Radiographic Classification of Temporal Bone Fractures

Clinical Predictability Using a New System

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Objective: To compare the traditional system of radiographic classification of temporal bone fractures (transverse vs longitudinal vs oblique) with a newer system (otic capsule violating vs otic capsule sparing) with respect to their ability to predict sequelae of temporal bone trauma.

Design: Retrospective chart and radiology review.

Setting: University trauma center and Department of Otolaryngology–Head and Neck Surgery.

Patients: Patients with temporal bone fractures.

Interventions: Clinic records and computed tomographic scans were reviewed to evaluate the clinical predictability of complications of temporal bone fractures.

Main Outcome Measures: Complications of temporal bone fractures (ie, sensorineural hearing loss, conductive hearing loss, cerebrospinal fluid leakage, and facial nerve weakness) were recorded. Two classification schemes for temporal bone fractures were statistically analyzed and compared as to their ability to predict each complication.

Results: A total of 234 temporal bone fractures were identified; 30 cases met our strict criteria for inclusion. The traditional classification system of temporal bone fractures did not significantly predict temporal bone complications ($P = .71$). On the other hand, the otic capsule-based system did demonstrate statistically significant predictive ability ($P < .001$). Patients with otic capsule-violating fractures were 5 times more likely to have facial nerve injury, 25 times more likely to have sensorineural hearing loss, and 8 times more likely to have cerebrospinal fluid otorrhea than those with otic capsule-sparing fractures.

Conclusions: The traditional radiographic classification system failed to demonstrate clinical predictability in our series. Furthermore, the newer system of classification (otic capsule sparing vs otic capsule violating) demonstrated statistically significant predictive ability for serious clinical outcomes associated with temporal bone fractures.

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Recent studies have questioned the predictive ability and significance of the traditional classification scheme for temporal bone fractures. The traditional classification of temporal bone fractures is based on a series of experiments in which weights were dropped on human cadaveric temporal bones and patterns of fractures were observed. These experiments demonstrated that fractures of the temporal bone occur along lines of anatomical weakness, such as suture lines or weak, aerated portions of the temporal bone. These patterns of experimental fractures were similar to those observed clinically. Therefore, fractures were categorized as transverse or longitudinal, depending on the axis of the fracture in relation to the petrous ridge. A longitudinal fracture typically runs parallel to the external auditory canal, through the middle ear, anterior to the otic capsule, and parallel to the petrous ridge, extending to the foramen ovale. Transverse fractures run perpendicular to the petrous ridge, from the foramen magnum across the petrous pyramid, often including the internal auditory canal, and into the foramen spinosum or lacerum. Longitudinal fractures typically result from lateral blows to the temporal or parietal skull, while transverse fractures are more often associated with frontal or occipital blows. A third fracture type, the oblique fracture, has more recently been described; oblique fractures cross the petrotympanic fissure, while lon-
Patients presenting with temporal bone fractures to the level 1 trauma center at the University of Virginia, Charlottesville, between January 2000 and December 2003 were identified by a computer search of all records with International Classification of Diseases, Ninth Revision (ICD-9) codes for basilar skull fracture and temporal bone fracture (ICD-9 codes 800-804). Once this patient sample was compiled, individual radiographic reports and computed tomographic scans were examined for the presence of a temporal bone fracture. Each temporal bone fracture was classified according to the traditional (longitudinal, transverse, or oblique) and new (otic capsule sparing or otic capsule involving) classification schemes. Longitudinal fractures were defined as fractures running parallel to the petrous pyramid. Transverse fractures were defined as fractures running perpendicular to the petrous pyramid. The oblique fracture, as defined by Ghorayeb and Yeakley, crosses the petrotympanic fissure laterally and proceeds anteromedially in a plane parallel to the long axis of the petrous ridge; this fracture is distinct from the longitudinal fracture, which courses parallel to the petrous ridge but does not cross the petrotympanic fissure. The new classification scheme is simply based on the integrity of the otic capsule bone. Interestingly, a transverse fracture does not necessarily have to violate the otic capsule (Figure 1).

Charts were reviewed for complications of temporal bone fractures. Complications evaluated included facial nerve paresis or paralysis, SNHL, CHL, dizziness or balance dysfunction, and CSF leakage. The diagnosis of dizziness or balance dysfunction was made on patient self-reporting. Caloric examinations were not performed on all patients. The diagnosis of CSF otorrhea was made based on clear fluid draining from the external auditory canal after the injury. The patients' fluid samples were not routinely sent for determination of β2 transferrin.

Strict inclusion criteria included temporal bone fracture on computed tomographic scan, with a complete medical record documenting facial nerve function and results of pure-tone audiometry. All audiograms were performed with standard air and bone conduction thresholds at 250, 500, 1000, 2000, 4000, and 8000 Hz. Exclusion criteria included death, isolated fractures of the squamous portion of the temporal bone, and the absence of an audiogram or documentation of facial nerve function. The number and type of complications were sorted by fracture according to both classification systems. Statistical analysis was performed with the Fisher exact test when comparing the frequency of occurrence of each complication between the 2 classification schemes and with the χ2 test when analyzing the 3 types of fractures (longitudinal, transverse, and oblique) according to the traditional system (Excel; Microsoft Corp, Redmond, Wash).

A total of 234 patients with temporal bone fractures were identified during the study period, and their charts were reviewed. Thirty patients (13%) met our strict criteria for inclusion in the study. One hundred seventy-four pa-
Complications of temporal bone fractures stratified by fracture type are presented in Figure 2 and Figure 3. The traditional classification system failed to predict any complication. On the other hand, the otic capsule–violating fractures were 5 times more likely to have facial nerve injury than those with transverse or oblique fractures. Of these same 7 patients, 4 (of 6) had otic capsule–violating fractures and 3 (of 24) had otic capsule–sparing fractures. Patients with otic capsule–violating fractures were 25 times more likely to have SNHL than those with otic capsule–sparing fractures (67% vs 12%; *P* < .05). Of the patients with SNHL, 3 had longitudinal fractures, 2 had transverse fractures, and 2 had oblique fractures. In the new system, 6 of 6 patients had otic capsule–violating fractures and 1 of 24 patients had an otic capsule–sparing fracture. Patients with otic capsule–violating fractures were 8 times more likely to leak CSF than those with otic capsule–sparing fractures (*P* < .005). In contrast, CSF leakage was found in equal proportions among the patients with transverse, longitudinal, and oblique fractures. The newer classification scheme was more predictive of CSF leakage than the traditional scheme.

Finally, an attempt was made to examine the incidence of vertigo with each associated fracture type. Unfortunately, adequate documentation of Dix-Hallpike testing, electronystagmography, and/or the presence of nystagmus was inconsistent in the charts reviewed. This information was excluded from our results.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic ratio</td>
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<tr>
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<td>14:16</td>
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<tr>
<td>Cause</td>
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<tr>
<td>Fall</td>
<td>10 (33)</td>
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<tr>
<td>Assault</td>
<td>4 (10)</td>
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<tr>
<td>Old system</td>
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</tr>
<tr>
<td>Longitudinal fracture</td>
<td>15 (50)</td>
</tr>
<tr>
<td>Transverse fracture</td>
<td>8 (27)</td>
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<tr>
<td>Oblique fracture</td>
<td>7 (23)</td>
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<tr>
<td>New system</td>
<td></td>
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<tr>
<td>Otic capsule–sparing fracture</td>
<td>24 (80)</td>
</tr>
<tr>
<td>Otic capsule–violating fracture</td>
<td>6 (20)</td>
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</tbody>
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*Values are given as number (percentage) unless otherwise indicated.

Table. Demographics of the Temporal Bone Fracture Population*

Patients had isolated fractures of the squamous portion of the temporal bone and were excluded. Thirty patients were excluded because of a lack of complete audiologic data or documentation of facial nerve function. The demographics of the study population are presented in the Table. The cause of fracture included motor vehicle crash (n = 14 [47%]), falls (n = 10 [33%]), and assault (n = 4 [10%]). According to the traditional classification system, 15 patients (50%) had longitudinal fractures, 8 patients (27%) had transverse fractures, and 7 patients (23%) had oblique fractures. According to the new system, 24 patients (80%) had otic capsule–sparing fractures, and 6 patients (20%) had otic capsule–violating fractures (Table).

The number of complications of temporal bone fractures were stratified by fracture type. CSF otorrhea was inconsistently documented in the charts reviewed. This information was excluded from our results. Of the patients with SNHL, 3 had longitudinal fractures, 2 had transverse fractures, and 2 had oblique fractures. In the new system, 6 of 6 patients had otic capsule–violating fractures and 1 of 24 patients had an otic capsule–sparing fracture. Patients with otic capsule–violating fractures were 25 times more likely to have SNHL than those with otic capsule–sparing fractures (67% vs 12%; *P* < .05). Of the patients with SNHL, 3 had longitudinal fractures, 2 had transverse fractures, and 2 had oblique fractures. In the new system, 6 of 6 patients had otic capsule–violating fractures and 1 of 24 patients had an otic capsule–sparing fracture. Patients with otic capsule–violating fractures were 25 times more likely to have SNHL than those with otic capsule–sparing fractures (67% vs 12%; *P* < .05). Three patients with transverse fractures, 7 patients with longitudinal fractures, and 1 patient with an oblique fracture had CHL. Three patients with otic capsule–violating fractures and 8 patients with otic capsule–sparing fractures had CHL. There was no statistically significant difference between the classification schemes for CHL (*P* = .64).

Patients with otic capsule–violating fractures were 8 times more likely to leak CSF than those with otic capsule–sparing fractures (*P* < .005). In contrast, CSF leakage was found in equal proportions among the patients with transverse, longitudinal, and oblique fractures. The newer classification scheme was more predictive of CSF leakage than the traditional scheme.

Finally, an attempt was made to examine the incidence of vertigo with each associated fracture type. Unfortunately, adequate documentation of Dix-Hallpike testing, electronystagmography, and/or the presence of nystagmus was inconsistent in the charts reviewed. This information was excluded from our results.
A radiographic classification system for temporal bone fractures must address several critical elements. First, any clinically useful system should be descriptive in nature; the system must be based on consistent, key components of temporal bone anatomy that are essentially the same from patient to patient. Furthermore, the descriptive findings on computed tomographic scans should correlate with clinical findings, such that the presence or absence of a fracture in a certain location or orientation has clinical relevance. The traditional system for radiographic classification of temporal bone fractures is based on fracture orientation in relation to the petrous ridge. Many studies have been performed in an attempt to correlate these fractures with clinical outcomes; however, consistent relationships between fracture orientation and clinical sequelae have been elusive. Part of the difficulty in applying the traditional classification system to modern temporal bone fractures results from a shift in the cause of these fractures. The traditional system is based on studies of temporal bone fractures induced by low-velocity, heavy impacts. As the majority of modern temporal bone fractures are caused by motor vehicle crashes,\textsuperscript{2,3,5,10} the traditional system loses significant applicability. The high-velocity impacts leading to temporal bone fractures today result in more complex fracture orientations than the traditional system can account for. The limitations of a system based on 2 dimensions (transverse and longitudinal) have led to a variety of modifications in an attempt to mitigate these limitations.\textsuperscript{5,11} Although the modifications have improved descriptive ability, they have not correlated with temporal bone fracture sequelae and therefore lack clinical significance.

In our study, we evaluated 30 temporal bone fractures using both the traditional system (transverse, longitudinal, and oblique) and a newer system (otic capsule violating and otic capsule sparing). We found the traditional system unable to predict complications of temporal bone fractures among our sample population. There was no statistically significant difference between the 3 fracture types (transverse, longitudinal, and oblique) in regard to facial nerve injury, SNHL, CHL, or CSF otorrhea.

We recognize the inherent statistical bias in comparing a population sample with 3 categories and a population sample with 2 categories. To address this shortcoming, we combined the data from the longitudinal and oblique groups and compared this combined group with the transverse fracture group (Figure 4). The data were statistically analyzed using the same method (Fisher exact test); no statistically significant difference was found between the transverse fracture group and the combined longitudinal-oblique fracture group for any of the complications studied or the overall complication rate ($P = .48$).

While the oblique fracture is accepted as distinct from the longitudinal and transverse fractures, some articles report “mixed” fractures, adding a fourth, perhaps more obscure category. We believe that the traditional system, while anatomically descriptive, can be cumbersome, and it falls short in clinical predictability.

As proposed by Dahiya et al\textsuperscript{2} and others, the newer system, based on involvement of the otic capsule, was a far better clinical predictor in our sample population. Otic capsule-violating fractures accounted for 20% of our sample and were found to correlate with statistically significant increases in facial nerve injury, SNHL, and CSF otorrhea (Figure 3). The vital structures housed within and around the otic capsule are well protected by the densest bone in the human skeleton. Violation of this bone will more likely lead to injury of the vestibular system, cochlea, facial nerve, and brain. Likewise, given the intimate association of the otic capsule with the middle and posterior cranial fossae, the higher incidence of CSF leakage is not surprising. A recent study also showed a surprisingly high incidence of associated intracranial injury (84%) in patients with temporal bone trauma.\textsuperscript{9} We are currently examining the 2 classification systems and their correlation to intracranial injury. Our prediction is that the traditional system is not predictive of intracranial injury but that the new system is. Fractures that do not violate the otic capsule are much less likely to damage the cochleovestibular system or the facial nerve, owing to the protective density of the otic capsule bone. Most fracture lines follow the weaker, aerated portions of the temporal bone. The force required to violate the otic capsule bone would likely result in more serious sequelae, including intracranial injury.

While our incidence of otic capsule-violating fractures is on a par with published reports of transverse fractures,\textsuperscript{5,7,15} our incidence of otic capsule-violating fractures is significantly higher than that reported by Dahiya et al\textsuperscript{2} (5.6%) and Brodie and Thompson\textsuperscript{10} (2.5%). This discrepancy is most likely the result of our strict inclusion criteria and relatively small sample size. The possibility exists that many patients with otic capsule-sparing fractures were unavailable for follow-up or were excluded from the study because of the lack of complete
clinical information, given that the lower incidence of clinical sequelae would result in underrepresentation of this population. Nevertheless, our rate of complications in patients with otic capsule-violating fractures is in agreement with those in the 2 previously mentioned studies.2,10 In Dahiya and colleagues’ study of 55 temporal bone fractures, patients with otic capsule-violating fractures were more than twice as likely to have facial nerve injury, 4 times as likely to have CSF leakage, and 7 times as likely to have SNHL than those with otic capsule-sparing fractures. In their review of 820 temporal bone fractures, Brodie and Thompson noted that 10 (47%) of 21 fractures of the otic capsule resulted in facial nerve paralysis, with only 6% of otic capsule-sparing fractures resulting in facial nerve injury. In their series, all patients with otic capsule-violating fractures had profound SNHL, and CSF otorrhea was twice as common in patients with otic capsule-violating fractures.

CONCLUSIONS

The ability to accurately predict clinical information, including complications of trauma, represents the core purpose of modern imaging technology. Radiographic findings have long been difficult to correlate with clinical outcomes in the setting of temporal bone fractures. The value of such predictive radiographic information in this setting may alert the emergency department physician, otolaryngologist, trauma surgeon, or neurosurgeon to other potential injuries, including intracranial injury, facial nerve injury, and the possible risk of meningitis, and may alter treatment to achieve the best possible outcome for the patient. Because many of these trauma patients are unconscious or sedated, obtaining accurate results from the physical examination, including facial nerve function, can be difficult. Therefore, the reliable integration of computed tomographic findings with clinical sequelae is crucial to provide appropriate treatment planning. Our study lends further support to the theory that the new otic capsule-based classification system is a more clinically predictive method than the traditional system.

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Author Contributions: Drs Little and Kesser had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Little and Kesser. Acquisition of data: Little and Kesser. Analysis and interpretation of data: Little and Kesser. Drafting of the manuscript: Little and Kesser. Critical revision of the manuscript for important intellectual content: Little and Kesser. Statistical analysis: Little and Kesser. Administrative, technical, and material support: Kesser. Study supervision: Kesser.

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REFERENCES