Various classifications of scaphoid fractures have been based on plain radiography, but there are difficulties in defining the actual fracture line without an appreciation of the three-dimensional anatomy.

Radiological fracture lines were therefore mapped on transparent methylmethacrylate models of the bone. An analysis of 91 acute fractures showed that 11 were apparently incomplete. The other 80 showed three basic anatomical patterns: transverse through the waist, oblique in the plane of the dorsal sulcus, or of the proximal pole. There was some variation and comminution in these patterns, but no distal fractures of the body were seen.

The interpretation of different radiological projections is discussed. The findings have implications for the management and the assessment of outcome.

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Fractures of the scaphoid may involve the body, the tubercle or be avulsions of bone fragments. Despite the many reports on the clinically important fractures through the body, these injuries are poorly understood because the radiological fracture lines are difficult to relate to the three-dimensional anatomy. This has led to problems in appreciating the natural history, the mechanics of collapse and the optimum surgical fixation of the various patterns of fracture.

The natural history of fractures of the body must depend on the type of injury. Classifications have usually been based on a limited number of radiological views, but the complex shape and orientation of the normal bone mean that these radiographs give distorted and confusing images. Plain radiographs, particularly single views, are very unreliable in determining the true level and alignment of a fracture. Confusion is even greater when there is displacement of an acute injury, or bone loss and collapse after nonunion. Most classifications which are based on a few views cannot actually group the fractures into true types and therefore are not able to predict the natural history. This is also true of some clinically based classifications which, although useful, do not extend knowledge.

Detailed understanding of the alignment of the fractures to the long axis of the bone and their relationship to ligament attachments would help to establish potential stability. This is important because nonunion is closely related to displacement and collapse as well as to loss of bone, and knowledge of which types of fracture affect stability would be of value in predicting outcome. Understanding of fracture alignment is also important for effective fixation both of acute injuries and after nonunion.

After an analysis of the anatomy of the scaphoid (Fig. 1), including study of the projection of anatomical landmarks on standard scaphoid radiographs, a method of delineating the line of fracture was devised, using three-dimensional methylmethacrylate models.

Material and Methods

After the analysis of 50 dry adult Caucasian scaphoids for shape, anatomical features and variability, ten clear methylmethacrylate models were made of ten bones which covered the full range of variation. The anatomical landmarks seen on standard radiological views were then matched to the appropriate models; their transparency meant that they could be overlaid on radiographs to allow easy visualisation of the bony landmarks. The transparency of the models mimicked the radiological views in showing both volar and dorsal landmarks.

A series of radiographs of scaphoid fractures was then analysed, using an appropriately selected model for each case. It is impossible to determine from a single film whether an apparent fracture line is on the ‘front’ or ‘back’ of the image, and therefore the fracture lines on each view were marked on the model only at points where they broke the ‘edge’ (Fig. 2). A single good radiograph provided two definite cortical points, when both ends of the line were visible and not obscured by overlap from other carpal bones or other parts of the scaphoid. For example, in a neutral posteroanterior (PA) view the tubercle overhangs the waist.
Study of a series of views of one fracture allowed it to be plotted circumferentially around the scaphoid model. This process transferred the fracture line from two-dimensional radiographs to the three-dimensional model (Fig. 3).

A total of 91 acute scaphoid fractures in adults was analysed, excluding small avulsion fractures around the scapholunate joint and fractures of the tubercle. Six views of each wrist were available for 44 fractures studied prospectively over a two-year period (Table I). Three of these 44 had required internal fixation for significant and increasing fracture displacement. The other 47 scaphoid fractures were studied retrospectively but all had adequate radiographs with at least four views at the time of injury. All these patients had undergone surgery and could be traced from the theatre records of four hospitals.

For each of the 91 fractures the model closest to the shape of the scaphoid was selected and the outline of the fracture marked as described above. The fracture patterns seen in the whole series were then analysed to derive a classification.

**Table I.** Recommended radiological views for the detection and classification of scaphoid fractures

<table>
<thead>
<tr>
<th>View Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>Neutral PA</td>
<td>Misleading, but the usual view taken of a painful wrist</td>
</tr>
<tr>
<td>Ulnar-deviated PA</td>
<td>Helpful, especially for fractures of the proximal pole</td>
</tr>
<tr>
<td>Ulnar-deviated PA with 20° tube angulation to the elbow*</td>
<td>Specific view for fractures of the waist; the beam at right angles to the long axis</td>
</tr>
<tr>
<td>45° oblique PA (semipronated)</td>
<td>Best for sulcal fractures, but also shows waist and tubercle fractures. Best for displacement of waist fractures and some sulcal and proximal-pole fractures</td>
</tr>
<tr>
<td>45° oblique AP (semisupinated)</td>
<td>Specific view for fractures of the proximal pole. Also shows dorsal avulsions. Best view for assessing flexion in the humpback scaphoid</td>
</tr>
<tr>
<td>Lateral</td>
<td>Poor for fracture detection unless penetration is good. Shows alignment, and its main use therefore is to demonstrate carpal collapse</td>
</tr>
</tbody>
</table>

* Bridgeman.\[^{32}\] Other views showing the long axis are equally acceptable\[^{33,34}\]

\[^{32}\] Bridgeman. Other views showing the long axis are equally acceptable.\[^{33,34}\]
Results

Fracture patterns. In 11 of the 47 retrospective cases, it proved impossible to define fully the three-dimensional pattern. In eight of these the fracture line appeared to break only a single cortex and could not be traced around the bone. In the other three the fracture line was doubtful despite a positive isotope scan and a clear clinical diagnosis. All 11 fractures united and it was uncertain whether the imaging had been inadequate, or the fracture was only partial as suggested by McLaughlin and Parkes and Herbert and Fisher.

In the 80 scaphoids for which a fracture line could be accurately defined on the appropriate methacrylate model, there appeared to be three main fracture patterns (Fig. 3; Table II) involving:
1) the ‘surgical waist’;
2) the dorsal sulcus; or
3) the proximal pole.

Waist (24; Fig. 4). Only one fracture was in the exact plane of the true anatomical waist, but the other 23 varied only slightly, by passing proximal rather than distal to the lateral apex of the dorsal ridge. Apart from this small variation, all
the fractures followed the anatomical waist at right angles to the long axis of the bone. In a few cases, there was some comminution at the lateral apex and in two cases part of the lateral apex was displaced.

Dorsal sulcus (29; Fig. 5). Fractures in the line of the dorsal sulcus are at 45° to the surgical waist and therefore to the long axis of the bone. The fractures did not follow the sulcus to the tip of the tuberosity, but crossed the palmar face to the scaphocapitate facet. At the lateral apex of the dorsal ridge there were three variations: the fracture line could pass proximally, distally or on both sides of the apex (Fig. 5b). The ‘butterfly’ fragment in the third subgroup showed displacement and comminution.

Proximal pole (27; Fig. 6). These fractures were proximal to the dorsal ridge and originated at the dorsal apex of this ridge, crossing the radioscaphoid joint and then the scaphocapitate joint near its proximal end. There was considerable variation in the relationship of the fracture to the tip of the proximal pole, which seemed to depend on the proximal extent of the facet with the capitate (Fig. 6b). When this facet nearly reached the tip, the fracture line tended to be more proximal. In some scaphoids with a well-developed proximal half, the scaphocapitate facet is distally placed and a fracture of the proximal pole will seem to be more vertical, with a larger proximal fragment on a PA view. The scaphocapitate facet is one of the most variable features of the scaphoid anatomy, and therefore proximal pole fragments also varied in size, although the anatomical basis remained constant.

Radiology. The pattern of a scaphoid fracture cannot be defined from a single radiological view. Neutral and ulnar-deviated PA films do not show fracture lines well, because the axis of the scaphoid is flexed towards the beam and the tubercle overhangs the body. In these views, both surgical waist and dorsal sulcal fractures appear to be transverse and may be difficult to see except as a discontinuity in the radial cortex (Fig. 7). Fortunately, some views provide specific images for each type of fracture. To define all
fractures, a series of scaphoid films should include 45° PA oblique (semipronated) and 45° AP oblique (semisupinated) views and one showing the long axis of the bone, such as an ulnar-deviated PA view with 20° angulation of the beam towards the elbow.

**Surgical waist fractures.** A true lateral film and an ulnar-deviated PA view with 20° angulation to the elbow lie closest to the plane of this fracture, but the lateral view (Fig. 4b) has variable value because of overlap by other carpal bones, although this projection is improved by taking it with the wrist extended. A transverse fracture line on an ulnar-deviated PA view with 20° angulation to the elbow is specific (Fig. 4c). A 45° PA (semipronated) oblique view sometimes gives good definition (Fig. 4d).

**Dorsal sulcal fractures.** This pattern and any associated comminution are best shown on a 45° PA (semipronated) oblique view on which the fracture line runs from the dorsal apex of the ridge adjacent to the lunate, and passes obliquely (Fig. 5c). No other view shows this fracture line as clearly.

**Proximal pole fractures.** These fractures may not be clearly visible unless they are displaced or have had time to develop sclerosis. The specific view is a 45° AP (semisupinated) oblique film (Fig. 6c), which will show the fracture crossing the radioscaphoid joint. A 45° PA (semipronated) oblique or a neutral or ulnar-deviated PA view shows the fracture well, only after often late displacement. The apparent size of the fragment and the angulation of the fracture on PA films depend on the relative size of the proximal pole, and also on the amount of anterior angulation of the scaphoid.

**Discussion**

Normally, two views of a bone are enough to define the plane of a fracture, but the scaphoid, with its significant natural twist at the waist and the overlap of other carpal bones, needs at least four views for the full classification of the pattern of fracture. The recommended views are listed and discussed in Table I, with a neutral PA view included since it is often provided, although it does not help classification.

It is difficult to classify scaphoid fractures from radiographs: careful study of dry cadaver bones or models is needed, and even then some method of three-dimensional reconstruction may be required in clinical practice. Other methods of imaging show displaced fractures and those which have collapsed after nonunion, but these meth-
ods are not yet sensitive enough to define acute ‘undisplaced’ fractures, while being of limited availability and too expensive for routine use. Classification based on plain radiographs has the problem that single views of different fracture patterns may look the same. An example is that a transverse fracture of the waist on Russe’s classification could actually be a type-2 or type-3 sulcal fracture or a fracture of the proximal pole with a large proximal fragment. The distinction requires a three-dimensional appreciation. The best single distinguishing feature between types of scaphoid fracture is the dorsal alignment of the fracture plane, and this cannot be seen or appreciated from a PA view.

Some authors do not appear to understand fully the radiological changes which follow collapse of a scaphoid fracture: the same fracture has been classified differently before and after it has collapsed. These changes are better understood when the fracture pattern is considered on a model or cadaver bone. Fractures of the distal pole or distal third reported in other classifications appear to be due to a similar radiological illusion. When a sulcal fracture collapses, flexion of the distal pole reduces the width of its image on a PA film and makes the fracture appear to be more distal. Excluding tubercle fractures, there were no true fractures of the distal pole or the distal third in the series.

The two fracture lines which pass through the waist of the bone are transverse (surgical waist) or oblique (dorsal sulcal) to the long axis of the scaphoid. The sulcal fracture is probably much less stable than a surgical-waist fracture and is the only pattern which leads to the ‘hump-back’ scaphoid. Nakamura et al describe volar and dorsal types of waist fracture, but do not relate these patterns to the osteology. If these two types, reported to have different patterns of collapse, correspond respectively to the waist and sulcal types described above, this would support the hypothesis that they have different natural histories.

The comminution of scaphoid fractures has been noted, but its extent is not well documented. In the 91 cases studied, undisplaced and displaced butterfly fragments were seen most commonly in dorsal sulcal fractures and to a less extent in those of the waist. In both types these were near the lateral apex of the ridge, on the palmar lateral side of the scaphoid. In general, butterfly fragments and comminution are most common on the compression side of a fracture, and this suggests that these types are not produced by hinging over the dorsal rim of the radius, which has been the usual explanation. Such comminution in the area described would suggest compression rather than distraction. The comminuted area is also similar to the area of bone which is sometimes lost and needs replacement by an anterior wedge graft in some cases of longstanding nonunion.

Classifying scaphoid fractures in three dimensions may not appear to be easy. Any surgeon treating these difficult injuries, however, requires a thorough knowledge of the scaphoid, its anatomy, its anatomical variation, and its radiology. One of the challenges of orthopaedic surgery is the ability to think and operate in three dimensions.

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