Cost Effective use of Audiograms after Pediatric Temporal Bone Fractures

Julia L. Frisenda, MD[1], James W. Schroeder, Jr., MD[2], Maura E. Ryan, MD[3], Taher S. Valika, MD[1], Kathleen R. Billings, MD[2]

[1]University of Illinois at Chicago, Department of Otolaryngology – Head and Neck Surgery, 1855 West Taylor Street, Chicago, IL 60612

[2]Ann & Robert H. Lurie Children's Hospital of Chicago, Division of Pediatric Otolaryngology – Head and Neck Surgery, Chicago, IL and the Northwestern University Feinberg School of Medicine, 225 East Chicago Ave, Chicago, IL 60611

[3]Ann & Robert H. Lurie Children's Hospital of Chicago, Department of Medical Imaging, Chicago, IL, and the Northwestern Feinberg School of Medicine, 225 East Chicago Ave, Chicago, IL 60611

Correspondence: Kathleen R. Billings, MD
Division of Otolaryngology-Head and Neck Surgery
Ann & Robert H. Lurie Children's Hospital of Chicago
225 East Chicago Ave, Box #25
Chicago, IL 60611
kbillings@luriechildrens.org
Phone: 312-227-6230
Fax: 312-227-9414

Word Count: 2997

Presented at the annual spring meeting of the American Society of Pediatric Otolaryngology Poster Session, Boston, MA; April 23-25, 2015.

Key Words: temporal bone fractures, pediatric temporal bone fractures, skull base fractures, pediatric head trauma, trauma related hearing loss, cost effectiveness

Abstract

Objective: To identify the relationship of pediatric temporal fractures to the incidence and type of hearing loss present. To analyze the timing and utility of audiometric testing in children with temporal bone fractures.

Methods: Retrospective case series of 50 pediatric patients with temporal bone fractures who were treated at an urban, tertiary care children's hospital from 2008-2014. A statistical analysis of predictors of hearing loss after temporal bone fracture was performed.

Results: Fifty-three fractures (69.7%) in 50 patients involved the petrous portion of the temporal bone. The mean age of patients was 7.13 years, and 39 (73.6%) were male. A fall was the most common mechanism of injury in 28 (52.8%) patients, followed by crush injury (n=14, 26.2%), and vehicular trauma (n=10, 18.9%). All otic capsule violating fractures were associated with a sensorineural hearing loss (n=4, 7.5%, p=0.002). Three of 4 otic capsule sparing fractures were associated with ossicular dislocation, with a corresponding mixed or conductive hearing loss on follow up audiometric testing. The majority of otic capsule sparing fracture patients (n=19/43, 44.2%) who had follow up audiograms had normal hearing, and those with otic capsule violating fractures were statistically more likely to have persistent hearing loss than those with otic capsule sparing fractures (p=0.01).

Conclusions: Patients with otic capsule violating fractures or those with ossicular disruption are at higher risk for persistent hearing loss. Cost-saving may be accrued by selecting only those patients at high risk for persistent hearing loss for audiometric testing after temporal bone fractures.

Introduction

Trauma is the leading cause of morbidity and mortality in children in the United States. Injuries to the temporal bone occur in 30-75% of cases of blunt head trauma.[1] Temporal bone fractures can lead to injury to the facial nerve, internal carotid artery, jugular vein, and can cause cerebrospinal fluid leakage, sensorineural hearing loss (SNHL), mixed hearing loss, and conductive hearing loss (CHL).[2,3] Temporal bone fractures have been traditionally classified as longitudinal, transverse or mixed with respect to the axis of the petrous pyramid as described by Ulrich et al.[4] On average, 75% of temporal bone fractures are longitudinal, 15% are transverse, and 10% are mixed.[5] A study by Dunklebarger et al. analyzed the current trends in management of pediatric temporal bone fractures, and compared radiographic classification schemes for these fractures.[3] Classification of temporal bone fractures as otic capsule violating (OCV) versus otic capsule sparing (OCS) was compared to the traditional method based on the axis to the petrous bone.[3] The study demonstrated that the OCS/OCV classification scheme was more predictive of SNHL than the Ulrich system. The presence of CHL or facial nerve injury was not predictable by either classification scheme.

Hearing loss after temporal bone fracture has been reported in a wide range of affected children (37-81%). Lee et al. demonstrated an 85% incidence of hearing loss in their series of 72 children.[1] Forty (56%) of the patients they studied demonstrated a CHL at the time of their injury. However, 10 of the 14 (72%) with CHL demonstrated normal hearing on an audiogram performed 3 weeks after the injury. The presence of blood or fluid in the middle ear space is a common cause of the conductive hearing loss in the acute setting in cases of temporal bone fractures, but this problem is generally self-limited. Transverse or OCV fractures have an association with SNHL. There is a marked variation in recovery with this type of injury, potentially taking months to recover or not at all. When diagnosing the type of fracture present, current guidelines suggest obtaining a dedicated computed tomography (CT) scan of the temporal bone in patients with a suspected fracture based on head CT imaging or clinical suspicion of temporal bone injury.[6] Protocols requiring low-dose radiation exposure for CT imaging of the temporal bone are suggested.[7]

The goal of the current study is to further explore the relationship of pediatric temporal bone fractures to hearing loss, and to determine if audiometric data provides meaningful information that would change the course of treatment or prognosis. The mechanism and severity of the injury and its relationship to SNHL or CHL is explored. The study will address whether the routine use of audiometric testing in all or just select children with temporal bone fractures is justified, and comment on the cost effectiveness of audiometric studies for this diagnosis.

Methods

Study Population

Approval for this study was obtained from the Institutional Review Board at Ann & Robert H. Lurie Children's Hospital of Chicago. This is a case series of children under 18 years of age diagnosed with temporal fractures between the years of January 1, 2008-December 31, 2014. Children diagnosed with traumatic skull fractures over this time period were included. An electronic medical record search of patients with the *Internal Classification of Disease, Ninth Revision, Clinical Modification (ICD9-CM)* diagnosis codes 801.00, 801.01, 801.21, 801.40, 801.41, 801.50, 801.60, 801.70, 804.00, 804.01, 804.30, and 804.50 was completed. A total of 399 patients with skull fractures were identified. Of these, 73 (18.3%) patients were diagnosed with fractures involving the petrous and squamous portions of the temporal bone. Twenty-three patients (30.3%) had fractures isolated to the squamous portion of the temporal bone, and these and those who sustained skull fractures that did not involve the temporal bone were excluded from analysis (n=297, 74.4%). Those patients greater than eighteen years of age, those without diagnostic imaging, and those not evaluated in the acute setting were excluded from analysis (n=29, 7.3%).

Predictor Variables

Data examined for association with fracture type were age at injury, gender, mechanism of injury, physical exam findings, and audiologic data. Mechanism of injury was divided into falls, blunt/crush trauma, vehicle (bicycle, motor vehicle accident, or pedestrian versus automobile), and penetrating injury (gun-shot wounds). Physical exam findings as determined by the emergency room physician and/or the Otolaryngologist including otoscopy results, tuning fork testing, facial nerve function, presence of cerebrospinal fluid (CSF) leak, and overall clinical status were identified. CT imaging was analyzed by a single board certified neuroradiologist (MER) who was blinded to demographic data, clinical findings and mechanism of injury. Radiographic information on each patient was collected including fracture orientation, affected side, OCS/OCV, mastoid opacification, middle ear opacification, ossicular disruption, external auditory canal debris, and extra-temporal skull fractures. Fractures were classified as longitudinal (parallel) or transverse (perpendicular) if they were within 20 degrees of the true axis of the petrous pyramid. Mixed fractures were classified as those between longitudinal and transverse, and/or those with more than one clear fracture orientation. The type of CT scan and the slice thickness was noted. When only standard CT head scans (4-5mm slices) were available, collection of all data points was limited, which did not always allow for definitive classification of fracture type. Audiologic results obtained at the time of injury and at follow up testing were recorded when available.

Statistical Analysis

Statistical analysis was performed using SAS software, version 9.4 (SAS Institute, Cary NC). Chi-square and Fisher's exact tests were used to evaluate relationships between categorical risk factors and initial and follow-up audiogram results. The Kruskall-Wallis test was used to assess the relationship between age of injury and audiogram findings. Post-hoc pairwise comparisons were evaluated for fracture orientation and otic capsule involvement. Bonferroni adjusted *p*-values were used to account for multiple comparisons (p=0.02).

Results

Fifty patients sustained 53 fractures (69.7%) of the petrous portion of the temporal bone. Thirty (56%) fractures were on the left. Each fracture was considered a separate event for the purpose of data collection and statistical analysis. The mean age of the patients was 7.1 years (range 6 months to 16 years), and 39 (73.6%) patients were male. Mechanism of injury to the temporal bone included falls ranging from 2-30 feet (n=28, 52.8%), crush or blunt injuries (n=14, 26.4%), vehicular trauma (n=10, 18.9%), and one penetrating gunshot wound (1.9%). Fractures were interpreted using the Ulrich classification system and based on otic capsule involvement. Twenty-one (39.6%) fractures were longitudinal, 4 (7.5%) were transverse, and twenty-eight (52.8%) were classified as mixed. Only four (7.5%) fractures were found to be OCV, while 43 (81.1%) were OCS. Six fractures (11.3%) were not specifically classified for involvement of the otic capsule based on paucity of available imaging. **(Table 1)** Eight fractures

(15.1%) were identified by standard CT head scans, and the remainder (n=45, 84.9%) had dedicated high resolution CT temporal bone studies.

Gender, mechanism of injury, Ulrich fracture classification, the presence of an opacified middle ear, or external auditory canal debris were not significantly associated with hearing loss at the time of the injury or on follow up testing. (**Table 1**) The presence of other skull fractures, mastoid opacification, ossicular disruption, or facial nerve paresis were not significantly associated with hearing loss after temporal bone fracture at either time point (data not shown). Of the twelve (22.6%) patients with ossicular disruption, four (33.3%) had persistent hearing loss. When assessing otic capsule involvement, there was a significant association with persistent hearing loss on follow up audiometric testing (p=0.01), such that OCV fractures were more likely to have hearing loss than OCS. (**Table 1**) One hundred percent of patients with OCV fractures had persistent SNHL (n=4, 7.5%). An example of an OCV is shown in **Figure 1a-c**.

Pairwise comparisons for the presence of persistent hearing loss were evaluated for otic capsule involvement. (**Table 2**) When comparing OCS and OCV fractures, there a significant greater likelihood of persistent hearing loss in those with OCV fractures (p=0.01). Comparing the OCV or the OCS fractures to the undefined, indeterminate fractures showed no significant differences between the groups. (**Table 2**) Forty-two (79.2%) patients were evaluated by the otolaryngology service during their hospital admission. Eight (15.1%) patients had audiograms preformed during the inpatient admission. Thirty-three (62.3%) had follow up testing. Audiologic data was reported in 35 (66.0%) total patients.

Three patients (5.6%) sustained bilateral temporal bone fractures. One of these patients was a 2.3 year old male who sustained a crush injury to the head. Both fractures were classified as mixed, but the left was OCV and had an ossicular disruption. **(Figure 2)** He was noted to have a left facial paresis on exam. The right temporal bone sustained an OCS fracture with ossicular discontinuity. Left profound SNHL and right severe mixed hearing loss was noted on follow up testing.

All patients with persistent hearing loss are described in **Table 3**. These patients were predominantly male (n=6/8, 75.0%). The most common mechanism of injury was fall in 4 (50.0%) patients. All patients with OCV fractures had a SNHL. Three of 5 patients with mixed or conductive hearing loss had evidence of ossicular chain disruption on imaging. Only 2 patients (25.0%) who did not have either an OCV fracture or an ossicular disruption had a hearing loss on follow up testing. One had only a head CT, and the presence of an ossicular disruption could not be ascertained. This patient underwent surgical intervention and was found to have rotation of the malleus requiring ossiculoplasty. The other patient had a mild to moderate CHL on follow up audiogram, and underwent ossiculoplasty for subluxation of the incus. Imaging for this patient was reviewed by an additional neuroradiologist, who confirmed that the injury was not identifiable by CT. An algorithm for audiologic management of pediatric patients with temporal bone fractures is proposed and shown in **Figure 3**.

Discussion

Temporal bone fractures can result in serious sequelae that may include facial nerve injury, cerebrospinal fluid leakage, conductive hearing loss, and sensorineural hearing loss. In the United States, about 200 in every 100,000 children suffer head injury, and hearing loss has been reported in 23-64% of those cases.[9] Ancillary services, including the otolaryngologist, neuroradiologist, and audiologist, are generally available to assist in the care of head injury victims in major trauma centers.[8] An audiogram has been recommended in pediatric patients who have experienced head trauma, particularly those patients with temporal bone fractures.[9,11]

The best timing and cost-utilization of audiologic testing in diagnosing temporal bone fracture related hearing loss has not been described. This study analyzed patient characteristics and fracture type to determine if there are predictors of hearing loss after sustaining a temporal bone fracture in an attempt to develop a cost effective approach to the timing and frequency of post trauma audiograms.

This study demonstrated that the age, gender, and mechanism of injury did not successfully predict a higher incidence of hearing loss after a temporal bone fracture. Clinical findings including middle ear fluid, mastoid opacification, facial nerve injury, and debris in the ear canal did not correlate with the presence of a persistent hearing loss. The best predictor of a persistent hearing loss was the facture location based on the OCS/OCV classification scheme.

The patients with OCV fractures demonstrated on CT imaging all had persistent SNHL. The OCS/OCV classification demonstrated better accuracy in predicting SNHL versus the traditional method that uses the relationship of the fracture to the petrous bone. When classifying the fracture orientation, many of the fractures were not strictly oriented to the longitudinal or transverse plane of the petrous pyramid. Thereby, 28 (52.8%) were described as either mixed or oblique by the neuroradiologist. Previous work by Dunklebarger et al. suggested that the Ulrich classification scheme failed to predict many clinically observed fractures even with the addition of the mixed and oblique descriptors.[3] The authors found the negative predictive value of the two schemes to be similar, but the positive predictive value was higher for the OCS/OCV system.[3] Our findings appear similar to this prior study, and support the OCS/OCS classification over the former system as a predictor for hearing loss after temporal bone fracture.

Bowman *et al*[9] suggested an algorithm for hearing assessment in pediatric patients with head trauma associated with a Glasgow coma score (GCS) ≤13 and/or loss of consciousness (LOC). The authors found a significant association between abnormal audiograms, and the presence temporal bone fractures, non-temporal bone skull fractures, and an age < 3 years at the time of injury in their analysis of 50 children with head trauma (n=17, 34% with hearing loss).[9] An audiometric evaluation was therefore recommended in all patients with a temporal bone fracture, in children < 3 years of age with head trauma, and in those with GCS ≤13 and/or loss of consciousness (LOC), although the optimal timing of audiometric testing was not described. Given the high incidence of debris in the ear canal, hemotympanum, or the altered mental status of the trauma victim, initial audiogram results may be unreliable. In addition, head trauma victims may not be immediate candidates for audiometric assessments due to the severity of their injuries, making it difficult to standardize timing of studies after initial injury. Only 8 (15.1%) of our patients had an audiogram performed at the time of their injury despite 42 (79.2%) having been seen the otolaryngology service. This likely reflects a trend already in place for waiting for resolution of hemotympanum and/or debris in the ear canal prior to formal testing.

CT scans are recommended for the imaging of skull base fractures, particularly given the incidence of associated intracranial injury (43%) noted by one study.[13] The authors discussed the concern about CT related radiation exposure, and felt that the substantial risk of traumatic brain injury outweighed the radiation exposure risk in pediatric head trauma victims. The temporal bone CT exposes the child to additional radiation risk. This creates a quandary, as the temporal bone CT affords the neuroradiologist a better ability to classify the fracture type, which is the best predictor of hearing loss after temporal bone injury. Retro-reconstructed images of a thin cut head CT may afford adequate analysis of the temporal bone in head trauma cases.

The majority of fractures analyzed (n=43, 81.1%) spared the otic capsule, and only 4(9.3%) of these had a persistent hearing loss on follow up. Two of these patients had a known ossicular disruption after the trauma based on CT scan findings. One was noted to have a rotation of the malleus at middle ear exploration that may have been identified if dedicated CT temporal bone had been obtained. The last patient had subluxation of the incus that was not appreciated on imaging. Both of these patients were under the age of three at the time of injury and would meet criteria for audiologic testing after injury based on the previously mentioned recommendations.[9] Auditory brainstem response (ABR) testing was not needed for these children, but should be considered if information from pure tone audiometry combined with tympanograms and otoacoustic emission testing is lacking. Based on our findings, Otolaryngology follow-up and audiometric testing about 6 weeks after temporal bone fracture is suggested. If there is suspected SNHL based on radiographic findings at the time of injury, audiometric testing confirming the diagnosis at the time of injury is unlikely to alter acute management. A 4-6 week time period after injury will allow for resolution of debris in the ear canal and hemotympanum, if present, related to the fracture.[14] Follow-up results are likely more reliable, and allow for more precise counseling of families about expectations for return of hearing loss.

In lieu of a lack of standard guidelines that outline treatment after temporal bone fracture, **Figure 3** describes our suggested algorithm for audiometric management of pediatric patients these fractures. In this series, twelve (15.8%) patients had an audiogram within a day of their temporal bone fracture diagnosis, and 33 (43.4%) had additional audiometric testing 4 to 6 weeks after the injury. If the **Figure 3** algorithm had been applied to the patients in this cohort, none of the patients with persistent hearing loss would have been missed and cost savings would have been accrued. Cost reduction methods, when safe and within acceptable standards, are being explored throughout the healthcare system.[15] Although broad statements about limiting audiograms in temporal bone fracture patients cannot be made based on our limited clinical data, predictors of hearing loss (OCV versus OCS based on temporal bone imaging) are described.

Conclusions

Pediatric patients who sustain traumatic otic capsule sparing temporal bone fractures are at low risk for persistent hearing loss. Patients with otic capsule violating fractures and ossicular disruption have a higher rate of SNHL and CHL, respectively. These outcomes can often be predicted based on imaging findings and emergent diagnosis of hearing loss on audiogram does not alter short-term management. Follow up testing, particularly in those patients at higher risk for hearing loss after their injury, is recommended.

Acknowledgements: We thank Hannah Louks Palac, MS from the Biostatics Collaboration Center of the Department of Preventative Medicine, Northwestern Feinberg School of Medicine, Chicago, Illinois for her assistance with the statistical analysis.

References

1. Lee D, Honrado C, Har-el G, Goldsmith A. Pediatric temporal bone fractures. *Laryngoscope*. 1998;108: 816-821.
2. Kang H, Kim M, Hong S, Lee H, Kim T, et al. Comparison of temporal bone fractures in children and adults. *Acta Otolaryngol*. 2013;133:469-474.
3. Dunklebarger J, Branstetter B, Lincoln A, Sippey M, Cohen M, et al. Pediatric temporal bone fractures: current trends and comparison of classification schemes. *Laryngoscope* 2014;124:781-784.
4. Ulrich K. Verletzungen des Gehorlorgans bel Schadelbasisfrakturen (Ein Histologisch und Klinissche Studie). *Acta Otolaryngol Suppl*. 1926;6:1-150.
5. Ishman S, Friedland D. Temporal bone fractures: traditional classification and clinical relevance. *Laryngoscope*. 2004;114:1734-1741.
6. Kennedy T, Avery G, Gentry L. Imaging of temporal bone trauma. *Neuroimaging Clin N Am*. 2014:467-486.
7. Nauer C, Rieke A, Zubler C, Candreia C, Arnold A, Senn P. Low-dose temporal bone CT in infants and young children: effective dose and image quality. *Am J Neuroradiol*. 2011:1375-1380.
8. Mills B, Rowhani-Rahbar A, Simonetti J, Vavilala M. Facility characteristics and in-hospital pediatric mortality following severe traumatic brain injury [published online May 8, 2015]. *J Neurotrauma.* doi: 10.1089/neu.2014.3733
9. Bowman M, Mantle B, Accortt N, Wang W, Hardin W, Wiatrak B. Appropriate hearing screening in the pediatric patient with head trauma. *Int J Pediatr Otorhinolaryngol.* 2011:468-71.

10. Williams W, Ghorayeb B, Yeakley J. Pediatric temporal bone fractures. *Laryngoscope.* 1992;102:600-603.

11. Gettig K, Lawson K, Roth J, Hopper E, Higginbotham N, et al. Hearing evaluation in pediatric patients treated at the hospital following head injury. *J Trauma Nurse*. 2009;16(3):169-178.

12. Castellanos-Alcarria A, Navarro-Mingorance A, Reyes-Domínguez S, León-León M, Cepillo-Boluda A, López-Guerrero A. Severe temporal bone fractures in children: clinical presentation, complications and sequelae observed in the last 11 years. *An Pediatr (Barc).* 2015;82:68-72.

13. Perheentupa U, Kinnunen I, Grenman R, Aitasalo K, Makitie AA. Management and outcome of pediatric skull base fractures. *Int J Ped Otorhinolaryngol*. 2010;74:1245-1250.

14. Pulec J, DeGuine C. Hemotympanum from trauma. *Ear Nose Throat J*. 2001;80(8):486.

15. Luther G, Miller P, Waters P, Bae D. Radiographic evaluation during treatment of pediatric forearm fractures: implications on clinical care and cost. *J Pediatr Orthop.* 2015;00:1-7.

Figure Legend

Figure 1. Otic capsule violating fracture. Axial (A,B) and coronal (C) high resolution CT images demonstrate a fracture lucency (white arrows) extending through the vestibule (curved black arrows) and basal turn of the cochlea (straight black arrows). Note the small focus of pneumolabyrinth in the vestibule.

Figure 2. Ossicular dislocation. Axial high resolution CT demonstrates multiple fracture lucencies (straight black arrows) with disruption of the incudomalleolar articulation (curved black arrow). Note that the medial fracture line extends through the basal cochlear turn.

Figure 3. Algorithm for suggested audiologic management of pediatric temporal bone fractures.