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Original Research Article

Temporal Bone Fractures: Clinical Implications, Radiological Patterns, and the Role of Mastoid Pneumatization

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Abstract:

Background: High-resolution computed tomography (HRCT) is the imaging standard for diagnosing temporal bone fractures (TBF). While traditional classification systems focus on anatomical orientation relative to the petrous ridge, contemporary clinical paradigms stress the importance of otic capsule status and structural variables such as mastoid pneumatization.

Objectives: To evaluate the radiological patterns of TBF on CT imaging and measure interobserver agreement with official radiology reports. Additionally, to determine the statistical association between specific fracture trajectories (including otic capsule involvement) and clinical outcomes, and to evaluate the impact of mastoid pneumatization on fracture susceptibility.

Methods: A retrospective cohort analysis was conducted on 110 patients diagnosed with TBF via CT between January 2016 and May 2019. Radiographic patterns were categorized using both traditional models (longitudinal, transverse, mixed) and the modern otic capsule status system. Statistical associations were analyzed using chi-square tests and Cohen's kappa (k) for interobserver agreement.

Results: The distribution of injuries comprised 52 transverse (47%), 34 longitudinal (30%), and 19 mixed fractures (17%), demonstrating substantial interobserver reproducibility ($k = 0.637$). Longitudinal fractures were significantly linked to conductive hearing loss ($P < 0.001$), whereas transverse fractures were tied to sensorineural hearing loss ($P = 0.005$). Otic capsule-violating fractures were identified in 8.2% of cases and were strongly predictive of sensorineural hearing loss ($P < 0.001$), facial nerve paralysis ($P = 0.019$), and acute vertigo ($P = 0.035$). Higher volumes of mastoid pneumatization correlated with an increased frequency of total fractures, and hyper-pneumatization was significantly linked to otic capsule disruption ($P = 0.024$).

Conclusion: The traditional anatomical orientation model remains reproducible, but its clinical utility is significantly improved when paired with otic capsule profiling. Mastoid pneumatization does not act as a protective structural cushion; instead, extensive pneumatization increases vulnerability to both temporal bone fractures and otic capsule violations.

Keywords: Computed tomography, Otic capsule, Facial paralysis, Temporal bone fracture, Hearing loss, Mastoid pneumatization.

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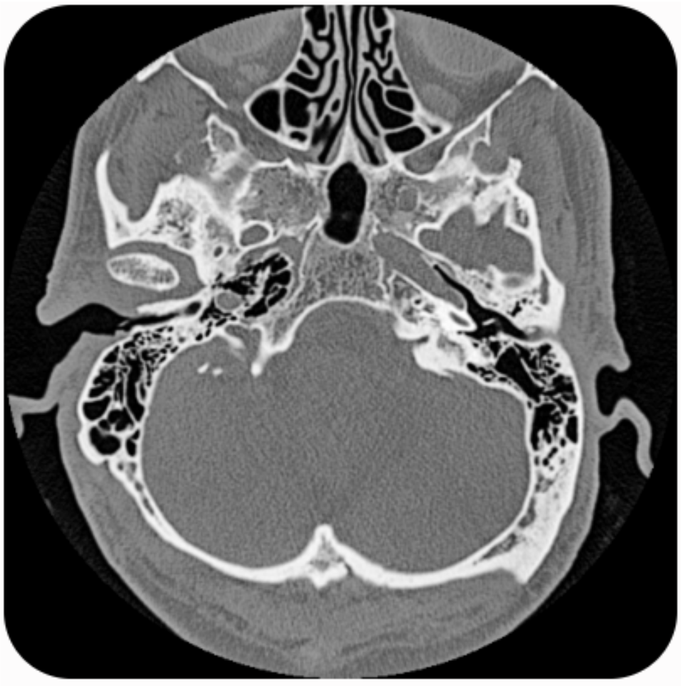
Introduction

The temporal bone houses an intricate network of neurovascular, auditory, and vestibular structures within a dense osseous landscape. Due to this anatomical complexity, high-impact blunt head trauma frequently compromises patient quality of life through long-term sensory and functional deficits [1]. High-resolution computed tomography (HRCT) serves as the primary imaging standard to evaluate these injuries, offering clear visualizations of delicate middle and inner ear components [2].



Classically, temporal bone fractures (TBF) have been classified by their orientation relative to the long axis of the petrous pyramid:

- **Longitudinal Fractures:** Running parallel to the petrous ridge, typically caused by temporo-parietal impacts.
- **Transverse Fractures:** Running perpendicular to the ridge, often resulting from occipital or frontal impacts.
- **Mixed Fractures:** Demonstrating multi-axial cleavage planes.

While this traditional framework remains widely utilized in radiology workflows, critics argue it does not consistently predict clinical symptoms [1, 3]. Consequently, contemporary neurotology highlights an alternative classification centered on the structural integrity of the dense bone surrounding the inner ear: otic capsule-sparing (OCS) versus otic capsule-violating (OCV) injuries [2, 3].

Furthermore, the structural impact of mastoid air cell system development (pneumatization) on fracture patterns remains a point of debate. Some structural hypotheses suggest that heavily pneumatized mastoid bones act as energy-absorbing cushions, while others propose that thin bony septa lower structural resistance to skull base trauma [4]. This study reviews a multi-year cohort to address these radiological and clinical associations.

Materials and Methods

A retrospective study was conducted evaluating 110 patients diagnosed with acute TBF via cranial or dedicated temporal bone CT imaging at a major trauma center between January 2022 and May 2024. Two independent neuroradiologists re-reviewed all CT imaging studies blinded to the original clinical reports. Fractures were categorized by trajectory (longitudinal, transverse, or mixed) and by the presence or absence of otic capsule disruption. Mastoid pneumatization was scored qualitatively using a established three-tiered metric: poor, moderate, or highly/very good pneumatization.

Concurrently, clinical charts were audited to document neurological and neuro-otological outcomes, including conductive hearing loss (CHL), sensorineural hearing loss (SNHL), facial nerve paralysis, and vestibular vertigo. Interobserver diagnostic agreement between the re-reviewers and the original emergency radiology reports was calculated using Cohen’s kappa (\$k\$). Statistical associations among fracture patterns, pneumatization grades, and clinical deficits were analyzed using Chi-square tests, with significance defined as \$P < 0.05\$.

Results

Radiological Distribution and Interobserver Concordance: The re-review of the 110 TBF cases revealed a clear distribution across traditional patterns: 52 transverse fractures (47%), 34 longitudinal fractures (30%), and 19 mixed fractures (17%). The remaining 5 cases represented highly localized or isolated mastoid cortex microfractures.

Comparing these study findings against the real-time emergency radiological reports yielded a Cohen's kappa coefficient of \$k = 0.637\$. This indicates substantial, reliable interobserver agreement for the classic orientation-based classification model.

Clinical-Radiological Associations: Clear, distinct correlation patterns emerged when matching traditional fracture orientations against documented clinical symptoms:

Fracture Trajectory Type	Key Clinical Correlation	Statistical Significance (P-value)
Longitudinal Fractures (30%)	Conductive Hearing Loss (CHL)	$P < 0.001$
Transverse Fractures (47%)	Sensorineural Hearing Loss (SNHL)	$P = 0.005$

The strong link between longitudinal fractures and CHL was consistently tied to middle ear issues, such as ossicular chain dislocation or hemotympanum. Conversely, transverse trajectories directly disrupted the inner ear structures or the internal acoustic canal, resulting in sensory nerve deficits.

Otic Capsule Involvement: Across the entire cohort, 8.2% of the fractures were found to cross and disrupt the otic capsule. Though less common, these otic capsule-violating (OCV) fractures were highly predictive of severe neuro-otological deficits:

Otic Capsule-Violating (OCV) Fractures (8.2% of cohort):

- **Sensorineural Hearing Loss (SNHL):** Strongly associated ($P < 0.001$) due to direct cochlear hair cell or vestibulocochlear nerve injury.
- **Facial Nerve Paralysis:** Strongly associated ($P = 0.019$) due to mechanical trauma along the fallopian canal.
- **Acute Vertigo:** Significantly associated ($P = 0.035$) resulting from disruption of the semicircular canals or vestibule.

The Impact of Mastoid Pneumatization: Analyzing bone structure variations disproved the theory that highly developed air cells offer protective cushioning. TBF frequencies were noticeably higher in patients with extensive mastoid pneumatization. Crucially, a significant statistical link was found between very good/hyper-pneumatization and direct involvement of the otic capsule ($P = 0.024$).

Discussion

Our study demonstrates that while the classic longitudinal/transverse classification system remains reproducible and reliable ($k = 0.637$), it works best when combined with an otic capsule status assessment [1, 2].

The clinical findings align with underlying anatomical paths: longitudinal fractures regularly disrupt the tympanic ring and ossicular mechanics, whereas transverse vectors shear the labyrinthine block [3]. However, evaluating the otic capsule status provides sharper prognostic insight. When a fracture line crosses the otic capsule, the risk of profound SNHL, facial paralysis, and persistent vertigo rises dramatically [2, 5].

Our structural analysis regarding mastoid development provides valuable new data for this debate. Rather than serving as a protective cushion, extensive mastoid pneumatization thins the surrounding petrous cortex. This reduction in total bone mass lowers the threshold for fracture propagation, allowing high-energy impact forces to travel deeper into the skull base and break into the delicate otic capsule ($P = 0.024$) [4].

Conclusion

The traditional orientation classification for temporal bone fractures remains useful and reproducible. However, its ability to predict real-world clinical deficits improves significantly when radiologists explicitly report otic capsule involvement. Furthermore, extensive mastoid pneumatization acts as a structural vulnerability factor rather than a protective shield, increasing the risk of complex inner ear damage.

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