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Clinical Paper
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Applied anatomy of the anterior cranial fossa: what can fracture patterns tell us?

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Abstract. The skull base is uniquely placed to absorb anteriorly directed forces imparted either via the midfacial skeleton or cranial vault. A variety of skull base fracture classifications exist. Less well understood, however, is fracture extension beyond the anterior cranial fossa (ACF) into the middle and posterior cranial fossae. The cases of 81 patients from two UK major trauma centres were studied to examine the distribution of fractures across the skull base and any relationship between the vector of force and extent of skull base injury. It was found that predominantly lateral force to the craniofacial skeleton produced a fracture that propagated beyond the ACF into the middle cranial fossa in 77.4% of cases, significantly more ($P < 0.001$) than for predominantly anterior force (12.0%). Fractures were significantly more likely to propagate into the posterior fossa with a lateral vector of impact compared to an anterior vector ($P = 0.049$). This difference in energy transfer across the skull base may, in part, be explained by the local anatomy. The more delicate central ACF acts as a 'crumple zone' in order to absorb force. Conversely, no collapsible interface exists in the lateral aspect of the ACF, thus the lateral ACF behaves like a 'buttress', resulting in increased energy transfer.

Key words: anterior cranial fossa; skull base fracture; skull base trauma; applied anatomy; craniofacial trauma; fracture pattern.

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The skull base represents an intricate osseous interface between the cranial vault and the face anteriorly, and the neck posteriorly. The face is the only sub-cranial structure related to the anterior cranial fossa (ACF), separating the neck from the base of the skull. It has long been postulated that the bones of the midfacial skeleton will act as a 'crumple zone', thereby reducing the transmission of force to the intercranial contents.[1] This has been supported experimentally by the work of Lee et al.,[2] who demonstrated that the paranasal sinuses and nasal cavity provide a crumple zone, reducing the transmission of energy and fracture to the posterior cranial fossa (PCF). This may become relevant clinically, as PCF injuries have been associated with mortality rates of up to 80% and poor neurological outcomes.[3–6]

These protective features in the skeletal anatomy of the midfacial skeleton have also been shown to exist in the anatomy of the ACF.[7] Given its position, the base of the skull is uniquely placed to absorb anteriorly directed forces. Support for this view is the fact that fractures of the midfacial skeleton do not, in general, propagate to involve the cranial vault, and vice versa. This reduces the transmission of impact energy to the brain.[7] Anatomically there is considerable variability in the thickness of the bone in the skull base, from the paper-thin cribriform plate to the more robust sphenoid wing, which provides support and protection for the structures of the orbital apex. This in turn has an impact on the injury mechanism in craniofacial trauma.

The vector of transmitted force determines the fracture severity and pattern. With anteriorly directed forces to the frontal bone, the central (sinonasal) compartment of the anterior fossa provides a collapsible interface. The anterior orbital rim and mid-portion of the orbital roofs fracture preferentially and again provide a collapsible interface.[8] It has been suggested that with predominantly lateral impact forces to the lateral aspect of the frontal bone, the inherent protective features present in the case of anteriorly directed forces are absent. The robust bone of the lateral supra-orbital rim/greater wing of the sphenoid conversely transmits rather than absorbs energy, resulting in more severe head injuries.

Bones fracture in a preferential manner leading to reproducible fracture patterns. This phenomenon exists in various areas of the skeleton, hence the occurrence of a multitude of eponymously named fractures, e.g. Smith and Colles fractures of the radius; typical examples for the facial skeleton are of course the Le Fort original midfacial fractures. It can be argued that these reproducible fracture patterns occur only with moderate impact energy. A feature of high-energy impact is that there is apparent disregard of conventional fracture patterns with gross comminution of the bones involved.

The aims of this study were (1) to demonstrate the patterns of propagation of fractures across the anterior skull base that extend into the middle and posterior cranial fossae, and (2) to test the hypothesis that laterally based forces exploit the relative biomechanical weakness of the construct and produce more extensive skull base injuries.

Materials and methods

A study of patients who had sustained frontobasal fractures due to non-penetrating trauma was conducted. These patients were seen at two major trauma centres (MTC) in the UK. A prospectively maintained database of surgery was used to retrospectively identify patients treated at MTC1 from 17 June 2006 to 17 July 2013. Similarly, all patients under the care of the oral and maxillofacial trauma team at MTC2 from 1 January 2012 to 28 February 2014 were identified prospectively using comprehensive electronic patient handover notes.

Ethical approval for this study was granted by the National Research Ethics Committee; Research and Development approval was granted at both study sites.

Inclusion and exclusion criteria

All patients who had sustained a fracture of the ACF from either an anteriorly or laterally directed impact to the frontal bone or midfacial skeleton, with available computed tomography (CT) images and accessible clinical data, were included.

The following patients were excluded: those with non-traumatic ACF disruption, those with penetrating skull base fractures, and patients sustaining fractures confined to the anterior table of the frontal sinus. In addition, patients with inadequate clinical information/CT imaging were excluded.

Clinical data

The following data were collected for each patient in the study: patient demographics, mechanism of injury, and direction of force.

The direction of force was recorded as either anterior or lateral as follows: a line at 45° to the right angle formed by the midline and the sphenoid wing was used to bisect the ACF. The force was deemed 'anterior' if the predominant force impacted the frontal bone anterior to this line and 'lateral' if behind the line (see Fig. 1). It is accepted that in a number of cases, due to the severity of the impact force, both anterior and lateral impact may occur. In these cases, an attempt was made to determine the 'predominant' direction of force, accepting that this would involve a degree of subjectivity in certain cases.

Fracture pattern assessment

The CT scans were analysed using OsiriX v.4.1.2 software (Pixmeo, Geneva, Switzerland) allowing for the manipulation of images into the desired view. The fractures identified on the CT scans were manually transferred onto an image of the superior aspect of the skull base using a Wacom Bamboo Pen Tablet and stored as an individual layer in Adobe Photoshop v. 14.0; this was done by two of the investigators (BTE and JRS). The prevalence of fracture propagation into the middle cranial fossa (MCF) and PCF was noted for each subject.

Statistical analysis

All data were analysed using IBM SPSS Statistics v. 21 (IBM Corp., Armonk, NY, USA) and Confidence Interval Analysis v. 2.2.0 (CIA; University of Southampton, UK). The χ^2 test was applied, and Fisher's exact test was used when any one cell count had an expected value of less than 5. A P-value of less than 0.05 was considered to show a statistically significant difference between data.

Results

In total, 81 patients met the inclusion criteria for the study; 36 patients were treated at MTC1 and 45 patients were treated at MTC2. There was no statistically significant difference between the patients in these two cohorts in any of the patient demographics or outcome measures. Mechanisms of injury are described in Table 1. In total, 50 patients sustained a predominantly anteriorly directed force (anterior group) and 31 patients sustained a predominantly laterally directed force (lateral group) to their craniofacial skeleton.

Of the patients who suffered a lateral impact, 77.4% had fractures that propagated from the ACF into the MCF compared to

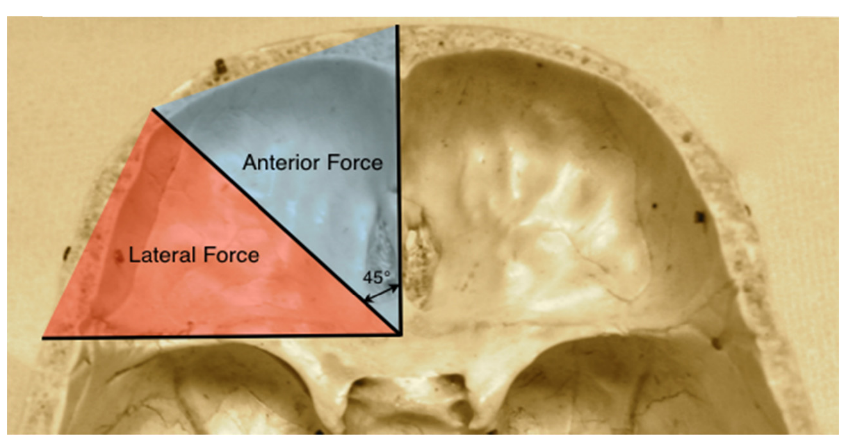

Fig. 1. Diagram showing the classification of either a predominantly anterior or predominantly lateral direction of force.