What are the radiological predictors of functional outcome following fractures of the distal radius?

The fracture most commonly treated by orthopaedic surgeons is that of the distal radius. However, as yet there is no consensus on what constitutes an ‘acceptable’ radiological position before or after treatment. This should be defined as the position that will predict good function in the majority of cases. In this paper we review the radiological indices that can be measured in fractures of the distal radius and try to identify potential predictors of functional outcome. In patients likely to have high functional demands, we recommend that the articular reconstruction be achieved with less than 2 mm of gap or step-off, the radius be restored to within 2 mm of its normal length, and that carpal alignment be restored. The ultimate aim of treatment is a pain-free, mobile wrist joint without functional limitation.

The fracture most commonly treated by orthopaedic surgeons is that of the distal radius. It is recognised as being largely associated with osteoporosis, and its incidence is expected to rise. The most common complication is malunion, and symptomatic malunion in the active patient usually requires corrective osteotomy. There is little consensus on what constitutes an ‘acceptable’ radiological position, which should be defined as one that will predict good function in the majority of cases. A perfect anatomical reduction is not always achievable, nor is it always necessary for a satisfactory result. A number of measurements are used in the assessment of distal radial fractures, including radial height, ulnar variance, dorsal/palmar tilt, carpal alignment, and intra-articular gaps and steps. In this paper we review the various radiological indices that are relevant to these radial fractures and identify potential predictors of functional outcome.

Radiological measurements
Posteroanterior (PA) and lateral radiographs are the routine views obtained when assessing a distal radial fracture. The orientation of the beam and the position of the wrist, forearm and arm have been shown to influence the appearance of the bony landmarks, which in turn can affect the accuracy of the measurements. The standard method of obtaining a PA radiograph is with the shoulder in 90° of flexion and the elbow in 90° of flexion with the hand positioned in the same plane as the humerus. Johnson and Szabo, in a cadaveric study, showed that a rotational change of 5° produced a change in palmar tilt of 1.6° on the conventional lateral view and a change of 1.0° on the 15° lateral view. This observation is echoed by a clinical study demonstrating an increase in palmar tilt with supination and a decrease in palmar tilt with pronation. Inter-observer error can also confound results, with mean SD between observers of 3.2° for radial angle, 3.6° for conventional lateral palmar tilt and 2.1° for 15° lateral palmar tilt. In addition, van der Linden and Ericson, after studying 250 radiographs, found that only the measurements of dorsal displacement and radial displacement were independent of each other. Significant correlation exists between dorsal tilt and dorsal translation, as well as between radial inclination and shortening.

Radial height. This is measured on the PA view and refers to the distance between a line drawn tangential to the tip of the radial styloid and tangential to the most distal part of the ulnar head (Fig. 1a).

Ulnar variance. This is also measured on the PA view and is the vertical distance between two lines both perpendicular to the long axis of the radius (Fig. 1b). Ulnar variance is a measurement of radial length, with particular emphasis on its effect on the distal radioulnar joint (DRUJ), and should not be confused with radial height.
Radial inclination. This is the measurement of the inclination of the radius towards the ulna on the PA view. It is the angle between a line drawn from the tip of the radial styloid to the medial edge of the articular corner of the radius and a line perpendicular to the long axis of the radius (Fig. 2).

Dorsal/palmar tilt. A line is drawn between the most distal points of the dorsal and volar lips of the distal radius on a true lateral view. The dorsal/palmar tilt is the angle created between this line and a perpendicular line to the long axis of the radius (Fig. 3).

Carpal alignment. Malalignment of the carpus compensates for the deformity of the distal radius and should not be confused with carpal instability ligamentous disruption. With dorsal or palmar tilt of the distal radius the lunate tilts in the same direction. The carpus adapts to this at the midcarpal joint, with either flexion of the distal carpal row in dorsal deformity or extension with palmar deformity of the lunate, and occurs without any disruption of the carpal ligaments. In order to measure this carpal malalignment, two lines are drawn on a lateral view, one along the long axis of the capitate and one along the long axis of the radius. If the lines do not intersect within the carpus, then the carpus is malaligned (Fig. 4).

Table I summarises the measurements that should be considered on each radiological view and details the normal values.

Teardrop angle and anteroposterior (AP) distance. Attention has recently been drawn to the teardrop angle and AP distance, as measured on a lateral radiograph. The teardrop of the distal radius articular surface refers to the U-shaped outline of the volar rim of the lunate facet. The teardrop angle refers to the angle between the central axis of the teardrop and the central axis of the radial shaft, which is normally 70° (Fig. 5). A depressed teardrop angle may be the only evidence that reduction is incomplete and articular incongruity remains. The AP distance is defined by the distance between the apices of the dorsal and volar rims of the lunate facet (Fig. 6).

Articular incongruity
The relationships between the initial insults to the cartilage, the effects of residual incongruity and the subsequent...
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In a retrospective review of 40 young adults at a mean follow-up of 6.7 years, Knirk and Jupiter\textsuperscript{18} showed that a step-off of 2 mm or more was associated with 100% incidence of radiological arthritis of which 93% (26 of 28) were said to be symptomatic. However, only one patient with bilateral fractures had to stop working as a direct result of the injuries. Overall, 61% reported an excellent or good outcome. Trumble, Schmitt and Vedder\textsuperscript{19} examined 43 surgically treated patients at a mean follow-up of 38 months and similarly found that the articular step-off and gap were strongly correlated with the outcome. However, one must recognise the limitations due to the inter- and intra-observer variability in interpreting gaps of less than 2 mm on plain radiographs.\textsuperscript{20}

In another retrospective review, Catalano et al\textsuperscript{21} evaluated 21 young patients at a mean follow-up of 7.1 years following open reduction and internal fixation (ORIF) of a displaced intra-articular fracture. Despite a 76% incidence of radiocarpal arthritis, no patient reported a poor functional outcome. At the last review, the injured wrists were found to have significantly less movement, grip strength, lateral key-pin strength and three-point pinch strength than the uninjured wrists. Flexion was found to be inversely correlated with the maximum displacement gap. Radiocarpal degenerative changes were noted to deteriorate over time, but the patients maintained a high level of function.\textsuperscript{22}

More recently, Forward et al\textsuperscript{7} reviewed 108 patients at a mean follow-up of 38 years after sustaining a distal radial fracture. The majority were treated with manipulation and plaster immobilisation, and only one patient underwent internal fixation. The mean age of the patients at the latest review was 64 years (51 to 80), and an incidence of malunion of 65% was reported. However, none of the patients had reported any limitation of activity as a result of the injuries, and none had required a salvage procedure. Intra-articular injury was again found to be a strong predictor of radiological degenerative changes, as well as reduced flexion. Comparing intra- and extra-articular injuries, the former group reported worse Patient Evaluation Measure and Disabilities of the Arm, Shoulder and Hand (DASH) scores.

Any incongruency of the lunate with the teardrop may indicate a displaced intra-articular fracture or subluxation/dislocation of the radiocarpal joint. Axial loading injuries can cause separation of the dorsal and volar fragments, leading to an increased AP distance. This may also imply disruption of the sigmoid notch.\textsuperscript{15} Forward et al\textsuperscript{7} used increased AP distance of the injured wrist when healed compared to the uninjured wrist as an indicator of previous intra-articular fracture. An arbitrary threshold of 4 mm was used, which was shown to have a sensitivity of 33% but a specificity of 100% for identifying intra-articular injuries.\textsuperscript{7} The teardrop angle was also studied, but no predictive value was reported.\textsuperscript{7} However, these two parameters have not been routinely studied, and so their potential impact on outcome could not be quantified.

Articular incongruity appears to adversely affect the biomechanics of the joint, and two separate cadaveric experiments using pressure-sensitive films have shown significant increases in contact stresses with articular step-offs as small as 1 mm.\textsuperscript{23,24} Such findings would help explain the degenerative changes observed in clinical studies.

**Table 1.** The minimum radiological assessment required for fractures of the distal radius. The mean values and range of values encountered in the normal population are shown.\textsuperscript{15}

<table>
<thead>
<tr>
<th>Radiological view</th>
<th>Normal (range)</th>
</tr>
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<tbody>
<tr>
<td>Posteroanterior</td>
<td></td>
</tr>
<tr>
<td>Radial height (mm)</td>
<td>11 to 12 (8 to 18)</td>
</tr>
<tr>
<td>Ulnar variance (mm)</td>
<td>-2 (-4 to 2)</td>
</tr>
<tr>
<td>Radial inclination (°)</td>
<td>22 to 23 (13 to 30)</td>
</tr>
<tr>
<td>Gap or step in joint</td>
<td>Nil (Nil)</td>
</tr>
<tr>
<td>Lateral</td>
<td></td>
</tr>
<tr>
<td>Dorsal/palmar tilt (°)</td>
<td>11 to 12 (0 to 28)</td>
</tr>
<tr>
<td>Carpal alignment</td>
<td>N/A*</td>
</tr>
<tr>
<td>Gap or step in joint</td>
<td>Nil (Nil)</td>
</tr>
</tbody>
</table>

* N/A, not available
A cadaveric experiment has shown that radial shortening caused the greatest alteration in the kinematics of the DRUJ and the most distortion of the triangular fibrocartilage, compared with loss of radial inclination and palmar tilt. In two retrospective studies, Solgaard and Batra and Gupta found that shortening had the most impact on the result and recommended that the restoration of radial length be the primary goal of surgery. Jenkins and Mintowt-Czyz, in a prospective study of distal radial fractures with plaster immobilisation, showed that shortening of more than 4 mm was associated with wrist pain at a mean follow-up of 23 months. Trumble et al. also concluded that the degree of surgical correction of the shortening was strongly associated with an improved outcome.

**Ulnar variance.** Zenke et al. examined 118 consecutive patients with a displaced distal radial fracture treated with plates. Patients who subsequently developed ulnar wrist pain were noted to have a greater mean ulnar variance at the time of injury and a greater loss of correction of ulnar variance after surgery than those who did not. In a prospective randomised trial involving 120 patients with re-displaced distal radial fractures, McQueen et al. showed that positive ulnar variance (> 3 mm compared to the contralateral wrist) resulted in diminished grip strength.

**Radial inclination.** Closely correlated with radial height is radial inclination, and both reflect the consequence of axial compression. At one to three years after a distal radial fracture, Jenkins and Mintowt-Czyz showed a correlation between the loss of radial inclination and decreased grip strength. In a study of 76 young patients after a mean of 30 years, a statistically significant correlation was found between axial compression and the presence of degenerative changes in the radiocarpal joint and the DRUJ. However, no patient had to change his occupation or leisure pursuits because of the fracture. In a retrospective review of 78 adults with a healed distal radial fracture after a mean of 22 months, Wilcke, Abbaszadegan and Adolphson highlighted the association between a loss of radial inclination of > 10° (compared to the uninjured wrist) and a poorer DASH score.

**Dorsal/palmar tilt.** There is conflicting evidence on the impact of loss of normal palmar tilt on functional outcome, partly due to the variable methods employed to assess function and partly due to the error rate in measuring this value. A number of studies have concluded that reduction of dorsal/palmar tilt was not associated with a better functional outcome, although Forward et al. noted that dorsal angulation was associated with narrowing of the joint space and reduced grip strength.

Other authors have reported that residual dorsal tilt compromises the functional result. McQueen and Caspers performed comprehensive functional assessments on 30 patients with extra-articular fractures after a mean of five years (4 to 6.75). They showed that malunion (dorsal tilt ≥ 12° and > 2 mm of radial shift) was clearly associated with significant functional limitation. In contrast, the limit of palmar tilt has not been well defined in the literature.

**Carpal alignment.** Carpal malalignment is a secondary result of the deformity in the distal radius, and its measurement is less dependent on the orientation of the radiograph than the measurement of dorsal and palmar tilt. McQueen et al. showed that carpal malalignment was associated with diminished recovery of grip strength and range of movement. Similarly, Batra and Gupta identified carpal malalignment as a marker of poor functional outcome, and specifically, a radiolunate angle > 25° was associated with an unfavourable result.

**Associated distal ulnar fracture.** Ulnar styloid fractures occur in approximately 60% to 70% of distal radial fractures, but their significance and treatment remain controversial. May et al. in a retrospective review of 166 patients, found that fracture of the ulnar styloid base and significant displacement of the fracture (> 2 mm) were risk factors for instability of the DRUJ. In a prospective study of 272 distal radial fractures with particular emphasis on DRUJ function, Stoffelen, De Smet and Broos noted that patients with an ulnar styloid fracture had a worse outcome than those without. Using data from a prospective study of distal radial fracture fixation, Souer et al. retrospectively compared matched cohorts of patients with and without an untreated fracture of the base of the ulnar styloid. No significant difference in the function or outcome between the groups was identified during their two-year evaluation, which was not influenced by the degree of displacement of the ulnar fracture.
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Classification

Altissimi et al. studied nearly 300 cases of conservatively treated distal radial fractures and failed to show any association between fracture type and functional results. Gliatis et al. reviewed 169 fractures in young adults at least 18 months after injury and found that neither the Frykman nor Mayo classifications predicted patient-reported outcome. These findings were echoed by a more recent series, with no demonstrable correlation between fracture type and outcome, except for the AO type C2 fracture, which was associated with persistent loss of flexion. It is postulated that the functional outcome depends on the displacement of the initial fracture placement rather than the precise grouping.

Conclusions

There are conflicting messages in the literature regarding the ‘acceptable’ radiological indices for the surgeon faced with a displaced distal radial fracture. This is due to the wide spectrum of injury patterns, different methodologies used by different investigators, and the number of possible parameters studied. The ultimate aim of treatment is a pain-free, mobile wrist joint without functional limitation, but it must be emphasised that such indices should be applied to the active patient who is likely to use their wrist for activities of daily living that require some strength, and not to the frail, dependent patient in whom malunion can more readily be accepted.

Articular incongruity has been consistently linked to the latest evidence suggests that associated fracture of the ulnar styloid does not require intervention, provided that the radius has been treated satisfactorily and the DRUJ is stable. Our recommendations for the levels of deformity beyond which intervention is recommended in the active patient are summarised in Table II.

References


