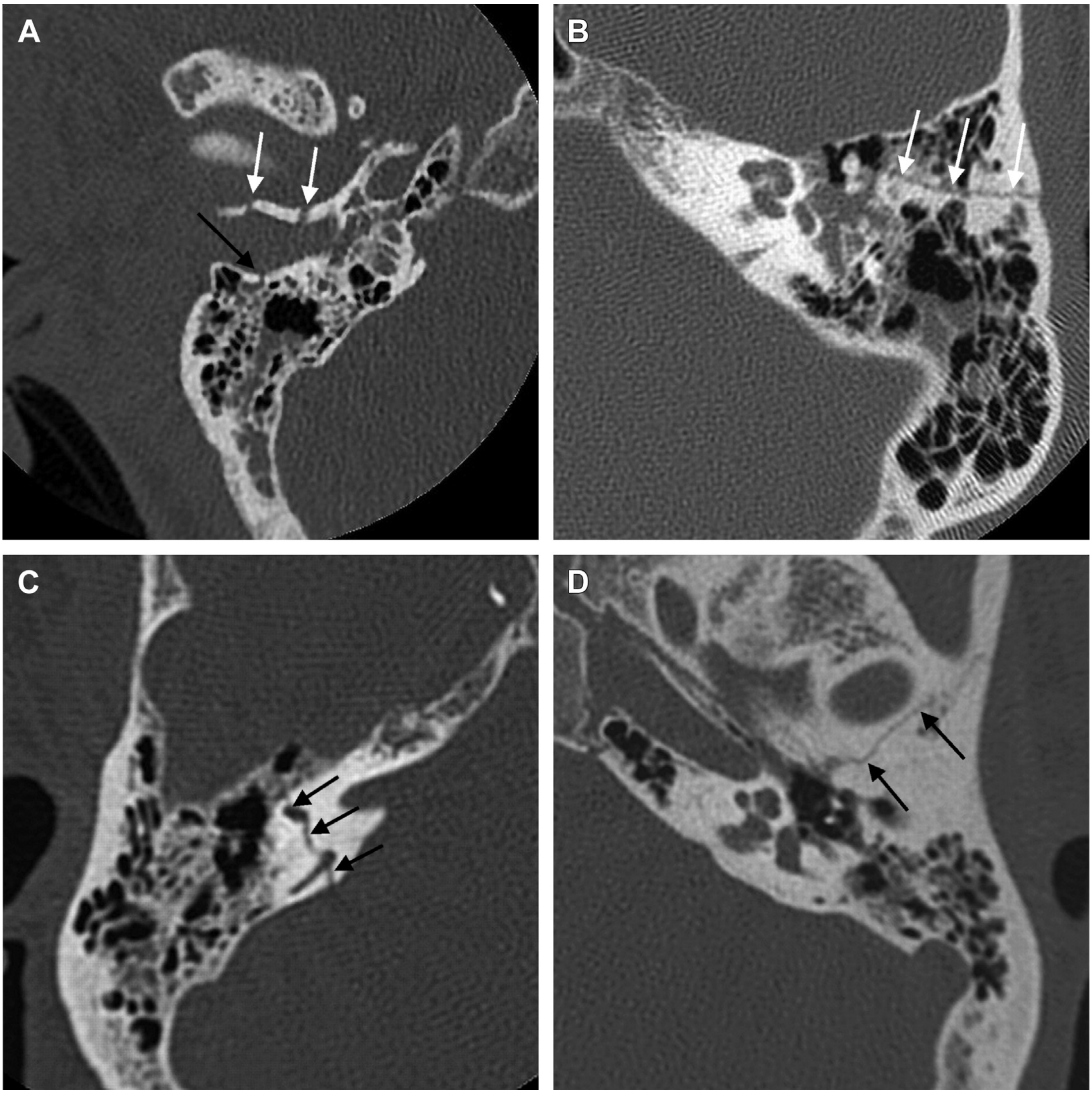

Fig. 3. Types of temporal bone fractures. Axial temporal bone CT images of 4 patients show 4 different types of temporal bone fractures (*A–D*). (*A*) A segmental longitudinal fracture of the tympanic ring (*A*, *white arrows*) with an additional fracture that extends through the mastoid (*A*, *black arrow*) with associated hemorrhage in the external auditory canal. (*B*) A characteristic longitudinal extralabyrinthine fracture of the mastoid that extends into the middle ear cavity (*B*, *white arrows*). (*C*) A transverse intralabyrinthine fracture with involvement of the semicircular canals (*C*, *black arrows*). (*D*) A transverse extralabyrinthine fracture traversing the squamous portion of the temporal bone (*D*, *black arrows*).

CHL

Traumatic CHL can occur from tympanic membrane perforation, hemotympanum, and derangement of the ossicular chain. In a review of 699 patients with 820 temporal bone fractures, Brodie and Thompson[4] reported that 21% of patients with hearing loss had a conductive type. CHL was identified in 80% of patients with hearing loss in the study by Dahiya and colleagues.[1] The most common cause of transient mild CHL is related to the presence of hemotympanum and tympanic membrane perforation.[13] A persistent CHL, defined as an air-bone gap measuring greater than 30 dB for longer than 6 weeks, usually implies a more significant injury and should raise concern for ossicular injury.[14]

Ossicular Injury

Ossicular injury may be related to direct traumatic forces or indirectly related to simultaneous tetanic contraction of the stapedius and tensor tympani muscles.[13,15] Injury to the ossicular chain occurs

Table 2
Summary of temporal bone fracture classification literature

Investigators, Date	Study Design	Results	Conclusions
Ghorayeb & Yeakley,[5] 1992	Evaluated direction classification and incorporated the oblique descriptor into the classification scheme	150 fractures in 140 pts • 112 (74.7%) oblique • 4 (2.7%) longitudinal • 18 (12%) transverse • 14 (9.3%) mixed • 2 (1.3%) petrous apex	Most fractures are more complex than traditional classification suggests. Most fractures are oblique, crossing the petrotympanic fissure

Brodie & Thompson,[4] 1997	Reviewed incidence of complications from temporal bone fractures. Incorporated otic capsule–sparing vs otic capsule–violating terminology; all otic capsule–violating fractures were classified as transverse fractures	820 fractures in 699 pts
		• 799 (97.5%) OCS
		  ◦ 6% FN injury
		  ◦ 16% CSF fistula
		• 21 (2.5%) OCV
		  ◦ 48% FN injury
		  ◦ 31% CSF fistula
			OCS fractures were most common. FN injury and CSF fistula were common in OCV injuries. CSF fistulae typically resolve spontaneously but, if persistent, pts are at risk for developing meningitis

Dahiya et al,[1] 1999	Compared traditional classification with otic capsule–sparing/violating fractures and assessed associated complications	55 fractures
		• 21 (38%) longitudinal
		• 34 (62%) mixed/oblique
		• 50 (94%) OCS
		• 5 (6%) OCV
		  ◦ 2-fold increase in FN injury
		  ◦ 4-fold increase in CSF leak
		  ◦ 7-fold increase in SNHL
			Temporal bone fractures should be classified based on whether the otic capsule is violated or intact. OCV fractures have a high association with FN injury, CSF leak, and SNHL

Ishman & Friedland,[8] 2004	Compared traditional classification with petrous vs nonpetrous fracture classification and assessed associated complications	155 fractures in 132 pts
		• 99 (64%) longitudinal
		  ◦ 4% CSF leak
		  ◦ 4% FN injury
		  ◦ 46% CHL
		• 36 (23%) transverse
		  ◦ 6% CSF leak
		  ◦ 14% FN injury
		  ◦ 62% CHL
		• 20 (13%) mixed
		  ◦ 25% CSF leak
		  ◦ 25% FN injury
		  ◦ 50% CHL
		• 154 (99.4%) nonpetrous
		  ◦ 4% CSF leak
		  ◦ 7% FN injury
		  ◦ 56% CHL
		• 18 (12%) petrous
		  ◦ 33% CSF leak
		  ◦ 22% FN injury
		  ◦ 20% CHL
			There is poor correlation between traditional classification systems and complications related to temporal bone fracture. Investigators advocate an anatomy-based classification system. Fractures that involve the petrous portion of the temporal bone had the highest association with FN injury and CSF leak. Nonpetrous fractures had the greatest correlation with CHL

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Table 2
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Investigators, Date	Study Design	Results	Conclusions
Rafferty et al,[11] 2006	Compared traditional and otic capsule classification systems and assessed associated complications	31 pts • 9 (29%) longitudinal ◦ 0% SNHL • 8 (26%) horizontal ◦ 50% SNHL • 14 (45%) mixed • 29 (93%) otic capsule–sparing ◦ 3% CSF leak ◦ 7% SNHL ◦ 52% brain injury • 2 (7%) otic capsule violating ◦ 50% CSF leak ◦ 100% SNHL ◦ 100% brain injury	Neither classification system was superior in anticipating associated complications. Investigators recognized that the small sample size may have diminished the power of their study
Little & Kesser,[6] 2008	Compared traditional and otic capsule classification systems and assessed associated complications	30 pts • 15 (50%) longitudinal • 8 (25%) transverse • 7 (23%) oblique • 24 (80%) otic capsule–sparing ◦ 13% FN injury ◦ 4% SNHL • 6 (20%) otic capsule violating ◦ 67% FN injury ◦ 100% SNHL	OCV fractures had a stronger correlation with FN injury and SNHL than OCS fractures. There was no significant difference in complication rate between fractures based on direction

Abbreviations: FN, facial nerve; OCS, otic capsule sparing; OCV, otic capsule violating; pts, patients.

more often with longitudinally oriented fractures that extend into the middle ear than with transverse-type fractures.[7,16,17] Ossicular injuries include fractures of the ossicles as well as dislocation of the incudomalleolar joint, incudostapedial joint, malleoincudal complex, incus, stapediovestibular joint, and the suspensory ligaments of the ossicles (**Figs. 4–10**).[16,17] Patients with ossicular derangement often sustain more than one type of ossicular injury.[17] The incus is the ossicle most commonly affected in the setting of temporal bone trauma because of its large size and weak ligamentous support within the tympanic cavity (see **Figs. 6** and **7**).[13] However, there is some debate about which joint is most often affected. Some studies report a higher incidence of incudomalleolar joint dislocation (see **Fig. 4**) and others report a higher incidence of incudostapedial dislocation (see **Fig. 5**).[7,13,16–18] Basson and van Lierop[13] reported a 63% occurrence of incudostapedial joint dislocation in their small review of 16 patients. In contrast, Meriot and colleagues[16] identified a higher percentage of incudomalleolar joint dislocation compared with incudostapedial involvement in their larger retrospective review of 163 patients.

Imaging of ossicular injury

The ossicular joints may be described as subluxed if there is only mild separation of the ossicles, and dislocated if there is frank separation of the ossicles (see **Figs. 4** and **5**). The incudomalleolar joint has a characteristic appearance on axial images with an ice-cream-cone configuration; the head of the malleus representing the ice cream and the incus representing the cone (see **Fig. 4**A). Derangement of the incudomalleolar joint is easily assessed on axial CT images even in the setting of associated hemotympanum (see **Figs. 4** and **6–8**). Coronal or oblique reconstructions may provide an additional perspective on ossicular malalignment (see **Fig. 4**D).[19]

The integrity of the incudostapedial joint is often more difficult to assess in the setting of trauma because hemotympanum typically obscures this small anatomic structure. The incudostapedial joint can be evaluated by scrolling through a series of axial CT images and assessing the relative

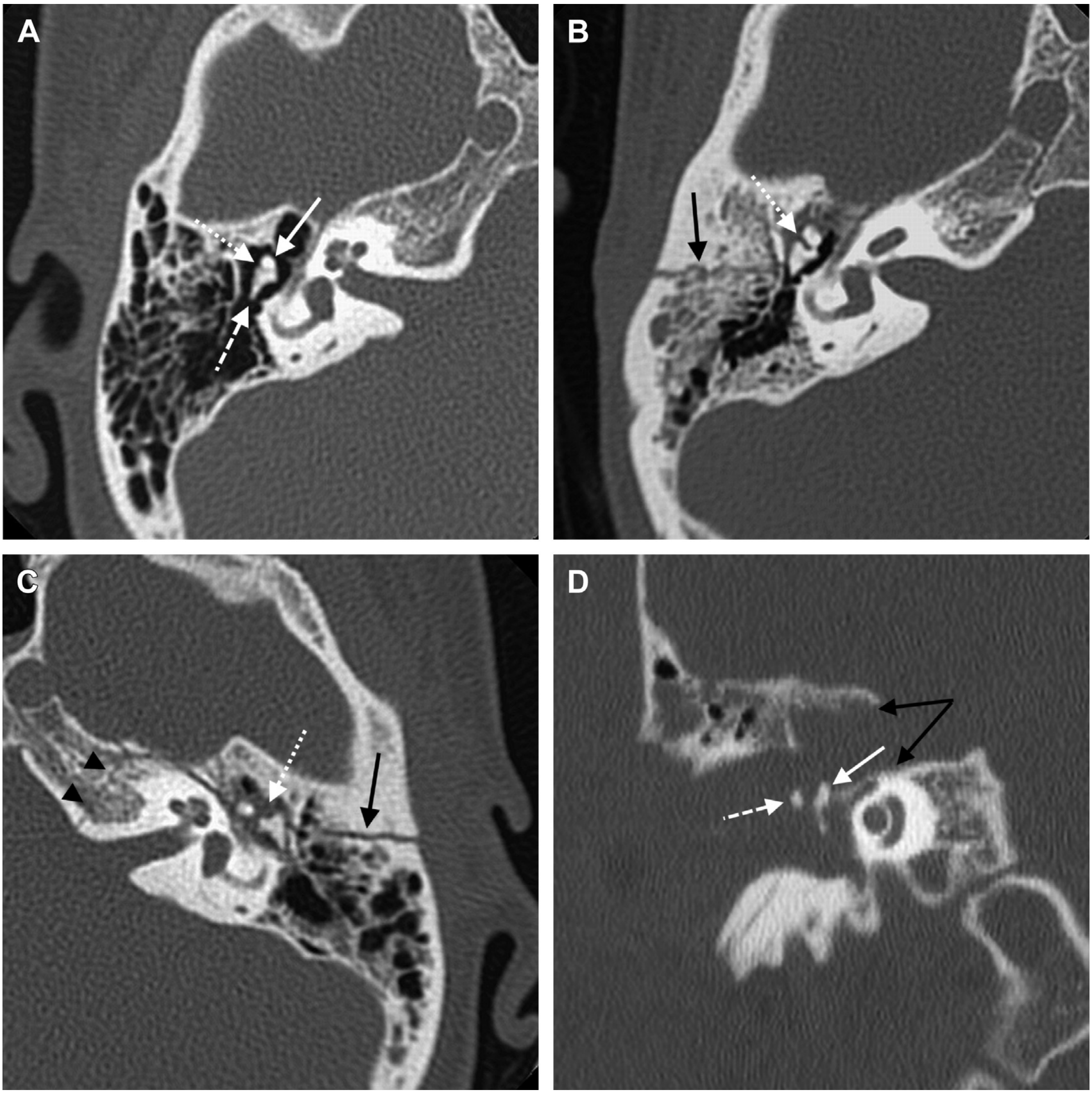

Fig. 4. Injury of the incudomalleolar joint. (*A*) The normal incudomalleolar joint in the axial plane (*A*, *dotted arrow*) with the head of the malleus (*A*, *solid arrow*) in close apposition with the body of the incus (*dashed arrow*). Disruption of the incudomalleolar joint can be easily identified in the axial and coronal planes and is shown in these 3 examples (*C*, *D*). (*B*) Mild subluxation of the incudomalleolar joint space (*B*, *dotted arrow*) related to an extralabyrinthine longitudinal fracture (*B*, *solid arrow*). (*C*) Frank dislocation of the incudomalleolar joint (*C*, *dotted arrow*) related to an extralabyrinthine longitudinal fracture (*B*, *solid arrow*). A transverse fracture of the petrous temporal bone is also present in this patient (*C*, *arrowheads*). Dislocation of the incudomalleolar joint can be seen in the coronal plane and has been described as the Y sign (*D*).[19] (*D*) There is lateralization of the incus (*D*, *dashed white arrow*) with respect to the malleus (*D*, *solid white arrow*) with an intervening gap. Also note the wide fracture gap through the tegmen (*D*, *solid black arrows*).

position of the long and lenticular processes of the incus with the capitellum, crura, and footplate of the stapes (see **Fig. 5**). Total incus dislocation can occur if the incus is dislocated at both the incudomalleolar and incudostapedial joints (see **Figs. 6** and **7**). In addition, the malleus and incus may be dislocated as a unit with primary disarticulation of the incudostapedial joint (see **Fig. 5**C). Disruption of the stapediovestibular joint is rare, being reported in only 3% of cases, likely because of its strong attachment by the annular ligament.[16]

Ossicular fractures are also infrequent, occurring in approximately 2% to 11% of cases.[7,16] Some studies report the stapes and others report the incus as the most commonly fractured ossicle.[16,17] Stapes fractures may involve the

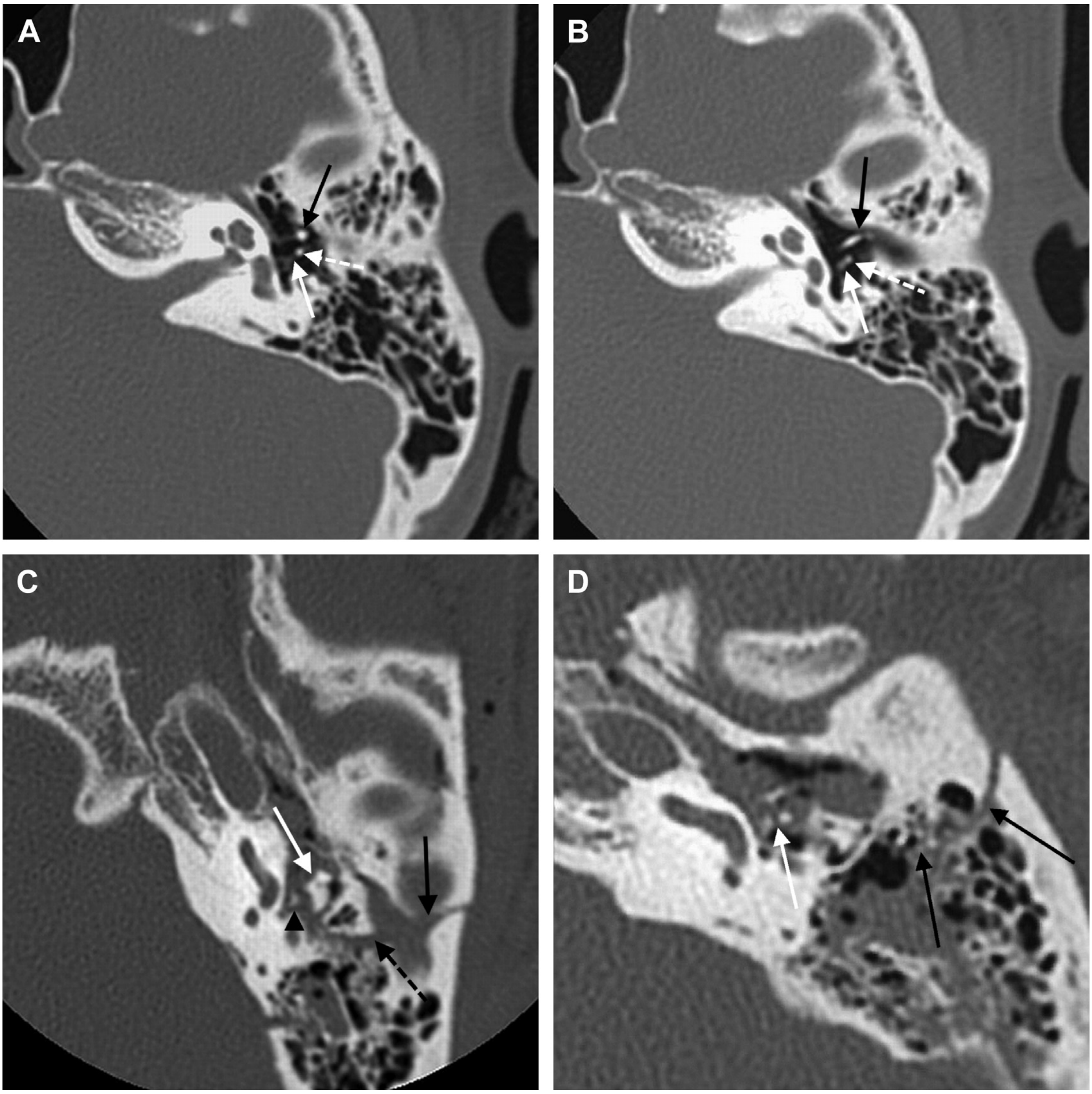

Fig. 5. Injury of the incudostapedial joint. The normal (*A*, *B*) and dislocated (*C*, *D*) appearance of the incudostapedial joint in the axial plane. At the level of the oval window, the normal appearance of the stapes is well profiled (*A*, *solid white arrow*) with visualization of the anterior and posterior crura. The distal tip of the long process of the incus is seen at this level (*A*, *dashed white arrow*) and the malleus is seen anteriorly (*black arrow*). Just below the oval window (*B*), the incudostapedial joint is profiled, showing the close apposition between the lenticular process of the incus (*B*, *dashed arrow*) and the capitellum of the stapes (*B*, *solid white arrow*). The malleus is anterior to the incudostapedial joint (*B*, *black arrow*). (*C*) Frank dislocation of the incudostapedial joint showing anterior and inferior dislocation of incudomalleolar complex (*C*, *white arrow*), which is now at the level of the stapes superstructure (*C*, *black arrowhead*). These findings are related to a displaced fracture fragment (*C*, *dashed black arrow*) from an extralabyrinthine oblique fracture (*B*, *solid black arrow*). (*D*) Mild subluxation of the incudostapedial joint in a different patient shown by mild widening of the joint space (*D*, *white arrow*) related to an underlying oblique temporal bone fracture (*D*, *black arrows*).

capitellum, arch, or footplate. Footplate fractures (see **Fig. 10**) are often related to transverse fractures, which extend through the oval window, whereas fractures of the arch most commonly occur in the setting of torsional forces.[16] Perilymphatic fistula (PLF) should be suspected in those patients with fractures that traverse the footplate. Axial CT images are most useful in the assessment of ossicular fractures, which can be subtle on imaging. The presence of a lucent line through the ossicles as well as a displaced bone fragment should raise the suspicion for an ossicular fracture

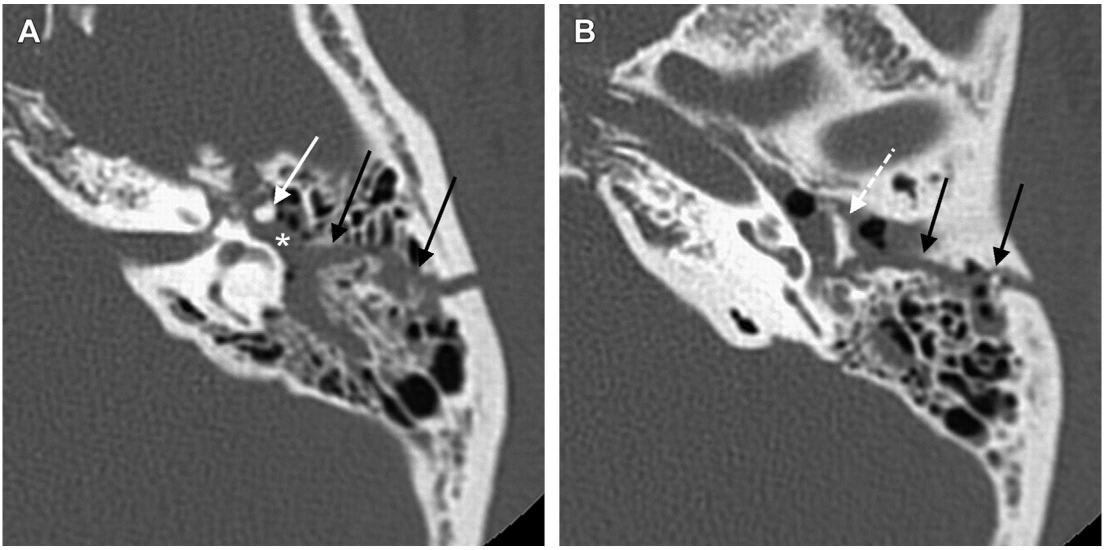

Fig. 6. Total incus dislocation. Axial CT images of the left temporal bone (*A*, *B*) show absence of the incus from its normal position within the incudal fossa (*A*, *asterisk*) with preservation of the normal position of the malleus (*A*, *white arrow*) related to a longitudinal extralabyrinthine fracture (*A*, *B*, *black arrows*). The incus is rotated and inferiorly positioned within the tympanic cavity (*B*, *dashed arrow*).

(see Fig. 9). Coronal reconstructions may better evaluate fractures of the manubrium and long process of the incus because of the vertical orientation of these ossicles (see Fig. 9).

Treatment of ossicular injury

Several treatment strategies have been used to manage patients with posttraumatic CHL, ranging from immediate exploration to delayed repair after 3 to 6 months. A conservative approach is likely warranted in those patients with tympanic membrane perforation, hemotympanum, and minor ossicular derangements because many of these patient's symptoms resolve without intervention. In a review of 45 patients presenting with posttraumatic CHL, Grant and colleagues[20] identified that 77% of ears showed improvement in pure tone averages using a conservative approach and only 5 of 47 ears eventually required surgical management. Surgery may be indicated in those patients with persistent CHL for longer than 6 months. Surgical repair of ossicular chain incongruencies is intended to restore transmission of sound from the tympanic membrane to the oval window and can be achieved using bone, cartilage, or prosthetic grafts depending on the location and type of ossicular injury. Reconstruction of the ossicular chain was performed in 5 patients in the study by Brodie and Thompson[4] with an average postoperative air-bone gap of 17.5 dB. Postsurgical improvement in CHL was also noted in 4 of 5 patients in the series by Dahiya and colleagues.[1]

SNHL

Traumatic SNHL may be caused by fractures that involve the labyrinth (see Fig. 10; Fig. 11) or internal auditory canal as well as by isolated intralabyrinthine hemorrhage without fracture (Fig. 12). In the past, transverse -type fractures have been reported to have a stronger correlation with SNHL. However, newer classification schemes that compare traditional classification methods with otic capsule–sparing/violating schemes argue that directional classification schemes are less predictive of complications including SNHL.[1,6,11] Otic capsule–violating fractures, which represent 2% to 6% of temporal bone fractures, are invariably associated with profound SNHL.[1,4,6] One study reports that otic capsule–violating fractures are 25 times more likely to be associated with SNHL than if the otic capsule is spared.[6] However, patients classified into the more traditional transverse, longitudinal, and oblique fracture patterns had similar percentages of SNHL, showing the lack of specificity of the directional classification scheme in predicting posttraumatic SNHL.[6]

Axial CT images are optimal at identifying otic capsule–violating fractures as manifested by fracture lines that extend through the cochlea, vestibule, or semicircular canal (see Figs. 1C, 3C, 10, and 11). Pneumolabyrinth may be seen as a secondary sign indicating that the otic capsule has been violated (see Figs. 1C and 10). Identifying hemorrhage within the otic capsule is not possible on CT. Magnetic resonance (MR) imaging may

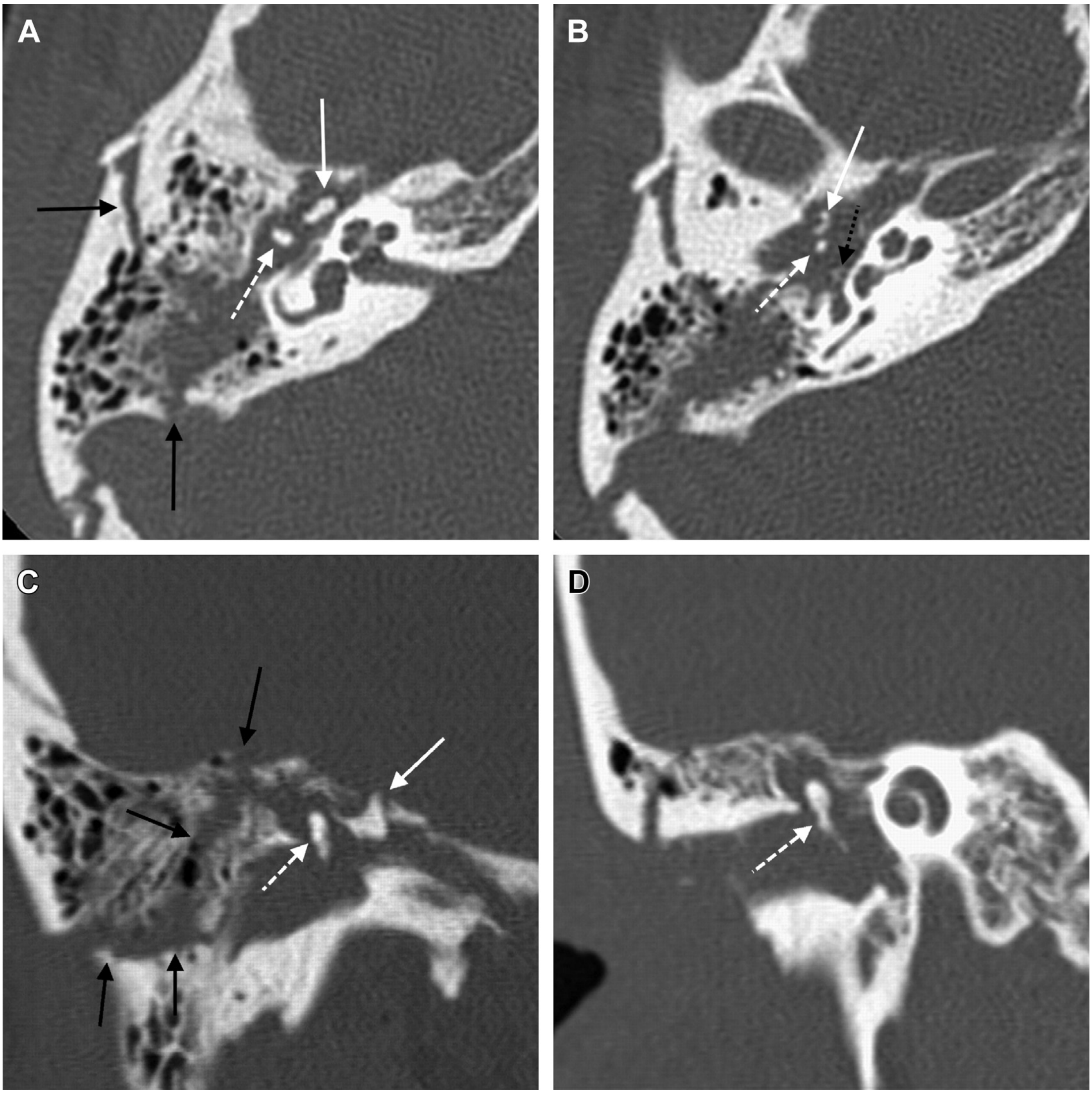

Fig. 7. Total incus dislocation. Axial and Stenvers reconstructions of the right temporal bone (*A–D*) show total incus dislocation related to a complex temporal bone fracture (*black arrows*). The incus is rotated with anterior and superior displacement (*white solid arrows*). Note the superior displacement of incus through the fractured tegmen on the Stenvers reconstruction (*C, solid white arrow*). The malleus (*white dashed arrows*) and stapes (*B, black dashed arrow*) remain normal in position.

show evidence of hemolabyrinth in some patients with trauma with SNHL even in the absence of fracture (see **Fig. 12**).

Vertigo

Patients may also experience vertigo, dizziness, or disequilibrium following temporal bone trauma.[21] As in SNHL, vertigo may result from fracture that violates the vestibule, semicircular canals, vestibular aqueduct, or vestibular nerve. In the absence of fracture, patients may have vertigo from a labyrinthine concussion, shearing of the nerve root entry zone, or from brainstem injury.[12,21] Alternate diagnoses including PLF and otolith dislocation should also be entertained in patients with vertigo without associated fracture.[12] Posttraumatic vertigo typically resolves spontaneously after 6 to 12 months.[12]

Axial CT images remain best for evaluating the labyrinth for associated fractures that violate the vestibular apparatus (see **Figs. 1**C, **3**C, **10**, and **11**). Stenvers and Pöschl reconstructions may be beneficial additional views because they profile the posterior and superior semicircular canals respectively. An MR examination using a gradient

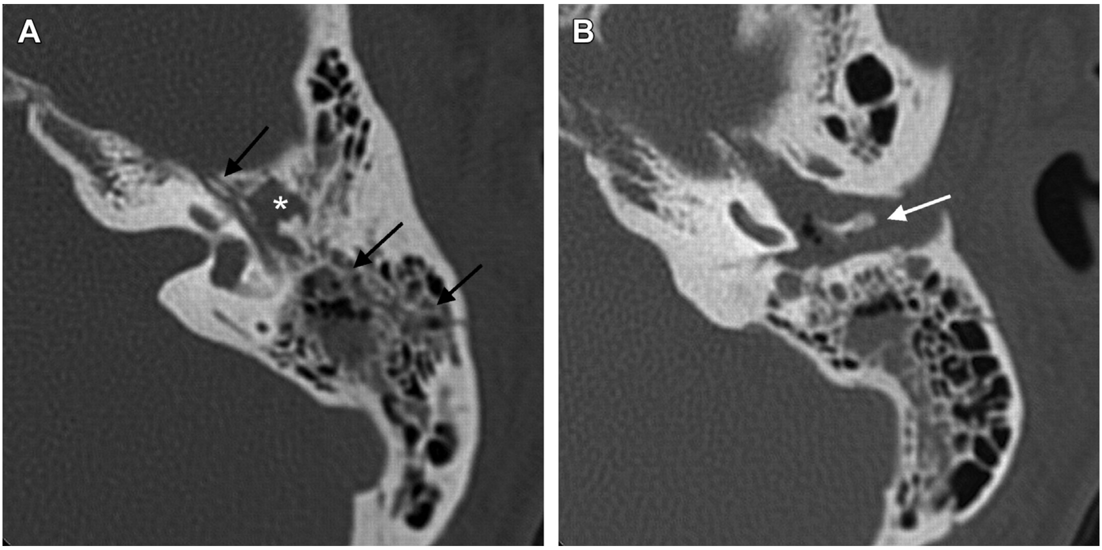

Fig. 8. Malleus dislocation. Axial CT images of the left temporal bone show malleus dislocation (*A*, *B*) related to a longitudinal otic capsule–sparing fracture (*black arrows*). The malleus is externally rotated and inferiorly dislocated (*B*, *white arrow*) from its normal position within the tympanic cavity (*A*, *asterisk*).

echo sequence may reveal hemorrhage within the vestibular nucleus or nerve root entry zone within the brainstem in patients with persistent vertiginous symptoms without a clear underlying cause on CT.

PLF

PLFs result from an abnormal connection between the perilymph and middle ear cavity and can be traumatic, congenital, or spontaneous.[22] Posttraumatic PLFs allow perilymph to leak into the tympanic cavity and may be related to disruption of the oval window or, less commonly, of the round window membrane.[21] Traumatic PLFs may occur from implosive or explosive mechanisms as described by Goodhill[23] in 1971. Direct external trauma to the tympanic membrane, oval window, or round window may result in an implosive injury,[23] or a sudden increase in intracranial pressure transmitted through the perilymph to the oval or round window may result in an explosive PLF.[23] Patients with PLF may present with a confusing clinical picture including persistent vertigo with intermittent SNHL and/or CHL.[22] Symptoms of PLF typically begin within 24 to 72 hours after injury, which can be used as a feature distinguishing PLF from traumatic Meniere syndrome, which often occurs months to years after injury.[21,24]

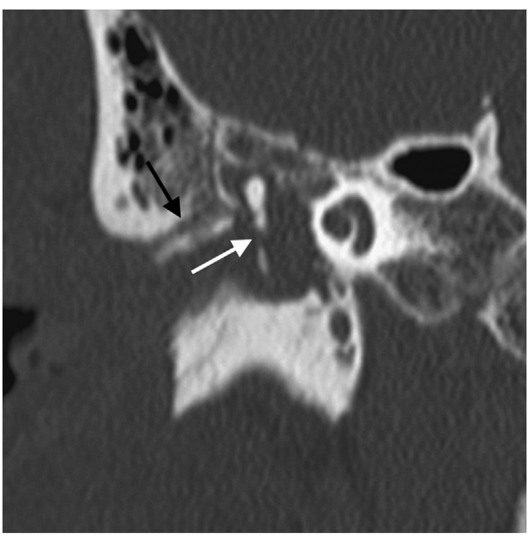

Fig. 9. Malleus fracture. A fracture of the manubrium of the malleus with inferior positioning of the lower fracture fragment (*white arrow*) related to a longitudinal otic capsule–sparing temporal bone fracture (*black arrow*).

Fractures through the stapes footplate or round window seen on CT should raise the suspicion of PLF (see **Fig. 10**). However, in the absence of a fracture, PLF is a difficult diagnosis to make. Pneumolabyrinth and unexplained dependently layering fluid within the middle ear may be secondary signs of PLF in patients without a temporal bone fracture.[22,24]

CSF Leak

Patients who sustain temporal bone injury are at risk for developing a CSF leak, a serious complication given the associated risk of meningitis. CSF leak may occur when there is violation of the skull

Fig. 10. Stapes footplate fractures. Axial CT images of the right temporal bone in 4 patients show the normal (*A*) and fractured appearance (*B–D*) of the stapes footplate. (*A*) The normal appearance of the stapes footplate and oval window in the axial plane (*A*, *arrow*). (*B*) A transverse otic capsule–violating fracture of the right temporal bone (*B*, *dashed arrow*). The fracture extends through the anterior margin of the stapes footplate (*B*, *solid arrow*). (*C*) A subtle depressed fracture of the stapes footplate (*C*, *dashed arrow*) with extensive associated pneumolabyrinth in the cochlea and vestibule (*C*, *solid arrows*). Although the fracture is subtle, the presence of air within the otic capsule should raise the suspicion for injury. (*D*) Another example of a subtle stapes footplate fracture (*D*, *dashed arrow*) with associated subtle pneumolabyrinth (*D*, *solid arrows*). An additional transverse fracture is identified coursing through the vestibular aqueduct (*D*, *arrowheads*). Fractures of the footplate should raise the concern for associated perilymphatic fistula.

and underlying dura. When CSF leaks involve the temporal bone, they can present as otorrhea with a disrupted tympanic membrane, or otorhinorrhea with an intact tympanic membrane via eustachian tube drainage.[25] A high index of suspicion is required for appropriate management of these patients because CSF leaks may be clinically subtle and related to slow, often positional, leakage of fluid. Confirmatory beta-2 transferrin testing should be performed for those patients in whom CSF leak is suspected.[25]

Posttraumatic CSF leak has been reported to occur in 13% to 45% of patients with temporal bone fractures, with meningitis in 7% of patients.[1,4,7,8,11] The risk of developing meningitis in the setting of CSF leak is multifactorial, the most

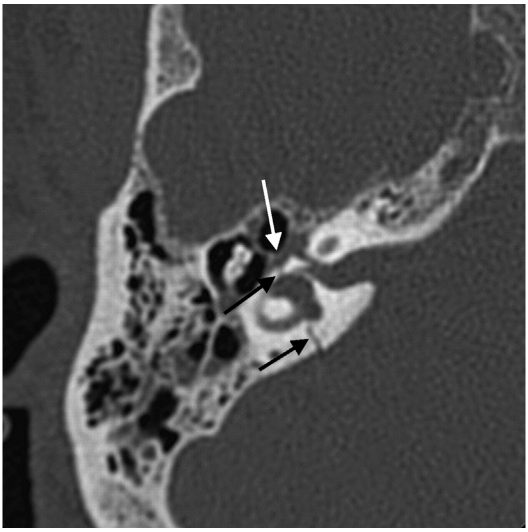

Fig. 11. Fracture of the vestibule and facial nerve canal. Axial CT image of the right temporal bone shows a transverse otic capsule–violating fracture that extends through the vestibule (*black arrows*), which propagates through the tympanic segment of the facial nerve canal (*white arrow*).

significant risk being related to the duration of CSF leak.[4] Patients with CSF leaks that continue for longer than 7 days are at higher risk of developing meningitis compared with those patients whose leaks stop by day 7.[4] It is rare for meningitis to occur in the absence of a CSF leak, therefore prophylactic antibiotic therapy is indicated only in those patients with a CSF leak. Patients with trauma who sustain injury to the temporal bone may have multiple skull base fractures, with alternate sources of CSF leak outside the temporal bone. Therefore precise localization of the site of CSF leak is critical in managing these patients with skull base trauma, because the surgical approach may be different depending on the anatomic location of the leak. There is an association between fracture pattern and the development of CSF leak. Patients with otic capsule–violating fractures are 4 to 8 times more likely to have a CSF leak than patients with otic capsule–sparing fractures.[1,4,6] However, the traditional directional classification scheme is a poor predictor of the presence or absence of CSF leak.[6,11]

Imaging findings of CSF leak

Scrutinizing the integrity and position of the tegmen is critical when evaluating temporal bone CT scans for potential sites of posttraumatic CSF leaks. Coronal and sagittal reconstructions are best at evaluating the tegmen for defects (**Fig. 13**). It is important to describe the location and size of the fracture defect, the presence and orientation of displaced fracture fragments through the defect, and the presence of any associated encephalocele (see **Fig. 13**). In the authors'

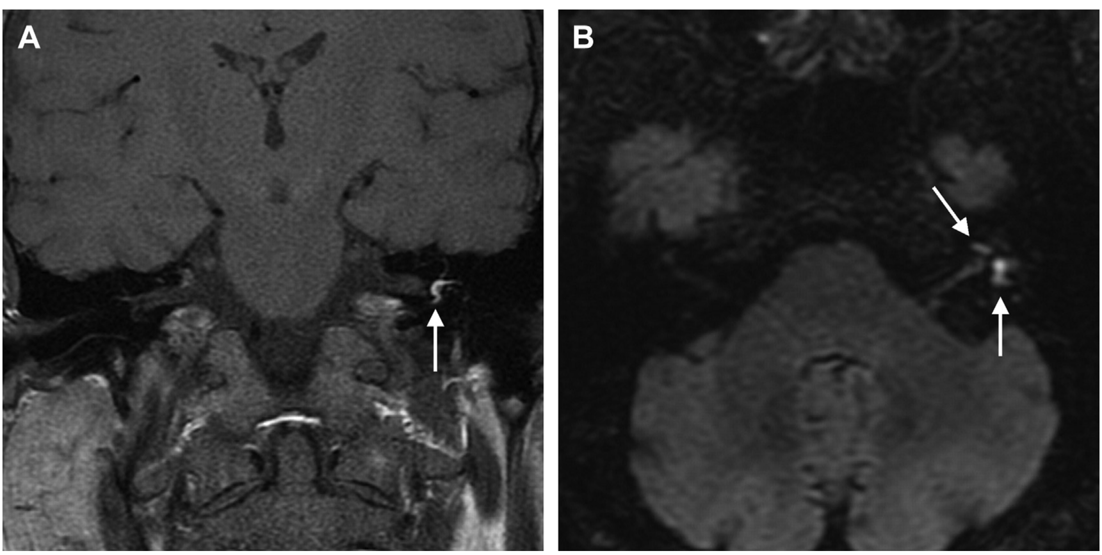

Fig. 12. Intralabyrinthine hemorrhage without fracture. Coronal unenhanced T1 (*A*) and axial T2 fluid-attenuated inversion recovery (FLAIR) (*B*) images through the internal auditory canals in a patient who presented with hearing loss after a minor fall shows findings of hemolabyrinth. There is intrinsic T1 signal hyperintensity (*A*, *arrow*) and T2-FLAIR signal hyperintensity (*B*, *arrows*) within the semicircular canals, vestibule, and cochlea of the left temporal bone. A head CT scan performed initially showed no evidence of temporal bone fracture or other abnormality within the brain (not shown).

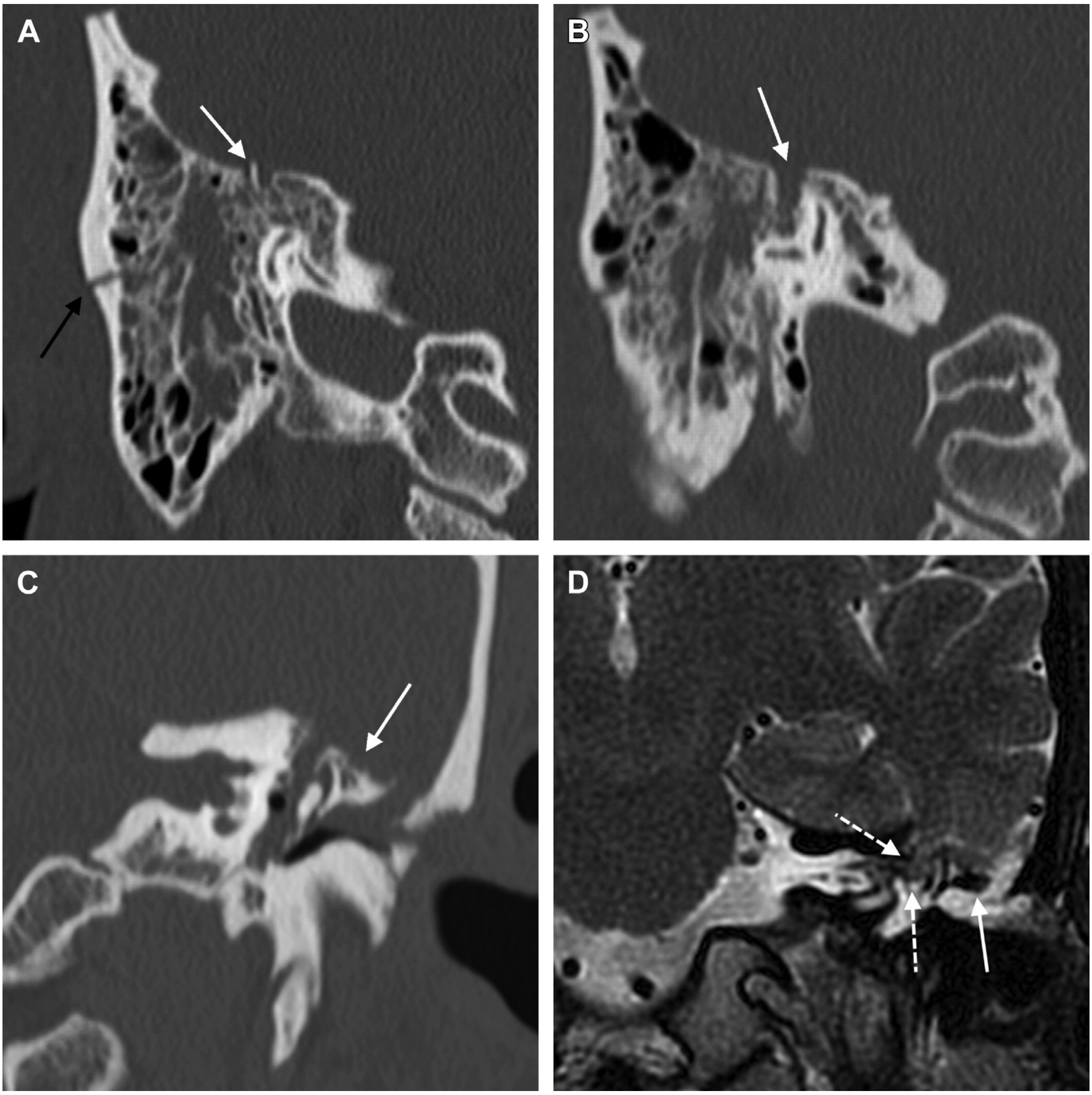

Fig. 13. Tegmen fractures. Coronal CT and MR images in 2 patients (*A*, *B* and *C*, *D*) show examples of fractures through the tegmen with associated complications. Coronal CT images of the right temporal bone (*A*, *B*) show an oblique fracture that involves the mastoid (*A*, *black arrow*) that extends through the tegmen with an associated fracture gap (*B*, *white arrow*). There is a fracture fragment that is perpendicular to the dura (*A*, *white arrow*) which may act as a wick, increasing the risk of subsequent CSF leak. Coronal CT and MR imaging of the left temporal bone in a different patient (*C*, *D*) shows a large defect within the left tegmen with an associated displaced fracture fragment (*C*, *D*, *solid white arrow*). There is evidence of a posttraumatic encephalocele with herniation of brain tissue and CSF through the fracture gap, which is seen best on MR (*D*, *dashed arrows*).

experience, factors that may increase the risk of persistent posttraumatic CSF leak include a widely spaced fracture defect and the presence of a bone spicule oriented perpendicular to the dura potentially acting as a wick (see **Figs. 4**D, **7**C, and **13**). Patients with persistent symptoms of CSF leak beyond 7 to 10 days may require further evaluation with MR imaging. MR imaging of the brain with dedicated high-resolution T2-weighted sequences of the temporal bone may be complementary to CT in evaluating patients specifically for the location and size of associated encephaloceles (see **Fig. 13**D). Contrast is indicated in these patients because the presence of dural enhancement may be a secondary sign of a dural tear, CSF leak, and focal meningitis.

Treatment of CSF leak

Most posttraumatic CSF leaks (78% in one series) resolve spontaneously within 7 days of injury.[4]

Therefore a conservative approach including bed rest with an elevated head, decreased straining, and lumbar drain is often warranted in these patients until day 10.[4] Surgical closure in those patients with persistent CSF leaks beyond day 10 is often performed because of the increased risk of meningitis.[4] The surgical approach for the treatment of CSF leaks depends on several factors including location of the leak, ipsilateral and contralateral hearing status, presence of associated encephalocele, and integrity of the external canal.[4] In patients whose hearing is completely compromised in the ipsilateral ear, a more aggressive approach is taken with obliteration of the middle ear and mastoid with placement of a duroplasty. Less aggressive approaches may be indicated in patients with intact hearing, including transmastoid, middle fossa, and combined approaches with placement of temporalis fascia over the defect.[4,26]

Facial Nerve Injury

The facial nerve's circuitous course through the temporal bone places it at risk for injury in multiple locations in the setting of temporal bone fracture. However, detectable injury to the facial nerve remains rare, occurring in an estimated 5% to 10% of patients with temporal bone fractures.[4,17,27] Motor vehicle accidents are implicated in 44% to 54% of cases of traumatic facial nerve palsy, followed by falls and assaults. The reported risk of facial palsy associated with temporal bone fracture has been gradually decreasing, likely because of increasing rates of seat belt use, the development of airbag technology, and increasing recognition of subtle temporal bone fractures though the use of CT.[21]

In the past, facial nerve palsy has had a greater association with transverse fractures than with the more common longitudinal temporal bone fracture.[28] Fractures that involve the otic capsule are similarly more likely to be associated with facial nerve paralysis than those that spare the otic capsule (48 vs 6%).[4] However, because otic capsule–sparing fractures are between 5 and 40 times more frequent than those involving the otic capsule, most trauma-related facial nerve palsy cases are caused by otic capsule–sparing fractures.[1,4,6]

Injury to the facial nerve can be caused by compression, contusion, stretching, perineural or intraneural hematoma, and/or nerve transection.[29] These injury patterns are typically inferred on CT because of displacement or violation of the facial canal (**Fig. 14**). High-resolution MR imaging of the temporal bone can directly show perineural hematomas, particularly those of the geniculate ganglion. MR imaging also allows demonstration of abnormal contrast enhancement in segments affected by scarring or fibrosis.[30]

The geniculate ganglion is consistently reported to be the most common site of injury of the facial nerve, implicated in 30% to 80% of cases of facial nerve paresis (see **Fig. 14**B). Other sites, including the canalicular, labyrinthine, tympanic, and mastoid segments, are less commonly involved (see **Figs. 11** and **14**).[22,28] Lambert and Brackman[28] identified synchronous lesions in the mastoid segment in 15% of patients in their series, suggesting that multiple sites of injury should be considered, particularly in patients with complex or comminuted fractures.

Treatment of facial nerve injury

Management of facial nerve palsy related to temporal bone fractures is controversial, with guidelines largely based on retrospective case series and established clinical practice.[27] Patients with delayed-onset facial palsy have an excellent prognosis, with greater than 90% eventually regaining House-Brackman (HB) grade I or II facial nerve function without surgical intervention. Patients with incomplete paresis (<90% of loss of function on electroneurography) also have a high rate of recovery, with large series reporting nearly universal recovery to HB grade I or II facial nerve function.[4,21,27]

Surgical management is typically limited to those patients with complete, immediate facial nerve paralysis and those with progressive near-complete loss of function.[31] The goals of surgery are to evaluate and decompress the facial nerve, with the addition of nerve rerouting, reanastomosis, or sural nerve grafting as indicated based on surgical findings. Injury at or proximal to the geniculate ganglion may require a middle fossa or transmastoid/supralabyrinthine approach in patients with intact hearing. For those patients with complete hearing loss, a translabyrinthine approach is possible and allows excellent exposure of the facial nerve. Exposure of the more distal tympanic and mastoid segments is typically achieved through a transmastoid approach.[4,23,31]

In surgical candidates with immediate, complete facial nerve paralysis there is a high rate of return of facial nerve function following decompression, with good (HB I or II) recovery in 38% to 55% of patients. In a recent meta-analysis of 612 patients with facial nerve paresis, only 6% of patients who were surgically decompressed showed persistent complete (HB VI) facial palsy.[27] Poor prognostic indicators for incomplete regrowth of the facial nerve include bone spicules that occlude the facial canal and widely displaced canal margins.

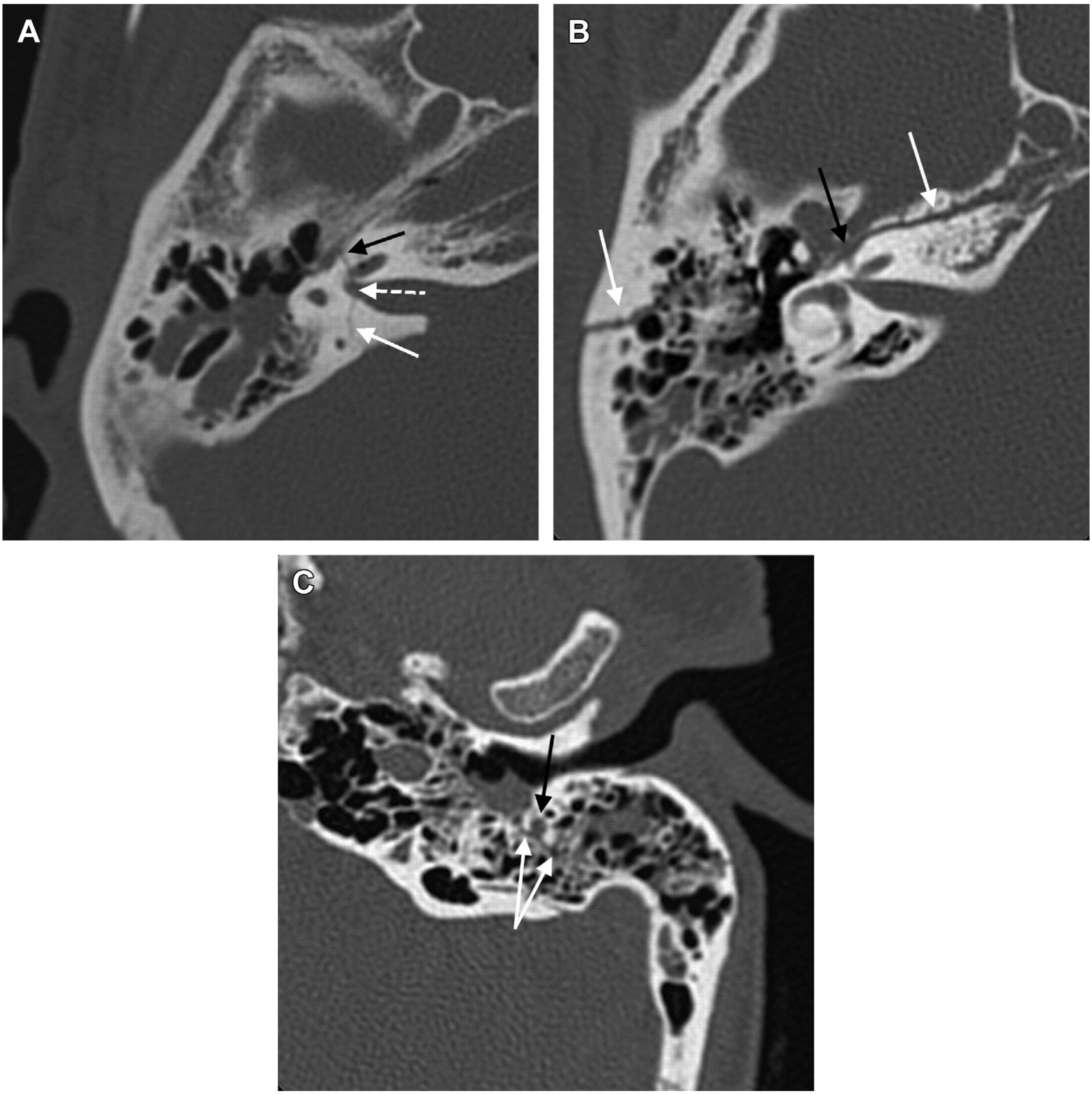

Fig. 14. Injury of the facial nerve canal. Axial CT images of 3 patients show fractures that violate the facial nerve canal (*A–C*). (*A*) A transverse intralabyrinthine fracture (*A*, *solid white arrow*) that extends through the fundus of the internal auditory canal (*A*, *dashed white arrow*) and subsequently propagates through the tympanic segment of the facial nerve canal (*A*, *black arrow*). (*B*) An otic capsule–sparing longitudinal fracture (*B*, *white arrows*) that extends through the mastoid, middle ear cavity, geniculate fossa of the facial nerve (*B*, *black arrow*), and through the petrous apex. (*C*) A nondisplaced longitudinal fracture of the left mastoid (*C*, *white arrows*) that extends through the medial aspect of the mastoid segment of the facial nerve canal (*C*, *black arrow*).

Timing of surgical decompression, when indicated, is also controversial. Some clinicians advocate decompression within 72 hours, which can be difficult to achieve in patients with multiple injuries, or those who initially present to centers that lack the surgical expertise to perform immediate decompression. There is evidence that surgical decompression within 2 weeks has the best probability (>90%) of a good outcome, with gradual diminution in prognosis for decompression performed up to and past 3 months.[22] However, even delayed decompression at 2 to 3 months may result in a good outcome in more than 50% of patients. Delayed decompression can be helpful in those whose injuries masked initial signs of facial paralysis, or those with a delayed presentation to a center with experience in facial nerve decompression.[21,22,29]

Vascular Injury

The carotid artery and venous vascular structures that traverse the temporal bone are at risk for injury in the setting of temporal bone trauma. The carotid artery enters the skull base through the carotid

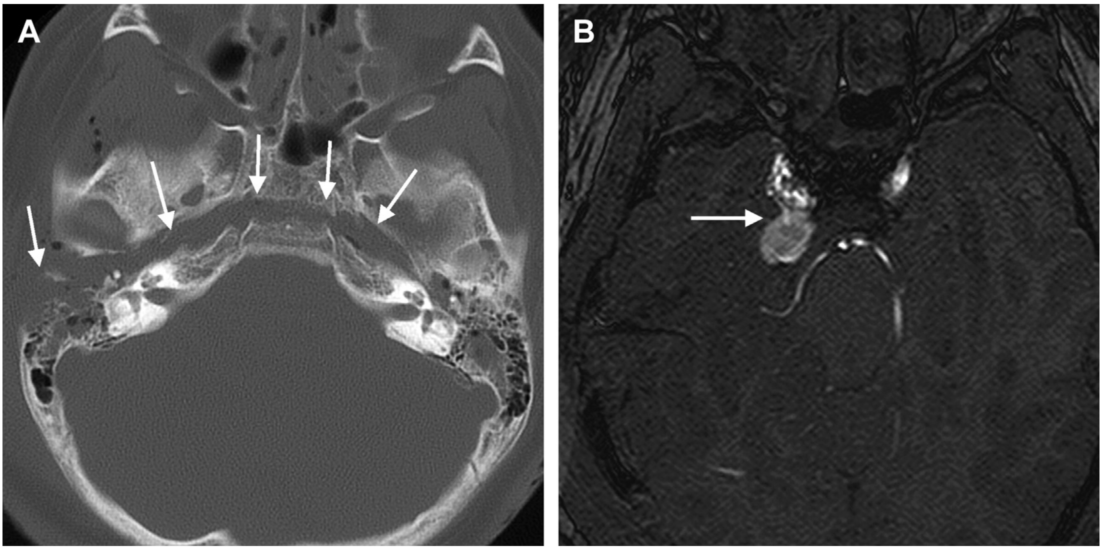

Fig. 15. Carotid canal injury. Axial head CT (*A*) of a patient involved in a skiing accident shows an extensive displaced fracture of the petrous portion of the right temporal bone and central skull base with widely separated fracture margins (*A*, *white arrows*). The fracture courses through the bilateral petrous carotid canals. 3D time-of-flight MR angiography of the circle of Willis (*B*) shows arterialized flow within the right cavernous sinus with a large associated outpouching that indicates a traumatic cavernous carotid fistula with pseudoaneurysm formation (*B*, *white arrow*).

canal and passes through the petrous portion of the temporal bone before it ascends within the cavernous sinus. In one series, carotid canal involvement was seen in 24% of patients with skull base fractures.[32] Resnick and colleagues[32] noted that 11% of patients with skull base fractures that involved the carotid canal showed evidence of vascular injury. Therefore fractures that extend through the carotid canal should be further evaluated with either CT angiography or MR angiography to assess for associated vascular complications including dissection, transection, pseudoaneurysm formation, occlusion, and arteriovenous fistula (**Fig. 15**).

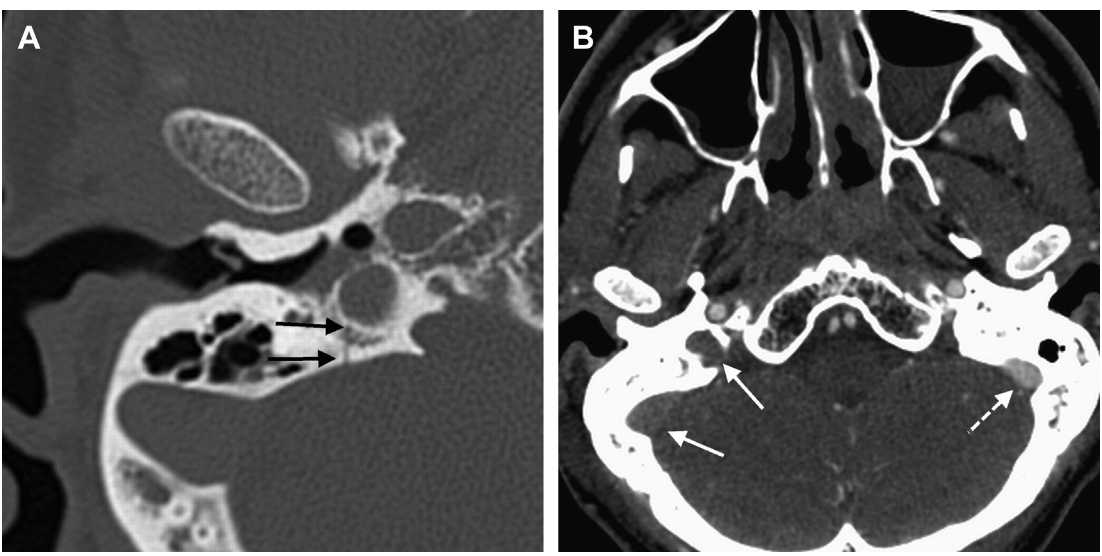

Fig. 16. Venous sinus injury. An axial CT image of the right temporal bone shows a nondisplaced fracture that extends into the jugular foramen (*A*, *arrows*). A postcontrast CT venogram shows nonopacification of the right sigmoid sinus and jugular bulb (*B*, *solid arrows*) indicating thrombus related to traumatic venous sinus injury. Note the normal contrast-enhanced appearance of the left sigmoid sinus (*B*, *dashed arrow*).

The distal transverse and sigmoid sinuses travel through the posterior fossa within a groove along the medial margin of the mastoid portion of the temporal bone before exiting the skull base at the jugular foramen. These venous structures may also be injured when a fracture violates the sinodural plate or extends into the jugular foramen. It is important to review the soft tissue algorithm images of the posterior fossa as part of the temporal bone CT examination to assess for associated hyperdense venous sinus thrombosis, venous epidural hematoma, as well as associated cerebellar hemorrhage. Further evaluation with either CT venography or MR venography should be performed in those patients with fractures that involve the venous sinuses to assess the integrity of the venous system more comprehensively (**Fig. 16**).

SUMMARY

Temporal bone trauma is commonly seen in patients with craniofacial injury and can be detected using multidetector CT. A thorough understanding of the different types of temporal bone fracture patterns is needed to accurately describe the trajectory of injury as well as anticipated complications. Fractures should be described based on direction, segment of temporal bone involved, as well as involvement of the otic capsule. More importantly, the radiologist plays an integral role in identifying complications of temporal bone injury, which often have significant clinical implications.

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