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Review

Dilemmas in Diagnosis and Management of Temporal Bone Fractures and Their Sequelae

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Abstract: Objective(s): The objective of this study was to report our experience with a series of patients with temporal bone fractures from 2019 to 2023 and to evaluate the dilemmas in diagnosing the extent of their ontological injuries through a narrative review of the literature focusing on the classifications of temporal bone fractures. **Methods:** Data were collected retrospectively from the electronic medical records of patients who presented to the emergency department and were diagnosed with temporal bone fractures using computed tomograms of the head and temporal bone between September 2019 and March 2023. A total of 117 patients were included in the study. Demographic data, fracture classification, mechanism of injury, and presence and/or repair of cerebrospinal fluid (CSF) leak, facial nerve injury (both immediate and delayed), and hearing loss (both immediate and delayed) were also recorded. **Results:** In total, 49.5% of our cohort were between the ages of 19 and 39, and the majority (66%) were males. The primary cause of the trauma was falls in 41% of patients, followed by motor vehicle accidents (29%), and 70% had a Glasgow Coma Score (GCS) between 13 and 15 at presentation. In total, 92.3% of temporal bone fractures did not involve the otic capsule, and 79.3% were longitudinal fractures. In total, 89% of the CSF leaks were seen in patients with longitudinal fractures. Similarly, 70% of facial nerve deficits were seen in patients with longitudinal and otic capsule-sparing fractures. Conclusion: Diagnosis of facial asymmetry and hearing loss in patients with TBFs can be challenging in acute care settings but was less challenging in our cohort due to patients presenting with good GCSs. Dilemmas in clinical evaluation in the acute care setting are due to poor GCSs, heterogeneity of documentation of injuries, and classification of TBFs. Implementation of universal protocols with homogeneity in the documentation and classification of temporal bone fractures may help improve patient care and prediction of outcomes.

Keywords: temporal bone fracture classification; temporal bone fractures; sequelae of temporal bone fractures

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1. Background

The temporal bone forms part of the base and side of the skull. It comprises five parts: the petrous, tympanic, mastoid, squamous, and styloid processes. Together, these five components protect the facial, vestibulocochlear, and lower four cranial nerves and major blood vessels. Temporal bone fractures require significant force and can be associated with neurovascular and otic capsule disruption with hearing loss. Diagnosing temporal bone fractures can present challenges due to the complex anatomy of the temporal bone with its anatomic fissures that may mimic a temporal bone fracture [1]. Travis et al., 1977, studied the impact of automobile impacts on cadaver temporal bones [2]. They noted that lateral impact produced longitudinal fracture with communication to the posterior fossa associated with disruption of the cochlea, middle ear structures, and facial nerve. Anterior–posterior trauma, on the other hand, can be associated with transverse fractures with

injury to the neurovascular structures traversing the various foramina within the temporal bone. Patients with a temporal bone fracture can, therefore, present with multiple injuries, hemorrhage, abnormal sensorium, and Glasgow Coma Scale (GCS) scores. Management is directed toward resuscitation of the unconscious patient, airway, and blood transfusion. Evaluation of facial asymmetry or hearing loss in this situation can be challenging and may have to be delayed until the patient is awake and able to respond. Radiological imaging with computed tomography (CT) is the main modality to identify temporal bone fractures in these trauma patients. It helps to classify temporal bone fractures. There are two dominant classification systems for temporal bone fractures (TBFs): traditional and functional. Traditionally, temporal bone fractures were classified as longitudinal or transverse based on the direction of the force causing the injury in relation to the long axis of the petrous ridge [3]. A study by Ghorayeb et al., 1992, reported that true longitudinal fractures were rare, and the majority were oblique [4]. This did not correlate with the clinical findings and predictability. In 1994, a new functional classification based on whether the otic capsule was injured or preserved was proposed by Kelly and Tami [5]. This classification demonstrated clinically significant predictability for serious outcomes of TBFs [6]. Otic capsule involving (OCV) fracture is associated with serious complications like facial nerve injury (2–5 times as likely), cerebrospinal fluid leak (4–8 times as likely), and sensorineural hearing loss (7–25 times as likely) [6,7]. Otic capsule sparing (OCS) fractures largely involve the squamous portion of the temporal bone and external auditory canal (EAC) and travel from the mastoid air cells to the tegmen tympani of the middle ear. These fractures, while associated with lower rates of facial nerve injury (FNI), are associated with increased rates of mixed or conductive hearing loss (CHL) and, in rare cases, disruption of the ossicular chain [8,9]. Additionally, it was found that the otic capsule was more likely to be violated in transverse fractures [6]. A study by Ilea et al. reported that cadaveric temporal bones that underwent a mastoidectomy before temporal bone trauma were more likely to have otic capsule involving (OCV) fractures, secondary to the loss of mastoid cells absorbing impact kinetic energy [10]. The protective factor of mastoid pneumatization remains controversial, and increased pneumatization has been reported to be associated with less severe sensorineural hearing loss (SNHL) [10–12].

2. Introduction

The complex temporal bone anatomy paired with the important structures housed within it requires thorough clinical and radiological assessment, follow-up, and—when appropriate—intervention of TBFs. As mentioned earlier, dedicated CT imaging of the temporal bone is the mainstay of diagnosis. Dilemmas in diagnosis can range from the evaluation of neurovascular injury in patients with abnormal GCS to the status of the patient upon arrival and resource availability. Another challenge in the initial radiological diagnosis of TBFs is due to the complex temporal bone anatomy. With a total of five distinct structures (squamous, petrous, tympanic, mastoid, and styloid) and four intrinsic fissures that surround the bony portion of the EAC, systematic evaluation of each structure must be performed by neuroradiologists to identify all aspects of a TBF and any critical structures harmed as a result [8]. This study describes our experience with a series of patients with temporal bone fractures managed at a level I trauma center from 2019 to 2023 with a narrative review of the literature focusing on the classifications for temporal bone fractures.

3. Materials and Methods

After approval of our institutional IRB, data were collected from the electronic medical records of patients presenting to the emergency department of LSU Health Shreveport, USA, diagnosed with TBFs using computed tomograms of temporal bone between September 2019 and March 2023. Data at the follow-up appointment at a minimum of one month post-trauma were also recorded. They were then followed to the next appointment with either their primary care, otolaryngology, neurology, neurosurgery, or oral–maxillofacial clinic appointment for assessment of potential development of the delayed-onset facial

nerve palsy and other sequelae. Inclusion criteria: Availability of complete documentation at the time of trauma and subsequent follow-up, as well as CT imaging of the temporal bone. Exclusion criteria: Incomplete documentation and absence of a dedicated CT image of the temporal bone. A total of 117 patients who met the inclusion criteria were included in the study. Demographic data, fracture classification, mechanism of injury, and presence and/or repair of CSF leak, facial nerve injury (both immediate and delayed), and hearing loss (both immediate and delayed) were also recorded in Microsoft Office Excel.

Statistical Analysis: A statistical analysis was performed using Microsoft Office Excel, with direct calculation of patient and fracture-specific factors in comparison to the patient pool.

4. Results

In our cohort, 66.6% of the patients were male, and 43.5% were between the ages of 19 and 39. Other demographic data are reflected in Table 1.

Table 1. Demographics (age and sex) of patients with temporal bone fractures from a level 1 trauma center.

Age (Mean = 38.05 years)	Number of Total Patients (n = 117)	Percentage (%)
<18	18	15.4
19–39	51	43.5
40–60	26	22.2
>60	22	18.8
Sex	**Number of Total Patients (n = 117)**	**Percentage (%)**
Male	78	66.6
Female	39	33.3

The majority of the patients (41%) in our cohort developed TBFs after a fall, followed by 29% after a motor vehicle accident (MVC), 7% after ATV accidents, and 6% after ballistic injuries. The categories of trauma and their distribution amongst our patient population are reflected in Figure 1.

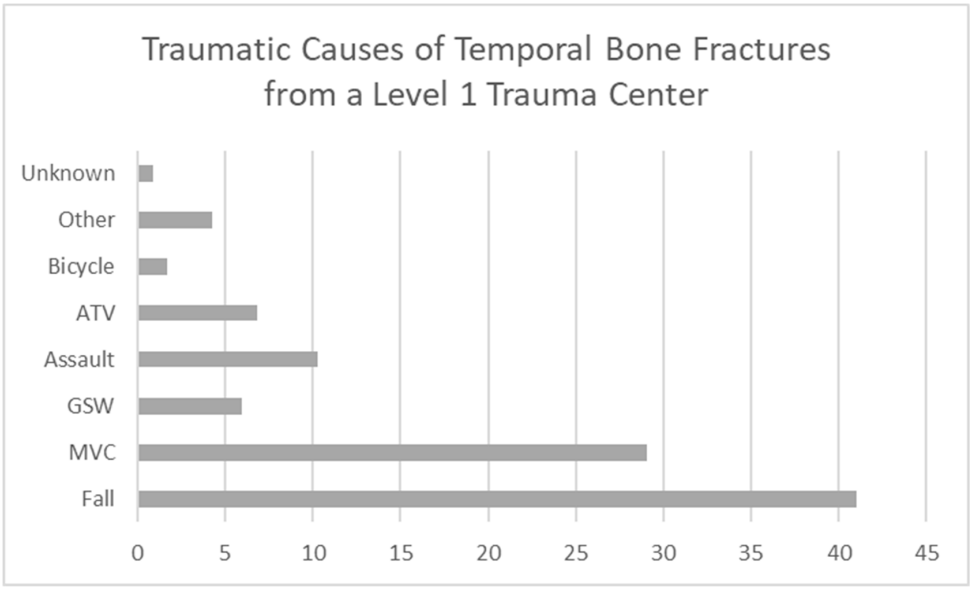


Figure 1. Traumatic causes of temporal bone fractures from a level 1 trauma center.

Right-sided TBFs were seen in 36% of patients, and bilateral fractures were found in 18%.

GCS was divided into three categories based on a common classification for acute traumatic brain injury: 3–8 (severe injury), 9–12 (moderate injury), and 13–15 (severe injury). A total of 16.4% of patients had a GCS < 8; 12.9% had a GCS between 9 and 12, and 70% had a score between 13 and 15.

A total of 9% of patients had early FNP (defined as FNP documented on initial clinical assessment), and 28% were identified as having early hearing loss (documented in the initial bedside clinical assessment). Facial nerve deficits occurred following TBFs after MVCs in 50% of patients (10 out of 20) and GSWs in 40% (8/20) of patients. Cerebrospinal fluid (CSF) leak was seen in 7% (n = 9) of patients with TBFs and occurred equally after MVCs, GSWs, and falls. The average GCS in patients with facial palsy and CSF leak was 12.

Only 5% (n = 6) of our patient population required subsequent or interval surgical intervention for either hearing loss or facial nerve injury. In total, 67% (n = 4) underwent surgical interventions for tympanoplasty with ossicular replacement, and 33% (n = 2) had surgical intervention for facial nerve decompression for facial palsy. The complication incidence in our patient population is reflected in Table 2.

Table 2. Sequelae of temporal bone fractures in a patient population from a level 1 trauma center. Legend: Facial nerve palsy (FNP); cerebrospinal fluid (CSF).

Sequelae	N	Percentage (%) of Total Patients (n = 117)
Early FNP	11	9.4
Delayed FNP	9	7.6
Early Hearing Loss	33	28.2
Delayed Hearing Loss	32	27.3
CSF Leak	9	7.7
CSF Surgical Correction	2	1.7

For this study, we used both the traditional and the functional classifications for TBFs. In total, 92.3% of temporal bone fractures did not involve the otic capsule, and 7.69% were OCV. According to traditional classification, 79.3% were longitudinal, and 20.6% were transverse fractures. The majority of the CSF leaks (8 out of 9) were seen in patients with longitudinal fractures. Similarly, the majority of facial nerve deficits (14 out of 20) were seen in patients with longitudinal and otic capsule-sparing fractures.

4.1. Discussion

The type of trauma, as well as the degree of severity, significantly impacts the initial management and clinical assessment of patients with TBFs upon arrival at the nearest emergency department. Evaluation and documentation of injuries in the acute care setting are important for subsequent management and studies. We present the observations in our cohort of 117 patients with TBFs compared to the published literature and the review literature focusing on the classifications of temporal bone fractures. We also present a proposed schema (Figure 2) comprising characteristics of multiple classifications with the aim to formulate a comprehensive predictor of sequelae.

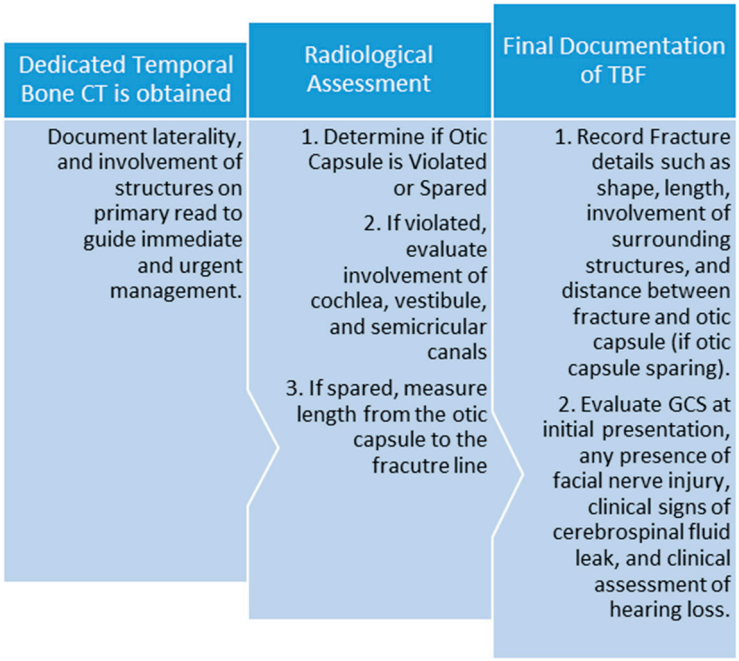


Figure 2. Authors' proposed schema for documentation of temporal bone fractures from first clinical assessment to radiologic imaging. [GCS: Glasgow Coma Scale].

4.2. Age Group

The majority of our patients (66.6%) were male and between the ages of 19 and 39 (44%), with 15% under the age of 18 years. Males are three times more likely than females to suffer temporal bone fractures, possibly due to their propensity towards high-risk behavior [9].

4.3. Etiology

A significant force between 1300 and 1875 pounds or 6000–8000 newtons is required to cause TBFs [2,5,8]. In total, 55% of TBFs are reported to be caused by motor vehicle accidents (MVAs) in adults, followed by mechanical falls (25%), industrial accidents (15%), and assault (4%) [8]. On the other hand, mechanical falls (60%) account for the commonest cause of pediatric TBFs, followed by MV accidents (30%) [8]. In our adult patient population, 41% had TBFs after falls, 29% of patients had TBFs due to MVAs, 7% had TBFs due to all-terrain vehicles (ATVs), and 6% had TBFs due to ballistic trauma. For our study, ATV-associated trauma was evaluated separately from MVCs. ATVs are more commonly used in semi-rural and rural areas. Likely, the location of our level 1 trauma center near a rural region contributed to the higher incidence of ATV-related TBFs. The pattern of injuries in TBFs after ballistic trauma presents a different set of clinical challenges, as the brunt of injuries is seen in the external auditory canal, mastoid tip, and periauricular soft tissues with a higher incidence of extratemporal facial nerve injury [13]. Brodie et al. found that GSWs (gunshot wounds) were the cause of TBFs in 3% of cases, and although that is not as prevalent as other mechanisms, such as MVAs, the severity of damage to the temporal bone must be considered [14]. Depending on the velocity of the firearm utilized, the projectile can take either a more direct or convoluted course through the temporal bone. While all the structures are at risk, the minimal skin damage can make GSW-inflicted TBFs difficult to approach. It was found that the common patterns seen in TBFs determined by both the traditional and functional classification systems were not obeyed in the setting of ballistic trauma, which can make further prognostic predictions difficult [14].

4.4. GCS and Associated Injuries

Another challenge in the assessment of TBFs is the clinical picture of the patient immediately after the trauma. Patients may have multi-organ trauma with unconsciousness at presentation, which takes precedence in management. Facial nerve injury and hearing loss can often be evaluated only after the patient recovers neurologically and is responsive. If patients have a moderate to severe TBI as evidenced by their GCS or have received sedation secondary to other injuries received, then an accurate assessment of their hearing capabilities cannot be determined. It may be possible to evaluate facial nerve injury by assessing a patient's ability to grimace. However, this would not be possible if any people with paralysis were administered. While this does present difficulty in the initial assessment of TBF complications, one study by Dedhia et al. found that GCS had prognostic capabilities. They found that patients with a GCS greater than 13, which is the definition of a mild traumatic brain injury (TBI), had statistically significantly fewer complications such as facial nerve injury and CSF leaks (5% vs. 23%; $p = 0.03$) compared to patients with a GCS < 13, constituting moderate to severe traumatic brain injuries, [15]. However, this was not observed in our patient population, as an average GCS of 12 was noted in patients with facial nerve injury and CSF leaks.

As mentioned, the importance of timely diagnosis influences clinical management. The approaches to treating, for example, facial nerve injury have well-reported timelines of when interventions are most likely to result in the most desired outcome for the patient. Facial nerve functionality at our institution is typically documented as a part of a pre-set template in the electronic medical record for incoming traumas as a part of the secondary survey of cranial nerves. The established literature states that the risk of developing facial nerve injury for patients with traumatic TBF is 6–7%, with approximately 27% having an immediate presentation [9,14]. At our level 1 trauma center, facial nerve injury was identified in 17% of patients (9.4% identified upon initial clinical assessment and 7.6% having a delayed onset). Conservative management can be associated with facial nerve recovery in approximately 63% of cases, but those who have more severe injuries to the course of the facial nerve must be evaluated for surgical candidacy [9]. If a complete transection of the facial nerve occurs, then the clinician and patient must discuss the approach to facial reanimation [16].

4.5. Hearing Loss

One of the most common complications resulting from TBFs is hearing loss. Whether conductive or sensorineural, it could leave a significant impact on a patient's quality of life. Bedside evaluation with a tuning fork and a whispered voice (masked) should be assessed to identify conductive versus sensorineural hearing loss early on. Pure tone audiometry can be performed if surgical intervention is planned or at the first follow-up visit to determine the persistence of the hearing loss. Deshmukh et al. investigated hearing loss outcomes associated with TBFs. This study found that the incidence of hearing loss following a temporal bone fracture was 80% (n = 40), and hemotympanum was found in 40% (n = 20) of patients [16]. While this was significantly more than the total of 55.5% of hearing loss present in our patient population, the range evident between both sets of data reflects a need for prudent follow-up and accurate documentation of hearing assessments both at the bedside and in the clinic.

4.6. CSF Leaks

The incidence of CSF leaks varies in the literature but typically ranges from 11% to 45% and resolves within two weeks without surgical intervention [8,9,14]. Our patient pool is reflective of these data, with CSF leaks present in 6% of patients and only two patients requiring surgical correction. Patients can present with either clear, watery otorrhea, or if the tympanic membrane is intact, then the CSF may drain through the eustachian tube and present as CSF otorhinorrhea [14]. Longitudinal fractures can be associated with CSF leaks through the middle cranial fossa, while transverse fracture leaks are typically through the

posterior cranial fossa. OCV fractures have a significantly higher incidence of CSF leaks [15]. Traditional classification had poor predictive capabilities when associated with CSF leaks. CSF leaks have been reported to be more common in transverse fractures (1.1 times more than in longitudinal) and 9.8 times more common in fractures that occurred through the petrous temporal bone; however, these traditional classifications are not utilized as frequently due to their overall poor prognostic capabilities [6]. The thin fibrous scar tissue that forms following a TBF increases the patient's susceptibility to the development of meningitis for an extended period [9]. Meningitis can develop in approximately 27.5% of patients with traumatic CSF [16].

4.7. Classification

TBF classifications have evolved over several decades. There are two main classifications in use for the classification of temporal bone fractures: the traditional and the functional. However, limited consensus guidelines are currently available [17]. CT images of the temporal bone have consistently been used to identify and classify the type of TBF. However, Schubl et al. reported that trauma imaging only captured 98.6% of TBFs [18]. Chen et al. investigated the reliability of temporal bone CT images and found that the assessment of injury to the facial nerve was reliable in most cases except for the assessment of damage at the posterior genu and mastoid segment [19]. Several studies have reported that the traditional classification system has poor prognostic predictive capabilities involving facial nerve symptoms [6,14,20,21]. Both the traditional and functional classification systems could not accurately predict facial nerve injury in the pediatric population [6]. Table A1 depicts the shortcomings of current temporal bone fracture classification mechanisms in the established literature.

In total, 20% of TBFs are otic capsules involving (OCV) and are most likely to be associated with facial nerve injury, CSF leak, and sensorineural hearing loss [6]. CSF leaks have been reported to be more common in transverse fractures (1.1 times more than in longitudinal) and 9.8 times more common in fractures that occur through the petrous temporal bone; however, this traditional classification is not utilized as frequently now due to its poor prognostic capabilities [20].

Several studies have stated that both classifications are not good at predicting conductive hearing loss [22,23]. Although conductive hearing loss is noted in all types of fractures, it is more common in OCS fractures and associated with hemotympanum in the initial stages and ossicular dislocation [9]. Sensorineural hearing loss is 25 times more common in OCV fractures but can occur in all types of TBFs [6]. Mun et al. utilized CT scans of temporal bones to measure the length between the otic capsule and fracture line and reported that patients with short lengths had a higher likelihood of sensorineural hearing loss (SNHL) [24]. This same finding was also seen in another study by Rafferty et al., which compared the classification systems ($p = 0.013$) [25]. In this study, the shorter length between the otic capsule and the fracture line was significantly associated with a higher likelihood of SNHL [25]. Uchiyama et al. found in their patient samples a significant loss of spiral ganglion cells ($p = 0.023$) and cochlear hemorrhage, predominantly in the basal turns, showing the pathologic changes inflicted by TBFs [26]. Park et al. recommend a more detailed approach to the classification centered around otic capsule involvement [27]. They further classified OCV fractures as OCV-C(VS) (when the cochlea was involved and regardless of vestibule or semicircular canal (SCC) involvement), OCV-V(S) (when vestibule was involved, and regardless of SCC involvement), and OCV-S (when the fracture line involved the SCC) [27]. In one study, OCV was found to have an incidence of pneumolabyrinth in 48.4% of fractures, and subsequently, 83.3% of these patients did not experience any improvement in their hearing [28]. In TBF patients with sensorineural hearing loss, cochlear implantation may be an option if their hearing worsens over time.

Cochlear implantation in this group of patients can be challenging. It is important to confirm the anatomical and functional integrity of the cochlear nerve, which may be avulsed or injured by traction. Mastoid and middle ear anatomy may be distorted by

fracture lines, fibrosis, and ossification [22]. Surgery can often be challenging, and full insertion of the electrode array may not be feasible [29]. A higher incidence of non-auditory stimulation, especially facial nerve stimulation, has been reported, possibly due to lower electrical impedance along the fracture lines [30]. Co-morbidities associated with head and temporal bone trauma, such as cognitive and physical impairment, can influence hearing rehabilitation [31]. In appropriately selected patients with TBFs, cochlear implantation has been reported to be an effective option for auditory rehabilitation [22]. Future prospects of this study include using the proposed schema utilizing multiple factors of existing temporal bone classification systems and determining its utility in the prediction of sequelae. The protocol would initially be limited to a single institution to determine its utility.

Limitations of our study include the retrospective nature of the study, which has inherent drawbacks due to its retrospective design. Additionally, our study is a narrative review of temporal bone fracture classifications, with the intent to formulate a schema for the prediction and assessment of sequelae seen in patients with temporal bone fractures. Statistical analysis was limited to a patient pool at a single institution, with the primary objective of ensuring comparability to reported statistics.

5. Conclusions

Management of patients with TBFs can present dilemmas beginning with clinical evaluation of facial nerve function, hearing loss, and vestibular function in patients with poor GCS in the acute care setting. The heterogeneity of documentation of injuries and classification of TBFs add to the challenges in caring for this group of patients (such as physical exams and radiologic documentation). Consensus guidelines with homogeneity in the documentation and classification of temporal bone fractures to optimally stratify risks and plan management regarding these patients are required.

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Institutional Review Board Statement: This study was conducted by the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of LSU Health Shreveport (protocol code 2398 and 15 May 2023) for studies involving humans.

Informed Consent Statement: This is a retrospective narrative review, therefore patient consent could not be obtained.

Data Availability Statement: The data presented in this study are not readily available for privacy issues and ongoing study.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Shortcomings of current temporal bone fracture classification mechanisms in the established literature.

Study	Population	Classification System	Description	Complications Addressed	Prognostic Predictions	Shortcomings
Little et al., Ishman et al., Cvorovic et al. [6,32,33]	Adult	Traditional	Description of fracture lines (longitudinal; transverse; oblique; mixed)	CSF leak FNI CHL SNHL	FNI reported in 25% of longitudinal fractures and 40–50% of transverse fractures	Reported facial nerve injuries are not consistent with the reported incidence of longitudinal and oblique fractures
Little et al. [6]	Adult	Functional	Description of fractures according to their involvement of the otic capsule	CSF leak FNI CHL SNHL	CSF leak OCV is eight times more likely to leak CSF than OCS ($p < 0.005$) FNI Predictive ability $p < 0.001$ OCV fractures are five times more likely to develop FNI than OCS (67% vs. 12%) SNHL OCV fractures are 25 times more likely to develop SNHL than OCS (100% vs. 4%; $p < 0.001$)	Prediction for CHL had no statistical difference between the functional or traditional classification systems ($p = 0.64$)
Park et al. [27]	Adult	Detailed Classification for OCV fractures	OCV fractures further classified according to cochlea or vestibule/SCC involvement OCV-C(VS) cochlea involved, regardless of vestibule/SCC involvement OCV-V(S) vestibule involved, regardless of SCC involvement OCV-S when only SCC was involved	CHL SNHL	OCV-C(VS) and OCV-V(S) had significantly higher BC and AC thresholds than OCV-S	Does not address CSF leakage, FNI complications in its schema

Table A1. *Cont.*

Study	Population	Classification System	Description	Complications Addressed	Prognostic Predictions	Shortcomings
Bhindi et al. [34]	Pediatric	Traditional and functional	Fracture line and involvement of otic capsule	CHL SNHL	CHL Similar rates were found among longitudinal, transverse, and mixed fractures (36–50%) and OCV and OCS fractures (42–44%) SNHL A total of 22% OCV fractures (2/9) had SNHL; a total of 0/33 patients with OCS fractures had SNHL (95% CI 0.01–0.60)	Failed to accurately predict CHL in the pediatric population
Dedhia et al. [15]	Pediatric	Traditional and functional; Glasgow Coma Scale score	Fracture line and involvement of otic capsule; GCS	CSF Leak FNI	A GCS > 13 had significantly fewer FNI and CSF leak events compared to patients with a GCS < 13	This study only addressed CSF leaks and FNI in relation to the GCS of pediatric patients
Sun et al. [35]	Adult	Traditional and functional	Fracture line and otic capsule involvement	Concomitant ICI	No statistically significant associations between the mechanism of injury, GCS at presentation, and concomitant ICI	Both classification systems are unable to predict the presence of concomitant ICI
Mun et al. [24]	Adult	OCS fracture length	Shortest length between the fracture line and the otic capsule	SNHL	OCS length was significantly associated with SNHL	This study only addressed the development of SNHL

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