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A novel classification of frontal bone fractures: The prognostic significance of vertical fracture trajectory and skull base extension

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Summary *Purpose:* The broad spectrum of frontal bone fractures, including those with orbital and skull base extension, is poorly understood. We propose a novel classification scheme for frontal bone fractures.
Methods: Maxillofacial CT scans of trauma patients were reviewed over a five year period, and frontal bone fractures were classified: Type 1: Frontal sinus fracture without vertical extension. Type 2: Vertical fracture through the orbit without frontal sinus involvement. Type 3: Vertical fracture through the frontal sinus without orbit involvement. Type 4: Vertical fracture through the frontal sinus and ipsilateral orbit. Type 5: Vertical fracture through the frontal sinus and contralateral or bilateral orbits. We also identified the depth of skull base extension, and performed a chart review to identify associated complications.
Results: 149 frontal bone fractures, including 51 non-vertical frontal sinus (Type 1, 34.2%) and 98 vertical (Types 2–5, 65.8%) fractures were identified. Vertical fractures penetrated the middle or posterior cranial fossa significantly more often than non-vertical fractures (62.2 v. 15.7%, $p = 0.0001$) and had a significantly higher mortality rate (18.4 v. 0%, $p < 0.05$). Vertical fractures with frontal sinus and orbital extension, and fractures that penetrated the middle or posterior cranial fossa had the strongest association with intracranial injuries, optic neuropathy, disability, and death ($p < 0.05$).

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Conclusions: Vertical frontal bone fractures carry a worse prognosis than frontal bone fractures without a vertical pattern. In addition, vertical fractures with extension into the frontal sinus and orbit, or with extension into the middle or posterior cranial fossa have the highest complication rate and mortality.

Introduction

Although frontal sinus fractures and their associated complications have been described extensively,[1–6] fracture patterns of the frontal bone as a broad unit of the craniofacial skeleton have not been rigorously characterized. Considering that the frontal bone is the most frequently fractured cranial bone in craniofacial trauma patients and accounts for 37 percent of cranial fractures,[7] it is important to understand frontal bone fracture patterns and related complications in greater detail.

The important elements to include in a thorough characterization of frontal bone fractures are the status of adjacent bony structures, including the frontal sinus, orbit, and skull base.[8] Previous studies have shown that frontal bone fractures may acquire an "oblique" or vertical trajectory through the frontal bone and extend to adjacent bones. In particular, vertical fractures that begin in the frontal bone and penetrate the midface have been described in children as a common fracture pattern related to their prominent foreheads and underdeveloped paranasal sinuses.[9,10] The occurrence of vertical fractures has not been made as explicit in adults, although "linear" fractures were recently described in an adult population as originating in the frontal bone and extending to the skull base.[11] The literature therefore supports the possibility of vertically oriented fractures in multiple contexts, but a comprehensive description of frontal bone fractures that accounts for involvement of adjacent bony structures is needed.

To our knowledge, no study has examined the spectrum of frontal bone fractures with consideration of frontal sinus, orbital and skull base involvement in both children and adults. An improved understanding of different frontal bone fracture types and their associated morbidity and mortality may enhance our ability to distinguish injury severity among patients with frontal bone trauma and provide prognostic information that can assist with patient counseling and treatment planning. Here we classify different frontal bone fracture patterns and their associated complications.

Methods

After receiving approval from the University of Wisconsin Health Sciences IRB, we used ICD-9 codes for calvarial, facial, mandibular and cervical spine trauma to retrospectively identify all patients with craniofacial trauma over a five year interval. Subsequently, all CT scans were reviewed by a neuroradiology attending to identify those individuals with frontal bone fractures.

Frontal bone fractures were primarily distinguished as having a non-vertical or vertical trajectory. Type 1 fractures were defined as comminuted fractures of the frontal sinus without a vertical trajectory. Vertical fractures were broken down into 4 distinct types, Types 2–5, as it was clear from radiologic analysis that these fractures represented a spectrum of injury patterns (Figure 1). Type 2 fractures are vertical fractures involving the orbit but not the frontal sinus. Type 3 fractures are vertical fractures involving the frontal bone and sinus but not the orbit. Type 4 fractures involve both the frontal sinus and the ipsilateral orbit. Type 5 fractures cross the midline of the face, involving the frontal sinus and the contralateral or bilateral orbits. The term non-vertical fracture is therefore used to describe Type 1 fractures while the term vertical fracture is used to describe Type 2–5 fractures.

In the case of children without a frontal sinus present, the classification scheme still applies with a few modifications. A Type 1 fracture is a non-vertical fracture through the frontal bone. A Type 2 fracture is a vertical fracture through the orbit only. A Type 3 fracture is a vertical fracture through the frontal bone that does not involve the orbit. There is no Type 4 fracture since there is no frontal sinus. A Type 5 fracture is a vertical fracture through the frontal bone that involves the contralateral or bilateral orbits. If a frontal sinus is present in some phase of development, then the adult classification scheme is used.

The depth of skull base extension was also classified for all fractures (Figure 2). Depth A is defined as involvement of the frontal bone without extension into the skull base. Depth B is characterized by extension into the anterior cranial fossa (orbital roof, fovea ethmoidalis, cribriform plate). Depth C fractures extend into the middle cranial fossa (sella, sphenoid body, carotid canal, optic chiasm sulcus). Depth D fractures involve the posterior cranial fossa (clivus, petromastoid temporal bone, petrosal segment of the carotid canal).

CT images were also reviewed by a neuroradiology attending to characterize intracranial injuries for all patients with frontal bone fractures. Injuries of interest included subarachnoid hemorrhage, subdural hematoma, epidural hematoma, stroke, subfalcine herniation, and transtentorial herniation. Additionally, the presence of midface fractures that fit accepted definitions of zygomaticomaxillary complex, nasoorbitoethmoid, and Le Fort 1, 2 and 3 fractures was described.

Medical records were reviewed to characterize patient demographics and outcomes. The outcomes we measured