A three-dimensional classification for fractures of the proximal humerus

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Existing classifications of fractures of the head of the humerus are inadequate in terms of interobserver reliability and the predictability of the clinical outcome. From a combined study of 73 fracture specimens in museums and 84 CT-three-dimensional reconstructions in patients, we have devised a classification which appears to be more useful clinically. Common patterns of fracture and a plausible mechanism of injury were observed.

In 3-D most proximal humeral fractures can be organised into five basic types. These correspond in some degree to the Codman/Neer classification, but differ significantly in regard to the more complex patterns of fracture. We observed a logical progression from simple to complex fractures. An interobserver reliability study was carried out which indicated the improved usefulness of this new 3-D concept in providing a common language among clinicians for classifying these injuries. When surgery is indicated, the 3-D concept is also invaluable in guiding the restitution of anatomy through either open or percutaneous means.

Neer’s modification of Codman’s classification of fractures of the proximal humerus has almost universal acceptance for its simplicity and elegance in spite of a growing recognition that it does not produce interobserver reliability, aids little in prognosis and decision-making and often does not correspond to reality at surgery. There are other classifications but they are cumbersome, inaccurate, and for the most part, do not contain any underlying concept of the mechanism of injury which may be helpful in understanding the disparate patterns of bony displacement which characterise this injury.

We inspected 73 museum specimens of fractures of the proximal humerus and reviewed 84 clinical cases. By turning museum specimens in the hand and examining them from multiple directions a three-dimensional (3-D) concept of the fracture may be obtained. A similar examination of fractures can be carried out in clinical practice using 3-D CT reconstruction techniques.

Previous classifications have been based on two-dimensional radiographic analysis of these complicated 3-D fractures. Small changes in rotation and positioning can engender considerable disagreement in the interpretation of standard radiographs. Even when supplemented by standard axial CT studies, a reliable system of classification has not been produced. By contrast, 3-D CT construction gives a much clearer view of the pattern of the fracture. These clinical observations, combined with assessment of the museum specimens, have given rise to an improved system for understanding and classifying these injuries.

Materials and Methods

Before the clinical part of this study was begun 3200 humeri from eight museum collections were examined. Most of these specimens had been collected for teaching purposes during the late 19th and the early part of the 20th century. Seventy-three fractures of the head of the humerus from these collections were reviewed. After study of the specimens an assessment was made of fractures of the proximal humerus in 84 patients who were either seen by the authors over a period of three years, or contributed by orthopaedic colleagues. Emphasis in the choice of these clinical cases was placed on the selection of complicated fracture patterns thought by the examining surgeons on the basis of standard films to be Neer three- or four-part injuries. These complex injuries constituted 61 of the 84 clinical cases (see Table I). 3-D CT reconstructions were performed on all patients. The exact technique of CT acquisition varied with the hospital and the apparatus, the common denominator being a slice...
thickness of 1 mm. Observations at the time of open surgery were recorded in 14 cases. MRI was performed on six patients four months after injury.

The 3-D CT reconstructions were presented in what we term a ‘Fracture Wheel’ format (Fig. 1b) in an attempt to overcome the inherent difficulties of presenting a 3-dimensional object on a two-dimensional printed page. In this format simultaneous 4-quadrant views of the fracture are displayed so that the injury is seen from the front, side, back and from above in one composite picture.

Statistical analysis of interobserver reliability was carried out on the 3-D classification derived from this study by a

Table I. Number of fractures in each 3-D classification category

<table>
<thead>
<tr>
<th>Classification category</th>
<th>Museum specimens</th>
<th>Clinical specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-part</td>
<td>25</td>
<td>16</td>
</tr>
<tr>
<td>Three-part</td>
<td>19</td>
<td>23</td>
</tr>
<tr>
<td>Shield fracture and variants</td>
<td>14</td>
<td>29</td>
</tr>
<tr>
<td>Isolated greater tuberosity</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Fracture dislocations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Posterior</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Avascular necrosis</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>73</td>
<td>84</td>
</tr>
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</table>

Statistical analysis of interobserver reliability was carried out on the 3-D classification derived from this study by a

modification of the methods used by Bernstein et al, Sidor et al and Siebenrock et al in their classical articles testing the reliability of systems for the classification of fractures of the proximal humerus. Twenty fractures were selected at random from among the 84 clinical cases. The cases were presented in a Fracture Wheel format and shown in random order to ten orthopaedic surgeons of varying degrees of experience. There were six senior consultants, two residents, one shoulder specialist, and one traumatologist. Each observer was provided with a numbered diagram of the new classification together with a short verbal and written explanation. The classification was simplified into

Figure 1a – (1) Anteroposterior and (2) axillary radiographs of a fracture of the proximal humerus in a 69-year-old man. View 1 was taken with the arm in a sling in internal rotation. In view 3 the sling has been removed and the arm positioned in slight external rotation. There is a marked change in the appearance of the fracture.

Figure 1b – 3-D reconstruction of the fracture seen in Figure 1a displayed in a “Fracture Wheel” format. Viewed from the front, side, back and from above this provides a comprehensive less distorted view of the injury and permits assignment in this case to the Three-Part category in the 3-D classification system. GT denotes the greater tuberosity. B is in the bicipital groove.
### A Three-Dimensional Classification for Fractures of the Proximal Humerus

#### Fig. 2

Diagram of the five basic types of fracture in the 3-D classification. Rare additional injuries not pictured are (1) fractures of the anatomic neck (2) isolated fractures of the lesser tuberosity and (3) posterior fracture dislocations.

<table>
<thead>
<tr>
<th></th>
<th>2 Part</th>
<th>3 Part</th>
<th>Shield fracture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Valgus</strong></td>
<td><img src="image" alt="Valgus 2 Part" /></td>
<td><img src="image" alt="Valgus 3 Part" /></td>
<td><img src="image" alt="Valgus Shield fracture" /></td>
</tr>
<tr>
<td><strong>Varus</strong></td>
<td><img src="image" alt="Varus 2 Part" /></td>
<td><img src="image" alt="Varus 3 Part" /></td>
<td><img src="image" alt="Varus 4-Part" /></td>
</tr>
<tr>
<td><strong>Neutral</strong></td>
<td><img src="image" alt="Neutral 2 Part" /></td>
<td><img src="image" alt="Neutral 3 Part" /></td>
<td><img src="image" alt="Neutral Shield fracture" /></td>
</tr>
<tr>
<td>Fracture dislocation</td>
<td><img src="image" alt="Fracture dislocation 2 Part" /></td>
<td><img src="image" alt="Fracture dislocation 3 Part" /></td>
<td><img src="image" alt="Fracture dislocation Shield fracture" /></td>
</tr>
<tr>
<td>Anterior (illustrated)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior (not illustrated)</td>
<td></td>
<td></td>
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</table>

#### Fig. 3a

Specimen from the Vienna museum showing fracture lines but with no displacement of the fragments. Figure 3a – The arrows and arrowheads indicate the primary anterior and posterior fracture lines in the greater tuberosity, B denotes the bicipital groove. Figure 3b – Photograph showing the triangular pattern of fracture lines in the humeral head in relation to the similar shape of the glenoid. Figure 3c – Diagram of proposed mechanism of injury in the majority of proximal humeral fractures. In a fall, the “parachute reflex” disposes the arm to varying degrees of flexion, abduction and internal rotation. The head of the humerus is then broken on the hard anvil of the glenoid.
four different sections\(^1\) as follows: 1) two-part fractures, 2) three-part, 3) shield fractures with their variants and 4) isolated fractures of the greater tuberosity. The observers were also asked to determine if the head of the humerus was dislocated. Each observer then assessed the fractures individually and no discussion between observers was allowed. Five minutes were allotted for making a decision on each fracture. The number of the chosen category for each fracture together with assessment as to dislocation was recorded on a separate form. Interobserver reliability was statistically analysed by weighted kappa coefficients.

**Results**

**Initial observations.** The key to the understanding of complex fractures lies in an appreciation of the simpler patterns of fracture and the mechanisms which underlie them. We have been led to this belief by examining a ‘Rosetta stone’ fracture in the Bone Pathology Museum in Vienna, Austria (Pathologisch-Anatomisches Bundesmuseum, Specimen # MN 10.373). This showed an incomplete fracture of the head of the humerus in a young adult male in which the lines of the fracture were clearly apparent but in which the gross architecture of the head had not yet been distorted (Fig. 3a). When holding this bone in a position of forward flexion, abduction and internal rotation in relation to the appropriate scapula (Fig. 3b) the outline of the incipient fractures on the humeral head traced a similar pattern to that of the triangular shape of the glenoid. The latter, which preserves its hard-packed bone into late old age, is the anvil on which the head breaks (Fig. 3c). The simulated position of forward flexion, abduction and internal rotation is the position in which the arm is usually held when the hand is outstretched to break a fall. This is an instinctive protective movement which infants first manifest at one year of age; the ‘parachute reflex’,\(^1\) and accounts for a large number and variety of injuries to the upper limb.\(^\text{19-21}\) Fractures of

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**Fig. 4**

The posterolateral tilt of the head fragment in a two-part injury is emphasised by noting the direction of the bicipital groove (B) in the museum specimen a) and in a clinical case of 54-year-old woman b) Two-part injuries also commonly present in varus as in the museum specimen c) and a 48-year-old woman d) especially when there is comminution in the area of the medial calcar.
the proximal humerus may also occur by other mechanisms of injury such as by direct impact against the ground or other hard object or with the arm in external rotation. However, the glenoid remains the anvil against which the head is broken. Fragments of the fracture may then be additionally displaced by activity of muscle or tendon.

This underlying concept of injury allows us to understand both the simpler two-part fractures and the more complex forms. The fractures in the museum specimens and in the 3-D clinical material, group themselves into five major patterns (Fig. 2) as follows: 1) two-part; 2) three-part; 3) “Shield” fractures and their variants; 4) isolated greater tuberosity; and 5) fracture dislocations.

We shall define and discuss the fractures in this order.

**Two-part fractures.** Many fractures of the proximal humerus involve only two segments, namely the head with tuberosities attached and the shaft (Fig. 4). The glenoid drives the head backwards because of the position of internal rotation in which the fall usually takes place augmented by normal retroversion of the head. The principal deformity is backward and downward tilting of the head on the shaft. The major fracture line is through the relatively weak metaphyseal bone of the ‘surgical neck’. The backward tilt may give rise to the impression of an exaggerated valgus of the head when seen on a standard anteroposterior (AP) radiograph, especially if taken in internal rotation, the posture in which a patient’s arm is commonly immobilised. However, true valgus deformity is usually minimal in these injuries (Figs 4a and 4b), and in fact, a tipping into varus is more common especially in those cases in which there is substantial comminution in the calcar resulting in loss of the medial support of the head (Figs 4c and 4d).

A similar pattern of forceful backward tilting of the fragment of the head can be seen in multipart fractures (Neer 3-
or 4-part injuries), but the pattern is more difficult to detect because of the overlapping and distortion of the numerous bone fragments. Multipart injuries typically occur in older persons with weak osteoporotic bone. The mean age of the museum specimens was 53 years and of clinical specimens, 66 years. In these cases, as in the less complicated injuries, the bony shell of the head yields to the backward thrust of the glenoid, tilting posteriorly through the fracture of the surgical neck. At the same time, in these more complex injuries, the tuberosities are shattered, the greater tuberosity much more commonly than the lesser.

**Three-part fractures.** This is the most common pattern seen in multipart injuries and leaves the lesser tuberosity attached to the head fragment which has fractured at the surgical neck and fallen into neutral, varus or valgus (Fig. 2). Key in this injury is the additional fracture(s) in the greater tuberosity (Fig. 1b) which breaks off from the main head/lesser tuberosity element as the glenoid continues to drive the head back and down. In these injuries, the superior part of the bicipital groove, where the principal anterior circumflex blood supply enters the humeral head remains intact and therefore avascular necrosis of the head is unlikely.

**Shield fracture.** Another common pattern seen in multipart injuries was initially the most difficult to understand. This produced what we describe as a Shield Fracture (Fig. 5). The Shield is a section of bone circling around the head fragment comprised of the greater and lesser tuberosities held together by the bicipital groove. The ‘Shield’ fracture is most easily understood as a worsening and a progression of the previously discussed three-part fracture pattern as the head segment continues to be driven down and back (Fig. 6). The cartilaginous head is sheared off from the ‘Shield’ by the anvil of the glenoid and tilts backwards into varus (Figs 7a and 7b) or into true valgus (Figs 7c and 7d). The ‘Shield’ itself, the greater tuberosity component in particular, is also usually internally comminuted, often along the incipient fracture lines seen in the specimen from the Vienna Museum (Fig. 3). The most posterior portion of the comminuted greater tuberosity is often displaced backwards by its musculotendinous attachments (Figs 6b and 7b). The remainder of the ‘Shield’ may, in turn, fracture at its base but displace minimally or may crack off completely and fold up and over the top of the depressed head producing what we have characterised as a ‘hat-over-head’ deformity (Figs 7b and 8b). The ‘Shield’ fragment can sometimes be appreciated on standard radiographs or on axillary (Fig. 8a) or coronal CT projections (Fig. 8b), but is best seen in 3-D reconstruction (Fig. 8c).

The Shield-fracture injury is a continuation and an exacerbation of the simpler patterns of injury previously demonstrated. As such, it re-emphasises the underlying continuity in the progression of severity in most fractures of the proximal humerus. In the simpler two-part injuries, the major fracture line is through the surgical neck alone. In three-part injuries, in addition to the surgical neck, the greater tuberosity fractures. With progression of the severity the major fracture line detaching the greater tuberosity...
from the head continues forward to incorporate the superior bicipital groove and the lesser tuberosity, creating a full blown ‘Shield’ configuration. The ‘Shield’ itself is then commonly split internally into several fragments. Usually, comminution in the greater tuberosity predominates but, in severe injuries, additional fracture lines open up. This produces three variants of the Shield-fracture which we call: (1) the Four-part, (2) the Shattered Shield and (3) the Head Split (Fig. 2).

Four-part Variant. This Variant is usually taken to be the classic Neer 4-part injury but is in fact a variety of Shield fracture in which there is internal comminution of the Shield in a characteristic fashion. The distinguishing portion of this fracture is a relatively small segment of greater tuberosity attached to the hard bone of the bicipital groove and via the groove to the lesser tuberosity (Figs 9a and 9b). The biceps groove does not form a plane of cleavage between the tuberosities as conceived in the Codman/Neer concept of injury in which the four pieces “pull apart” along old lines of epiphyseal weakness. Instead the characteristic fracture bypasses the hard bone of the groove and is cleaved by the glenoid in the softer bone of the greater tuberosity just lateral to the supratrochlear facet (arrows, Figs 9a and 9b) from which the fragment proceeds medially across the groove to include to the lesser tuberosity. In neither the museum specimens or in the clinical cases did we find a discrete, isolated lesser tuberosity fragment.

Shattered Shield Variant. In this pattern (Figs 9a and 9b), generalised comminution is more severe. Multiple fracture lines in the Shield spill over from both the lesser and the greater tuberosities surrounding the hard bone of the bicipital groove. The superior portion of the groove remains intact with tiny fragments of the lesser and greater tuberosities attached to it. A small ‘bone island’ is thus formed...
within the Shattered Shield (arrows, Figs 9a and 9b). This intense comminution takes place in exactly the area of ingress of the major anterior circumflex blood supply to the head and thus these injuries carry with them an overwhelming risk of avascularity of the head.

**Head-split variant.** The Shield-fracture pattern also accounts for what has been characterised as a “Head-split” fracture.\(^1\) In this, as in other types of Shield injury, most of the head is detached and driven backwards by the thrust of the glenoid. But, in this type, a part of the cartilaginous head is left attached to the Shield fracture. On standard radiographs, the head may appear to split vertically into two major fragments (Fig. 10a). However, this vertical split is an illusion, which may be suspected on two-dimensional CT (arrow, Fig. 10b) but is best understood on a 3-D view (Fig. 10c). The sagittal shearing away of the head from the Shield fragment, rather than a vertical Head-Split, is invariably confirmed at operation (Fig. 10d).

**Isolated fractures of the greater tuberosity.** Most fractures of the greater tuberosity are combined injuries associated with either three-part or Shield Fracture patterns. However, isolated fractures of the greater tuberosity do occur (Fig. 11). They are a different entity and constitute the fourth of our five fracture categories. Together with the final category of anterior fracture dislocations, these injuries appear to occur with the arm in external rather than internal rotation.\(^2\) However, the glenoid remains the anvil on which the head breaks. Isolated fractures usually involve the posterolateral aspect of the greater tuberosity and do not extend all the way to the bicipital groove. These injuries, of which there were five museum and five clinical cases, were always associated with Hill-Sachs fractures (Figs 11a and 11b) and appeared to be extensions or...
Figures 9a and 9b – 4-part variant is a result of internal fractures in the Shield with the major fracture line passing through the tuberosity just lateral to the bicipital groove (arrow a). In a more severe injury b) this fracture line opens up widely. Fragments: #1 = head; #2 = greater tuberosity; #3 = lesser tuberosity element; #4 = shaft. B is the bicipital groove; G, the greater tuberosity; L the lesser tuberosity. The Shattered-Shield Variant c,d) is a result of intense comminution in the Shield fragment producing a small ‘island’ of bone (arrows) within the overall Shield fragment.

Fig. 10
Head-split Variant of the Shield fracture. All the illustrations are of the same patient. Figure 10a – An apparent ‘vertical’ split of the head is seen on the standard AP radiograph (arrows). Figure 10b – The Shield fragment (arrow) can be appreciated on the standard axillary CT view. However, the 3-D reconstruction view Figure 10c – from overhead best shows the superior ‘Head-split’ component (H-1) attached to the Shield element. The remaining major portion of the head (H-2) is driven backwards and down by the glenoid (GL) anvil. d) Operative specimens of the injury excised at hemiarthroplasty. The fracture has been reduced and laid on an intact skeletal model.
enlargements of these lesions (Figs 11c and 11d) In the presence of an isolated fracture of the greater tuberosity it may be that an episode of anterior instability with spontaneous reduction has taken place even though the patient may not have been aware of it at the time of injury.

Fracture dislocations. The mechanism of injury in anterior dislocations involves external, not internal rotation, with the anterior glenoid rim impacting the head.\textsuperscript{23} Fracture dislocation (Fig. 12) constitutes the last group of our major classification types. They may recreate variations of any of

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fracture_wheel}
\caption{Fracture-wheel presentation of (1) anterior and (2) posterior fracture dislocation. Fractures accompanying dislocations may recreate any of the other 4 types of injury we have seen in the 3-D classification (Fig. 2). Here example #1 is a Shield pattern with the head sheared away completely from the Shield and left anteriorly. #2 is a varus two-part posterior fracture dislocation with the additional element of a Reverse Hill Sachs lesion.}
\end{figure}
the previous four types of injury in addition to the added element of dislocation (Fig. 2). The rare posterior fracture dislocation (Fig. 12b) occurs in extreme internal rotation with the fracture anvil being the posterior rather than the anterior glenoid rim. The patterns of fracture in posterior dislocation are accompanied by the characteristic reverse Hill-Sachs lesion.

Special case considerations

Valgus impacted injury. This fracture is the subject of much controversy in the literature because it appears to heal more benignly and with less tendency to avascularity than would be expected from the degree of severity seen on standard radiographs (Fig. 13a). This disparity can be explained when the fracture is seen in 3-D. Thus appreciated (Fig. 13b) these injuries are typically three-part fractures with the head characteristically driven back and down. The lesser tuberosity and the area of vascular ingress into the head through the upper part of the bicipital groove remain structurally intact. The blood supply is not compromised and the fractures heal satisfactorily. Valgus-impacted fractures occur less frequently as Shield injuries. The distinction between these two types of valgus injury can only be made with 3-D CT. Although the blood supply would seem to be potentially more compromised in the impacted shield rather than the more common impacted three-part pattern avascularity remains to be determined by long-term follow-up studies.

Avascular necrosis. Avascular necrosis of the humeral head is typically three-part fractures. The distinction between these two types of valgus-impacted injury can only be made on 3-D examination. c,d) Two examples of avascular necrosis of the humeral head. In c the head fragment (H) is depressed backward and has collapsed under the greater tuberosity (G) component of the Shield producing a “hat-over-head” deformity. L is the lesser tuberosity, B the bicipital groove.

Results of interobserver reliability analysis. With the use of the 3-D classification system, the mean Kappa coefficient
The experience gained from understanding the patterns of fracture seen in 3-D also helps in a better understanding of standard two-dimensional images when only these are available. The future, however, is clearly in three dimensions, not only for this injury but also for other common and uncommon fractures, the precise anatomy and classification of which remain in dispute.3,5,35-37

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References

Discussion
We concluded that most fractures of the proximal humerus can be organised into five basic types. This constitutes a modification of the Codman/Neer classification especially in regard to the concept of the ‘Shield Fracture’ which had not been previously recognised as a major element in the evolution and anatomy of the more complex fractures.

Statistical analysis of interobserver reliability shows that this 3-D classification gives an approximate twofold improvement over previous classifications. Other authors6,9,13,14 have shown that intraobserver reliability, levels of clinical expertise, the number of fracture categories, and pretraining of observers may also impact on the validity of a classification, but not to the extent of changing the overall superior results revealed by our kappa analysis.

Clinical Implications. Recent large-scale studies have suggested that surgery done under the direction of classifications based on two dimensions alone gives no better results than non-operative care.31-34 Understanding the fracture in three dimensions has the potential to modify and to improve surgical procedures. For example, when hemiarthroplasty is indicated the biceps tendon remains a helpful guide if the actual fractures within the Shield are appreciated before operation in 3-D. Pinpointed beforehand, these major fracture lines can be found at surgery and provide easy and less destructive access to the head fragment than conventional approaches and allow a more anatomical reconstruction. A renewed appreciation of the primacy of the backward tilt deformity in severe two- and three-part injuries, together with a better understanding of the characteristic cleavage patterns in the greater tuberosity, has also been indispensable in addressing these injuries when reduction of the fracture is indicated by either open or percutaneous means.

Three-dimensional reconstruction is a powerful tool in the surgeon’s hands. It is worthwhile for the clinician personally to supervise the manipulation of images in these cases. Minimally displaced or thin subcondral fractures, such as those in the Vienna bone specimen (Fig. 2), are difficult to detect. Marked comminution of the fracture can also compromise 3-D reconstruction. Lack of quick and easy acquisition of pictures is the current limitation in 3-D reconstruction techniques. With the present technology, the surgeon, radiologist and technician must work together diligently to obtain useful images. However, in addition to becoming more universally available, the 3-D techniques continue to improve with time and, no doubt, in their turn will be superseded by other 3-D methods, such as MRI, which will not require exposure to radiation and may ultimately provide better resolution.

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