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ORIGINAL ARTICLE

# Fracture line morphology of complex proximal humeral fractures

**Afsana P. Hasan, MBBS[a,c,*], Joideep Phadnis, MD, FRCS(Tr&Orth)[a,b], Ruurd L. Jaarsma, MD, FRACS, Fa(Ortho)A, PhD[a,c], Gregory I. Bain, MBBS, FRACS, FA(Ortho)A, PhD[a,c]**

[a]*Department of Orthopedics and Trauma, Flinders Medical Centre, Adelaide, South Australia, Australia*
[b]*Department of Trauma and Orthopaedics, Brighton and Sussex University Hospitals, Brighton, UK*
[c]*Department of Orthopedics and Trauma, Flinders University, Adelaide, South Australia, Australia*

**Background:** The aim of this study was to assess proximal humeral fracture patterns using 3-dimensional computed tomography images and relate them to the normal osseous landmarks and soft-tissue attachments.
**Methods:** Forty-eight 3-dimensional computed tomography scans of proximal humeral fractures were retrospectively collected, and the fractures were transcribed onto proximal humeral templates. We analyzed the common location and orientation of the fracture lines, with a focus on fractures of the articular surface, tuberosities, metaphysis, and proximal diaphysis. These fractures were compared with the attachments of the rotator cuff and glenohumeral capsule.
**Results:** Fifty-two percent of the fractures involved the articular surface. No fractures passed through the bicipital groove, and fractures were more commonly found on the posterior lesser tuberosity and on the anterior greater tuberosity, coinciding with the intervals between the rotator cuff tendon insertions. Intracapsular fractures of the calcar were more common (68%) than extracapsular fractures (32%). On the anterolateral aspect of the proximal humerus, fractures radiated from the articular margin, vertically down through the tuberosity zone between the rotator cuff footprints, meeting horizontally oriented fractures in the metaphyseal zone. On the posterior aspect, vertical fractures from the tuberosity zone continued downward to the metaphyseal zone adjacent to the infraspinatus and teres minor footprints.
**Conclusions:** Fractures of the proximal humerus follow characteristic patterns. Fractures frequently split the greater tuberosity and are closely related to the intervals of the rotator cuff attachments.
**Level of evidence:** Basic Science; Anatomy Study; Imaging


**Keywords:** Fracture; pattern; proximal humerus; three-dimensional CT; tracing; classification; rotator cuff footprint

The classification of complex fractures of the proximal humerus has typically been described according to a 4-segment theory[6,11,18,23] or based on the fracture planes that separate these segments.[13,29] Neer[22,23] first proposed that these segments were associated with soft-tissue injuries and that the major segments are retracted by the rotator cuff muscles. Resch and colleagues[17] have proposed the descriptive pathomechanical model that fractures can be further described as either "impaction" or "distraction" injuries according to the direction

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*Reprint requests: Afsana P. Hasan, MBBS, 30/22 Cambridge St, North Adelaide, SA 5006, Australia.

E-mail address: afsana.hasan@gmail.com (A.P. Hasan).

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of forces. The surgical management of these injuries requires satisfactory reduction and stabilization of the bony and soft-tissue components.[14] The precise locations of these fracture planes separating the main segments have not been previously identified; nor have they been described in relation to the attachments of the rotator cuff.

These systems were initially developed based on plain radiographs, and since then, technology has advanced and we now have high-resolution 3-dimensional (3D) computed tomography (CT) scans available to us. No study to date has taken advantage of this technology to map proximal humeral fracture configurations. Edelson et al[11,12] were the first authors to use 3D CT scans to develop a new classification system and were able to describe subsets of these injuries in greater detail than was previously possible. The lines that divide proximal humeral fragments have not been clearly defined. This is important because a better understanding of where these fracture lines commonly occur may influence all facets of surgical care, including exposure, reduction techniques, and implant design.

Since 2008, Sugaya and colleagues[4,15,19,20,24] have evolved our understanding of the anatomic attachment sites of the rotator cuff and described their dimensions in great detail from cadaveric specimens. In particular, they proposed that the footprint of the supraspinatus is much smaller and the footprint of the infraspinatus is much larger than previously thought. As our knowledge of the rotator cuff (which is responsible for retracting segments) has changed, it is necessary for us to re-evaluate their location relative to the main fracture lines. The aim of this study was to identify the location and distribution of fractures of the proximal humerus and relate them to the location of the soft-tissue attachments.

## Materials and methods

### Patient demographic characteristics

In this retrospective study, a database search was performed to identify all proximal humeral fractures managed at our level 1 trauma center between 2007 and 2013. All adults (aged ≥18 years) who had a CT scan to assess their fracture were included in the study. The final cohort consisted of 48 patients with a wide range of fracture types. There were 36 women and 12 men. The mean age was 62 years (range, 21-88 years). There were 25 right and 23 left shoulders. Of the fractures, 40 were from low-energy mechanisms and 8 were high-energy injuries.

### General characteristics

Of the 48 patients, 20 had 2-part, 23 had 3-part, and 5 had 4-part fractures as defined by the Neer classification[23] and 13 had A-type, 21 had B-type, and 14 had C-type fractures as defined by the AO classification.[18] There were 28 varus and 11 valgus angulated fractures and 9 in which there was no significant angulation. There were 13 fracture-dislocations, of which 6 were anterior, 5 were posterior, and 2 were inferior.

### Three-dimensional CT

All CT scans were performed at the same institution using a standardized protocol. CT scans of the proximal humerus were performed with 0.5- to 2-mm slices and displayed in the coronal, sagittal, and axial planes. Three-dimensional reconstructed images were also obtained.

### Proximal humeral templates

Anterior, lateral, posterior, and superior images of a 3D proximal humerus positioned in the anatomic plane (parallel to the plane of the scapula, with the shaft oriented vertically) were exported from Essential Skeleton 4 (3D4 Medical, San Diego, CA, USA). The superior view was perpendicular to the humeral shaft. These four 2-dimensional (2D) images were imported into Adobe illustrator (Adobe Systems Software Ireland, Dublin, Ireland) and became the templates for the fracture model.

### Fracture models

The clinical proximal humeral fracture 3D CT reconstructions were imported into a viewing program, OsiriX (Pixmeo, Bernex, Switzerland), and oriented to create 2D images that were in the same anatomic plane as the 4 proximal humeral templates. With the 2 applications open side by side, the fracture lines were transcribed freehand onto the templates to create fracture models (Fig. 1). For ease of analysis, small areas of high comminution were represented as single fracture lines.

We used several measures to optimize the accuracy of this process: The transcriptions were performed by one author and were reassessed by a consultant shoulder surgeon. Any discrepancies between reviewers were reassessed.

The reference ruler on the original 3D reconstruction was used to measure the true distances of individual fractures from known anatomic landmarks (bicipital groove, articular rim, prominences of the tuberosities) on the proximal humerus. On the template, a sphere of best fit was drawn over the humeral head, and by use of previous measurements of the diameter of this sphere,[5,27] a reference scale was developed for the template. The true distances of fractures were converted using this scale and transcribed accordingly.

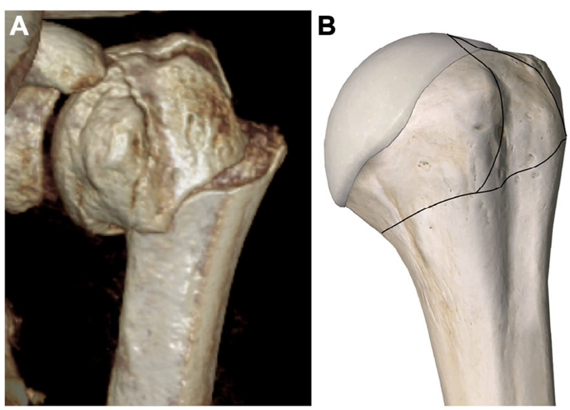


**Figure 1** Side-by-side comparison of proximal humeral fracture: 3-dimensional computed tomography reconstruction (**A**) and fracture model (**B**). Copyright © Dr Gregory I. Bain.