A three-dimensional classification for fractures of the proximal humerus

G. Edelson, I. Kelly,
F. Vigder, N. D. Reis

*From Poriyya
Government
Hospital, Tiberias,
Israel*

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 humerus¹⁻³ has almost universal acceptance^{4,5} 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.⁶⁻¹⁴ There are other classifications^{8,15-17} 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 (Fig. 1a). Even when supplemented by standard axial CT studies, a reliable system of classification has not been

produced.^{6,18} By contrast, 3-D CT construction gives a much clearer view of the pattern of the fracture (Fig. 1b). These clinical observations, combined with assessment of the museum specimens, have given rise to an improved system for understanding and classifying these injuries (Fig. 2).

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

■ G. Edelson, MD, FFAO,
Chief, Department of
Orthopaedics
■ F. Vigder, MD, Chief,
Department of Radiology
Poriyya Government
Hospital, Tiberias 15208,
Israel.

■ I. Kelly, MD, FRCS, Senior
Consultant Orthopaedic
Surgeon
Glasgow Royal Infirmary,
Glasgow G4 0SF, UK.

■ N. D. Reis, MD, MS, FRCS,
Senior Consultant
Orthopaedic Surgeon
Rambam Hospital Centre,
Haifa 31096, Israel.

Correspondence should be
sent to Dr G. Edelson.

©2004 British Editorial
Society of Bone and
Joint Surgery
doi:10.1302/0301-620X.86B3.
14428 \$2.00

J Bone Joint Surg [Br]
2004;86-B:413-25.
Received 15 April 2003;
Accepted 8 August 2003

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

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

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

modification of the methods used by Bernstein et al,⁶ Sidor et al¹³ and Siebenrock et al¹⁴ 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

Fig. 1a**Fig. 1b**

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.

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.

Fig. 3a

Fig. 3b

Fig. 3c

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.

Fig. 4

The posterolateral tilt of the head fragment in a two-part injury is emphasised by noting the direction of the bicapital 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.

four different sections¹⁴ 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 Bundersmuseum, 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',¹⁸ and accounts for a large number and variety of injuries to the upper limb.¹⁹⁻²¹ Fractures of

Fig. 5

The Shield-fracture pattern in three clinical cases. The Shield comprises the lesser tuberosity (L), the bicipital groove (B) and the greater tuberosity (G). The head fragment (H) is pushed down and back by the impact of the glenoid. It may be disposed in neutral, varus or valgus.

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-

Fig. 6

Overhead views showing diagrammatic representations and clinical specimens illustrating progression of the fracture line(s) from a Three-part to a Shield-fracture injury. The posterior aspect of the Shield fragment is often comminuted and displaced backwards probably as a result of the pull of the attached muscle/tendon units. Arrowheads outline the Shield in the bottom left specimen.

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

Fig. 7

Anterior and posterior views of two museum specimens illustrating Shield-fracture variant patterns. Figure 7a – the anterior portion of the Shield is comprised of the lesser tuberosity (L), the bicipital groove (B) and the greater tuberosity (G). A small “Head-split” element (H) remains attached to the Shield. From b) a posterior aspect the greater tuberosity is seen to be comminuted with a portion displaced backward; (c,d) the Shield pattern has gone on to avascular necrosis with the head displaced into valgus. The Shield with part of the head remaining attached forms a “hat-over-head” pattern seen both from the front and from behind.

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 supranatus 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

Fig. 8

The Shield-fracture fragment (arrows) seen in (1) standard axillary CT, in (2) coronal (CT), and in (3) a 3-D reconstruction in the same patient. B is the bicipital groove.

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.¹⁷ 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.²³ 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

Fig. 9

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.

Fig. 11

Figure 11a – 3-D reconstructions showing an ‘isolated’ fracture of the greater tuberosity. A Hill-Sachs (HS) lesion is seen. Figure 11b – A similar HS lesion seen in a museum specimen. The dotted line indicates the potential course of a fracture. Figures 11c and 11d – Museum specimens showing HS lesions extended into fractures of the greater tuberosity after anterior dislocations. GL is the glenoid; T, the greater tuberosity and B, the bicipital groove.

Fig. 12

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.

1 = Anterior fracture dislocation
2 = Posterior fracture dislocation

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.²³ Fracture dislocation (Fig. 12) constitutes the last group of our major classification types. They may recreate variations of any of

Fig. 13

Valgus-impacted fractures are typically Three-part injuries a,b). Less commonly they are Shield 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.

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 literature²⁴⁻²⁶ 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 head fragment with major segmental collapse was seen in five museum cases and in one clinical case. The typical picture of total involvement of the head produced a ‘fried-egg’ deformity with the central head fragment collapsed into a splayed-out, ring of surrounding tuberosities (Figs 13a and 13b) comprised of the still largely viable Shield-fracture element. Avascular necrosis occurs most commonly in the Shattered Shield and in other severely displaced Shield Variants, or in severe fracture dislocations in which the cartilaginous head is detached completely (Fig. 12a). Avascular necrosis is unpredictable, presumably as a consequence of the variability of the blood supply to the head,²⁷⁻²⁹ and may occur with any pattern of fracture. However, the type of fracture which most often predisposes to this consequence can be identified and only in these should primary prosthetic replacement be considered.

Results of interobserver reliability analysis. With the use of the 3-D classification system, the mean Kappa coefficient

(interobserver reliability) was 0.69 (confidence limit 0.66 to 0.72). Previous papers evaluating kappa values for other classifications of these fractures have shown interobserver reliability to be less than half that which we have demonstrated.³⁰

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 authors^{6,9,13,14} 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 subchondral 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.

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.^{5,35-37}

We thank the following museums, curators and staff, for providing access to their skeletal collections: The Terry Collection of the Smithsonian Museum, Washington, DC, USA; The Cobb Collection of the Howard University, Washington, DC, USA; The Mutter Museum of the Philadelphia College of Physicians; The Heymon Todd Collection of the Museum of Natural History, Cleveland, Ohio, USA; The Pathologisch-Anatomisches Bundesmuseum, Vienna, Austria; the Combined Museums of the Royal College of Surgeons, London, UK; the Guy's Hospital Museum, London, UK and The Museum of the Department of Anthropology/Anatomy, Sackler School of Medicine, Tel Aviv, Israel.

We also acknowledge the following physicians for their case contributions: Drs M. Perry, C. Milgram, V. Barsalon, S. Karkabi, S. Velkes and N. Roseberg. We also thank K. Williamson and T. Nunn for graphics, S. Mendel for CT reconstructions, D. Zrihan for photography, H. Geva and T. Mashiach for statistical analysis, and J. Schwartz for her preparation of the manuscript.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References

1. **Neer CS 2nd.** Displaced proximal humeral fractures: I. Classification and evaluation. *J Bone Joint Surg [Am]* 1970;52-A:1077-89.
2. **Neer CS II.** *Shoulder reconstruction*. Philadelphia: WB Saunders Company, 1990: 364-98.
3. **Neer CS 2nd.** Four-segment classification of proximal humeral fractures: purpose and reliable use. *J Shoulder Elbow Surg* 2002;11:398-400.
4. **Bigliani L, Flatow EL, Pollock RG.** Fractures of the proximal humerus. In: Rockwood CA, Matsen FA III, eds. *The shoulder*. Vol 1. Second ed. Philadelphia: WB Saunders Company, 1998:337-74.
5. **Fransen PA, Anderson E, Madsen F, Skjødt T.** Garden's classification of femoral neck fractures: an assessment of inter-observe variation. *J Bone Joint Surg [Br]* 1988; 70-B:588-90.
6. **Bernstein J, Adler LA, Blank JE, et al.** Evaluation of Neer system of classification of proximal humerus fractures with computerized tomographic scans and plain radiographs. *J Bone Joint Surg [Am]* 1996;78-A:1371-5.
7. **Boileau P, Walch G, Romeo A, Sinnerton R.** Classification and treatment for the sequelae of proximal humerus fractures: a prospective multicenter study of 71 cases. *Seventh International Conference Surgery of the Shoulder*. 1998:501.
8. **Brien H, Nofall F, MacMaster S, et al.** Neer's classification system: a critical appraisal. *J Trauma* 1995;38:257-60.
9. **Brorson S, Bagger J, Sylvest A, Hrobjartsson A.** Improved interobserver variation after training of doctors in the Neer system. *J Bone Joint Surg [Br]* 2002;84-B: 950-4.
10. **Burstein AH, Adler LM, Blank JE, et al.** Evaluation of the Neer system of classification of proximal humeral fractures with computerized tomographic scans and plain radiographs. *J Bone Joint Surg [Am]* 1996; 78-A:1371-5.
11. **Kristiansen B, Andersen UL, Olsen CA, Varmarken JE.** The Neer classification of fractures and of the proximal humerus: an assessment of interobserver variation. *Skeletal Radiol* 1988;17:420-2.
12. **Kristiansen B, Christensen SW.** Proximal humeral fractures: late results in relation to classification and treatment. *Acta Orthop Scand* 1987;58:124-7.
13. **Sidor M, Zuckerman J, Lyon T, et al.** The Neer classification system for proximal humeral fractures: an assessment of interobserver reliability and intraobserver reproducibility. *J Bone Joint Surg [Am]* 1993;75-A:1745-50.
14. **Siebenrock K, Gerber C.** The reproducibility of classification of fractures of the proximal end of the humerus. *J Bone Joint Surg [Am]* 1993;75-A:1751-5.
15. **Dehne E.** Fractures at the upper end of the humerus: a classification based on the etiology of the trauma. *Surg Clin North Am* 1945;45:28-47.
16. **Mueller ME, Nazarian S, Koch P, Schatzker J.** *The comprehensive classification of fractures of long bones*. New York: Springer 1990:54-63.
17. **Sjoden G, Movin T, Guntner P, et al.** Poor reproducibility of classification of proximal humeral fractures: additional CT of minor value. *Acta Orthop Scand* 1997;68: 239-42.
18. **Neer CS II.** *Shoulder reconstruction*. Philadelphia: WB Saunders Company 1990: 395.

19. **Gross RH.** Normal development of the newborn, in Morissy TM, Weinstein SL eds: *Pediatric orthopaedics*. Vol. 1. Philadelphia, etc: Lippencott – Raven Publishers, 1996: 55-9.
20. **Dobyns H, Linscheid RL.** Fractures of the distal radius, in Rockwood CA and Green DP: *Fractures and dislocations of the wrist*. Vol. 1. Philadelphia etc: JB Lippencott Company, 1984:432-50.
21. **Hildebrand K, Patterson S, King G.** Acute elbow dislocations, simple and complex. *Orthop Clin North Am* 1999;30:63-79.
22. **Kasser J.** Forearm fractures, in Macewen G, Kasser J, Heinrich S eds. *Children's fractures: a practical approach to assessment and treatment*. Baltimore: Williams & Wilkins, 1993:165.
23. **Matsen F III, Thomas S, Rockwood C Jr, Wirth M.** Glenohumeral instability. In: Rockwood CA, Matsen FA III, eds. *The shoulder*. Vol. 2. 2nd ed. Philadelphia: WB Saunders Company, 1998:611-89.
24. **Jakob R, Miniaci A, Anson P, et al.** Four-part valgus impacted fractures of the proximal humerus. *J Bone Joint Surg [Br]* 1991;73-B:295-8.
25. **Court-Brown C, Cattermole H, McQueen M.** Impacted valgus fractures (B1.1) of the proximal humerus: the results of non-operative treatment. *J Bone Joint Surg [Br]* 2002;84-B:504-8.
26. **Elkowitz S, Koval KJ, Zuckerman JD.** Decision making for the treatment of proximal humerus fractures. *Techn Shoulder Elbow Surg* 2002;3:234-50.
27. **Brooks CH, Revell WJ, Heatley FW.** Vascularity of the humeral head after proximal humeral fractures. *J Bone Joint Surg [Br]* 1993;75-B:132-6.
28. **Duparc F, Muller JM, Freger P.** Arterial blood supply of the proximal humeral epiphysis and anatomical basis of post-traumatic necrosis. *J Shoulder Elbow Surg* 2000:545-8.
29. **Gerber C, Schneeberger A, Vinh TS.** The arterial vascularization of the humeral head: an anatomical study. *J Bone Joint Surg [Am]* 1990; 72-A:1486-94.
30. **Sanders, RW.** Editorial: the problem with apples and oranges. *J Orthop Trauma* 1997;11:465-6.
31. **Court-Brown CH, et al.** Epidemiology and outcome in the older patient. *J Bone Joint Surg [Br]* 2001;83-B:6.
32. **Rasmussen S, Hyass I, Dalsgaard J, Christensen BS, Holstad E.** Displaced proximal humeral fractures: results of conservative treatment. *Injury* 1992;23:41-3.
33. **Young TB, Wallace WA.** Conservative treatment of fractures and fracture dislocations the upper end of the humerus. *J Bone Joint Surg [Br]* 1985;73-B:373-7.
34. **Zyto K, Ahrengart L, Sperber A, Tornkvist H.** Treatment of displaced proximal humeral fractures in elderly patients. *J Bone Joint Surg [Br]* 1997;79-B:412-7.
35. **Dirschl DR, Adams GL.** A critical assessment of factors influencing reliability in the classification of fractures, using fractures of the tibial plafond as a model. *J Orthop Trauma* 1997;11:471-6.
36. **Gehrchen PM, Nielsem JO, Olesen B.** Poor reproducibility of Evans classification of the trochanteric fracture: assessment of 4 observers in 52 cases. *Acta Orthop Scand* 1993;64:71-2.
37. **Rasmussen S, Madsen PV, Bennicke K.** Observer variation in the Lauge-Hansen classification of ankle fractures: precision improved by instruction. *Acta Orthop Scand* 1993;64:693-4.