MRI and plain radiography in the assessment of displaced fractures of the waist of the carpal scaphoid

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We treated 50 patients with fractures of the waist of the scaphoid in a below-elbow plaster cast for up to 13 weeks. Displacement of the fragments was assessed independently by two observers using MRI and radiographs performed within two weeks of injury.

The MRI assessments showed that only the measurement of sagittal translation of the fragments and an overall assessment of displacement had satisfactory inter- and intra-observer reproducibility and revealed that nine of the 50 fractures were displaced. Only three of the 49 fractures with adequate follow-up failed to unite, and all were displaced with more than 1 mm of translation in the sagittal plane. If the MRI assessment of displacement of the fracture was used as the measurement of choice, assessment of displacement on the initial scaphoid series of radiographs showed a sensitivity of between 33% and 47% and a positive predictive value of between 27% and 86%. Neither observer was able correctly to identify more than 33% to 47% of the displaced fractures from the plain radiographs. Although the overall assessment of displacement and gapping and translation in the coronal plane on the plain radiographs influenced the rate of union, none of these parameters identified all three fractures which failed to unite.

We conclude that the assessment of displacement of scaphoid fractures on MRI can probably be used to assess the likelihood of union although the small number of nonunions limits the power of the study. In contrast, the assessment of displacement on routine radiography is inaccurate and of less value in predicting union.

Approximately 85% of fractures through the waist of the scaphoid unite uneventfully with immobilisation in a below-elbow plaster cast for six to 12 weeks.1-3 Displacement of the fracture4-6 and avascularity of the proximal fragment are thought to increase the risk of nonunion. A recent study, however, failed to show an association between vascular changes in the proximal fragment and union of the fracture,7 and another demonstrated that two experienced hand surgeons were unable to predict the likelihood of union from a scaphoid series of plain radiographs.8 Filan and Herbert9 reported that the features of a fracture of the scaphoid on plain radiography correlated poorly with the findings during operative fixation and thus displacement as assessed on radiographs may not reflect the true displacement. Trispiral tomography, CT and MRI have been used to assess displacement more accurately,10-14 but we are unaware of any study which has compared assessments of displacement on plain radiography with those of other modalities. Furthermore, no study has demonstrated an association between displacement, as assessed by any of these modalities, and the rate of union after immobilisation in a below-elbow plaster cast.

Patients and Methods

Approval of the Ethics Committee was obtained for this study. We recruited 50 patients who presented within seven days of sustaining an isolated fracture of the waist of the scaphoid, which was visible on the initial scaphoid series of radiographs (posteroanterior (PA), lateral, 45° pronation and supination obliques, and Ziter views). All were treated nonoperatively by immobilisation of the wrist in a standard ‘Colles’-type below-elbow plaster cast for a mean period of nine weeks (6 to 13). MRI was performed on every patient within two weeks of injury and the images were used to assess displacement of the fragments. The management was not influenced by the findings of MRI. The plaster was removed from the injured wrist after six to eight weeks if the clinician considered that the fracture had united, based on his clinical assessment and the appearance of the fracture on scaphoid series.
radiographs.\textsuperscript{15} If the clinician was uncertain whether a fracture had united, the injured wrist was immobilised further for up to a total of 13 weeks and then mobilised, regardless of the clinical or radiological findings. When there was persistent doubt concerning union, CT was performed, and all fractures which had failed to unite by 16 weeks underwent bone grafting.

The assessment of union was based on a scaphoid series of radiographs performed at least 18 months after injury in 19 patients, between six and 18 months after injury in 23 (three of whom also had CT), between three and six months after injury in five (two of whom had CT), and just after removal of the plaster, at six and 12 weeks, in two patients who then took their discharge and could not be traced. One patient was lost to follow-up during treatment in the cast and was excluded from the study, leaving 49 patients who had follow-up.

**MRI technique.** All the MR scans of the fracture were undertaken with the wrist in plaster within two weeks of injury using a 1.5 Tesla superconducting system (Magnetom Vision; Siemens, Erlangen, Germany). The patients lay supine on the scanner couch with both arms lying alongside the trunk with the elbows and wrists extended and the forearms pronated. A small flexible surface coil was wrapped around the plaster cast which was steadied by Velcro straps. Fat-saturated proton density-weighted fast spin-echo images (3 mm slices) were obtained in the true coronal and sagittal planes of the scaphoid.\textsuperscript{16}

**Assessment of displacement and the reproducibility of its measurement on MRI.** Observer 1 (MB), a senior trainee, who was unaware of the outcome of each fracture, assessed all the MR scans of the scaphoid and selected the best sagittal and coronal sections for each patient. Transparent sheets were taped on to these MR sections and microtipped pens were used to outline the scaphoid and the line of the fracture.
Measurements were made on the sagittal MR images as follows.

(a) The lateral intrascaphoid angle (Fig. 1a) was determined by lines drawn perpendicular to the proximal and distal articular surfaces. However, the method for determining the limits of these surfaces has not been clearly defined and we did not find distinct borders to either surface, which made these measurements difficult. Our technique was more consistent with that of Bain et al than that used by Amadio et al and Trumble et al (Fig. 1a).

(b) The height-to-length ratio (Fig. 1a) was determined by a line drawn along the palmar aspect of the scaphoid, along which the distance between the most proximal and distal limits of the scaphoid (its length) was measured. The maximum height of the scaphoid was measured on a line perpendicular to the first line; the ratio was then calculated.

(c) The maximum gap between the two main fragments of the fracture.

(d) The maximum translation (‘step-off’) between the two main fragments at the palmar cortical surface.

(e) The dorsal cortical angle: lines were drawn along the dorsal cortices of the proximal and distal scaphoid fragments and the angle between them was measured (Fig. 1b).
On the coronal images the anteroposterior (AP) intrascaphoid angle and the maximum gap and translation of the fracture were measured (Fig. 2). As with the sagittal images, difficulty was encountered in determining the borders of the proximal and distal articular surfaces of the scaphoid for the measurement of the AP intrascaphoid angle. Since the reproducibility of these measurements of displacement is uncertain, observer 1 (MB) repeated all the measurements from the same sagittal and coronal MR sections from 15 patients, randomly selected from the 50, after an interval of one week using new transparencies so that there were no visible markings from the first assessment to bias the second. Observer 2 (JAO), a consultant hand surgeon, then used an identical technique to assess the same sagittal and coronal images of the same 15 sets of MR scans to determine inter-observer reproducibility.

Observer 1 (MB) also categorised the 50 scaphoid fractures according to their overall general features (translation, gapping and rotational displacement) into undisplaced (Fig. 3), moderately displaced (Fig. 4) and severely displaced (Fig. 5) fractures. For this assessment of displacement, all sagittal and coronal MR sections were used rather than the single best sagittal and coronal images. This allowed a better three-dimensional appreciation of displacement of the fracture. In order to assess the inter-observer reproducibility of this qualitative assessment of displacement, observer 3 (SD) assessed the MR scans of all 50 patients in the same manner.

Inter- and intra-observer reproducibility was assessed by determining the 95% limits of agreement for the measurement of the intrascaphoid and dorsal cortical angles and the height-to-length ratio which conformed to normal distribu-
tions. The MR measurements of translation and gapping at the fracture were categorised as either ≤0.5 mm or ≥1 mm and their inter- and intra-observer reproducibility was assessed using Cohen’s kappa test. This was also used to determine the reproducibility of the overall assessments of displacement made by observers 1 and 2. It is generally accepted that a kappa value of <0.2 indicates poor reproducibility, 0.21 to 0.4 fair, 0.41 to 0.6 moderate, 0.61 to 0.8 good and 0.81 to 1.0 very good reproducibility.

Assessment of displacement on the scaphoid series of radiographs. These were obtained within a week of the fracture. All the details of the patients were masked on the radiographs but each set was given an identifying code and covered with a transparency, on which landmarks could be drawn. Observer 1 then measured the maximum gap and translation of the fracture in the coronal plane and the AP intrascaphoid angle from the PA (all three measurements) or Ziter (gapping and translation only) radiographs. The scapholunate angle was measured on the lateral view, but it was not possible to measure sagittal gapping or translation on this because other superimposed carpal bones obscured the fracture. In view of the MR findings, the maximum
fracture step-off, seen on either the pronated or supinated oblique view, was also measured. This was considered to be the best possible estimate of sagittal translation of the fracture. Overall assessments of displacement (minimal, moderate or severe) and comminution were also made. After an interval of one week, and with new transparencies, observer 1 repeated these measurements on all the sets of radiographs. The same procedure was then repeated for all the sets of radiographs by observer 4 (MM), except that he did not measure translation on the oblique views. When these data were reviewed, gapping and translation of the fracture were categorised as $\leq 0.5 \text{ mm}$ or $\geq 1 \text{ mm}$ for the reproducibility analyses and $\leq 0.5 \text{ mm}$, 1 mm or $\geq 1.5 \text{ mm}$ for the assessment of the influence of displacement, as seen on the scaphoid series of radiographs, on union. Inter- and intra-observer reproducibility was assessed using the 95% limits of agreement for the measurement of the scapholunate and intrascaphoid angles and Cohen’s kappa test\textsuperscript{18} for translation and gapping of the fracture and the overall assessment of displacement.

**Results**

**MRI assessments**

**Reproducibility.** Table I shows the mean, range and 95% limits of agreement for the intrascaphoid and dorsal cortical angles and the height-to-length ratios. The intra- and inter-observer 95% limits of agreement for all these measurements were wide, and equivalent to between 60% and 132% of the range (maximum-minimum value) of each parameter. This indicated poor reproducibility. By contrast, the assessment of translation and gapping of the fracture ($\leq 0.5 \text{ mm}$ or $\geq 1.0 \text{ mm}$) on the sagittal MR scans demonstrated at least moderate intra- and inter-observer reproducibility although the reproducibility of these measurements on the coronal slices was much less satisfactory (Table II). There was good inter-observer reproducibility (kappa = 0.69) for the overall assessment of displacement, in which the only discrepancy was that observer 1 (MB) considered that six of the fractures were moderately displaced, which observer 3 (SD) had considered to be undisplaced.

**Union of the fractures.** Only three of the 49 fractures with adequate follow-up failed to unite within 16 weeks. Observers 1 and 3 agreed that two of these were moderately displaced and that one was severely displaced. All the fractures which were classified as undisplaced either by one or both observers united. The difference between the rates of union for the undisplaced and displaced fractures was significant (Fisher’s exact test, $p = 0.01$), regardless of which observers’ assessments of displacement were used (Table III). Both observers’ assessments of displacement showed a sensitivity of 100%, a specificity of 74% to 87%,
The influence on union of the fracture of the gap between, and translation of, the fragments in the sagittal plane, which were the only two quantitative assessments of displacement which were reasonably reproducible was also investigated. None of the 37 fractures with sagittal translation of 0 or 0.5 mm failed to unite, compared with three of the 12 with translation of 1 mm or more (Fisher's exact test; p = 0.03). This assessment showed a sensitivity of 100%, a specificity of 80%, positive and negative predictive values of 25% and 100% and an overall accuracy of 82% in predicting nonunion. In addition, none of the 26 fractures with a gap of 0 or 0.5 mm in the sagittal plane failed to unite. This contrasts with three failures in the 23 with a gap of 1 mm or more, but this difference was not significant (Fisher's exact test, p = 0.2).

Table IV. Displacement assessment on the 46 sets of scaphoid series radiographs

<table>
<thead>
<tr>
<th>Medium Range</th>
<th>Kappa intra-observer</th>
<th>Kappa inter-observer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coronal gap</td>
<td>0.5 to 2.5*</td>
<td>0.67</td>
</tr>
<tr>
<td>Coronal translation</td>
<td>0.5 to 3.0*</td>
<td>0.62</td>
</tr>
<tr>
<td>Oblique step</td>
<td>0.5 to 2.5*</td>
<td>0.46</td>
</tr>
</tbody>
</table>

* maximum values for these three measurements are all from one fracture

Table V. Features of the fractures on the scaphoid series of radiographs

<table>
<thead>
<tr>
<th>Overall assessment of displacement</th>
<th>Minimal</th>
<th>Moderate</th>
<th>Severe</th>
<th>Influence on union (Fisher’s exact test)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kappa intra-observer 0.4</td>
<td>39 (1)*</td>
<td>6 (1)</td>
<td>1 (1)</td>
<td>p = 0.02</td>
</tr>
<tr>
<td>Kappa inter-observer 0.6</td>
<td>Not comminuted</td>
<td>Comminuted</td>
<td>36 (2)</td>
<td>10 (1)</td>
</tr>
</tbody>
</table>

| Coronal translation (median 0.5; range 0.5 to 3.0)† | 36 (1) | 8 (1) | 2 (1) | p = 0.05 |
| Kappa intra-observer 0.62 | Kappa inter-observer 0.05 |
| Coronal gapping (median 0.5; range 0.5 to 2.5)† | 38 (1) | 6 (1) | 2 (1) | p = 0.07 |
| Kappa intra-observer 0.67 | Kappa inter-observer 0.22 |
| Oblique step (median 1.0; range 0.5 to 2.5)† | 18 (1) | 33 (2) | 4 (1) | p = 0.18 |
| Kappa intra-observer 0.46 |

* the numbers in parentheses indicate the number of fractures which did not unite
† the maximum values for these three measurements are all from one fracture

Radiographic assessment of scaphoid series. There were 47 initial sets of radiographs available for assessment, but one was the patient who was lost to follow-up before completion of the study and so was excluded. The mean scapholunate angle was 49° (SD 9°) and had reasonable intra-observer reproducibility (95% limits of agreement -4.5° to +8.5°) although less satisfactory inter-observer reproducibility (95% limits of agreement -20° to +14°), but it did not influence the rate of union. The mean AP intra-scaphoid angle was 32°; (SD 11°) and it also had reasonable intra-observer reproducibility (95% limits of agreement -6° to +8°), although with less satisfactory inter-observer reproducibility (95% limits of agreement -26° to +8°), but again it did not seem to influence the rate of union. Coronal gap and translation had good intra-, but only fair or poor inter-observer reproducibility (Tables IV and V). Assessment of fracture step-off on the two oblique views had moderate inter-observer reproducibility whereas the overall estimate of displacement had good inter-observer reproducibility.

Statistical analysis (Fisher’s exact test) showed that observer 1’s overall assessment of displacement (p = 0.02) and coronal translation (p = 0.05), but not of gapping (p = 0.07), influenced the likelihood of union of the fracture. However, as shown in Table V, none of these measurements identified all three fractures which did not unite. Thus, for practical purposes, the assessment of comminution and coronal gapping and translation, as well as of the overall assessment of displacement, were not useful for predicting nonunion with treatment by plaster cast. Although none of the 18 fractures with a step-off of 0.5 mm or less on the oblique views, failed to unite, 23 of the 26 with greater displacement did unite (p = 0.18), indicating that this measurement was not a sensitive discriminator on which to predict the likelihood of union of the fracture.

Comparison of assessment of displacement on MRI scans and radiographs. This was performed on the 46 patients whose initial radiographs and MR scans were available. Comparison of the overall assessments of observer 1 of displacement of the fracture from the scaphoid series of radio-
graphs with those of observer 3 from the MR scans, showed limited agreement (Table VI). Only three of the nine fractures which were considered to be displaced (moderate or severe) on the MR scans were identified as displaced on plain films (33% sensitivity), and four of the 37 fractures which were classed as undisplaced on the MR scans, were classed as displaced on the scaphoid series radiographs (42% positive predictive value). Further analyses were performed to assess the validity of the overall assessments of displacement on the radiographs by observers 1 and 4 using either the MR assessments of displacement of observers 1 and 3 as being correct. These demonstrated that the assessment of the overall displacement of the fracture on the radiographs had a sensitivity of 33% to 47% and a specificity of 78% to 97% for identifying displaced fractures, a positive predictive value of 27% to 86%, a negative predictive value of 77% to 83%, and an overall accuracy of 70% to 78%. As shown by the sensitivity values, neither observer was able correctly to identify more than 33% to 47% of the displaced fractures.

Comparison of the measurements of sagittal translation on the MR scans and on the oblique radiographs, revealed a reasonable correlation (Spearman’s correlation, 0.465, p < 0.01), indicating that both measurements to some extent measured the same parameter. Coronal translation of the fracture on the radiographs also correlated with oblique translation (Spearman’s correlation 0.340, p < 0.05), which is not surprising since oblique translation is a composite of both coronal and sagittal translation.

Discussion
A previous study has reported that the reproducibility of measurements of the lateral intrascaphoid angle is poor, whereas those of the dorsal cortical angle and the height-to-length ratio measurements are moderate and excellent, respectively. However, only three CT scans were assessed in that study and the correlation statistics used for the reproducibility analyses were not appropriate. By contrast, we found that all these three parameters, as well as the AP intrascaphoid angle and translation and gapping of the fracture in the coronal plane, had unsatisfactory intra- and inter-observer reproducibility. In view of the difficulty which we experienced in defining the borders of the proximal and distal articular surfaces of the scaphoid, the poor reproducibility of the intrascaphoid angle measurements is not surprising.

In our study, translation and gapping in the sagittal plane were the only MR measurements with acceptable reproducibility, but whether this would have been the case if the different observers had each been allowed to select which MR slice was used for these measurements is uncertain. Furthermore, although translation in the sagittal plane influenced the rate of union, an overall qualitative assessment of displacement of the fracture, using all the MR slices of the scaphoid fractures, had similar reproducibility and also influenced the rate of union. We consider that our qualitative assessment of displacement, using Figures 3 to 5 as standards, is as effective and a more practical method in the clinical setting.

Fracture displacement and union. When we planned this study we anticipated that there would be between five and eight patients with nonunion in a study group of 50. However, only three of our 49 fractures with adequate follow-up failed to unite. Ideally, we should have recruited another 50 patients to increase the statistical power of the study, but financial constraints made this impossible. Although our low rate of nonunion reduces the power of the study, it should be remembered that most scaphoid fractures unite with careful conservative management.

The findings of our study suggest that displacement, as assessed on MRI, is a significant determinant and predictor of union of a scaphoid fracture. All of the 40 undisplaced fractures united whereas only six of the nine displaced fractures united. Our results appear to contradict the findings of Desai et al., who reported no effect of displacement of the fracture on the outcome of a consecutive series of 151 scaphoid fractures. However they assessed displacement on scaphoid series radiographs alone and the results of our study suggest that, when using radiography alone, many displaced fractures are not detected and some undisplaced fractures are categorised as displaced. In our study, two of the assessments of displacement using standard radiographs influenced the rate of union, but neither identified all three fractures which failed to unite. We conclude that displacement, unless severe, is difficult to assess on plain radiographs, but is clearly seen on MR scans.

We would suggest that all fractures of the scaphoid should be assessed with an MR or CT scan along its axis. Those fractures which are undisplaced should be treated conservatively in a below-elbow plaster cast which need not incorporate the thumb. Those which are displaced may be better treated operatively by reduction and internal fixation, assuming that this treatment reliably results in union. This treatment protocol might be more cost-effective than either standard plaster immobilisation of all fractures of the waist of the scaphoid, or the increasing trend towards operative fixation of all such fractures. It is well established that conservative management of all fractures of the waist of the scaphoid results in a 5% to 15% non-union rate and thus the operative fixation of all these fractures would result in

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**Table VI. Comparison of overall assessments of fracture displacement from scaphoid series radiographs (observer 1) and MRI (observer 3)**

<table>
<thead>
<tr>
<th>Scaphoid series radiographs (n = 46)</th>
<th>Minimal</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRI scan*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimal</td>
<td>33</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

* only 46 of the 49 cases had both MRI and scaphoid series radiographs available
the majority undergoing unnecessary surgery and risking operative complications.\textsuperscript{9,21,22}

If our proposed treatment protocol had been applied to the 49 scaphoid fractures included in this series and the MRI displacement assessments of observer 3 (SD) had been used, the 40 undisplaced ones would have been treated nonoperatively and, as actually occurred, all would have united. The nine displaced scaphoid fractures would have been treated operatively in the hope that this would have prevented the three nonunions and this may also have prevented any deleterious affects of malunion.\textsuperscript{10} However, studies\textsuperscript{10,23} which have assessed the influence of malunion on clinical outcome assessed malunion by measuring the intrascaphoid angles, which Bain et al\textsuperscript{11} and we have found to have unacceptably low reproducibility. Thus the conclusions of these studies must be open to question. We are aware that all the six of the displaced fractures which united had satisfactory subjective outcomes and five of them who could be examined had normal wrist movements, including extension. A further potential benefit of assessing all acute scaphoid fractures with an MRI scan is that the undisplaced fractures can clearly be identified and could be studied separately. It is generally accepted that undisplaced fractures of the distal radius and other carpal bones unite without consequence following shorter periods of immobilisation than displaced fractures. Perhaps it is also true that undisplaced scaphoid fractures unite more rapidly than displaced ones, and could be safely managed by immobilisation in a below-elbow plaster for a period of only four weeks.

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

References


