Patterns of healing of scaphoid fractures

THE IMPORTANCE OF VASCULARITY

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We studied 45 patients with 46 fractures of the scaphoid who presented sequentially over a period of 21 months. MRI enabled us to relate the pattern of the fracture to the blood supply of the scaphoid. Serial MRI studies of the four main patterns showed that each followed a constant sequence during healing and failure to progress normally predicted nonunion.

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Fractures of the scaphoid frequently result in nonunion. When the proximal pole of a nonunion is avascular, the chance of union after surgery is small.1,2 To our knowledge the vascular status of the scaphoid in acute fractures has not been studied. We have used MRI to study the vascularity and healing of a consecutive series of acute fractures of the scaphoid treated in a standardised way.

Patients and Methods

All acute fractures of the scaphoid which presented at the fracture clinic of the senior author (NC) over 21 months were included in the study. There were 47 patients, but two were excluded, one because he refused the treatment offered and the other because of associated carpal instability due to the initial trauma. Both had internal fixation with uneventful healing of the fracture. Of the remaining 45 patients, 35 were men (mean age 27.7 years) and ten were women (mean age 47.1 years). One had bilateral fractures, making a total of 46 for review.

An acute fracture was defined as one which had occurred during the three weeks before presentation at the hospital. A below-elbow fibreglass cast was applied, which included the thumb, with slight radial deviation of the wrist. MRI was then carried out using a 1.0 Tesla scanner (General Electric, Milwaukee, Wisconsin) with a dedicated wrist coil. T1 (TR350 and TE20)- and T2 (TR3000 and TE 85)-weighted images were obtained in the coronal plane.

The patients were seen six weeks after the initial consultation for further radiographs and a change of cast. At 12 weeks the cast was removed, the MRI repeated and another set of radiographs obtained. The wrists were then left free, with patients being recalled at six-weekly intervals until either clinical or radiological signs of nonunion were present3 or the wrist was clinically normal, with radiographs showing the presence of trabeculae crossing the fracture site in all four views. We were able to divide the outcome of treatment into nonunion or union, with an MR scan in cases of doubt. An observer, who was unaware of the clinical or radiological condition, reviewed the MR images. An arbitrary scale graded the brightness of the image, ranging from +3 to -3, with 0 being isodense with the head of the capitate.

A diagnosis of avascular necrosis was made if MRI of the scaphoid showed low signal intensity on both the T1- and T2-weighted images, and a low signal on the T1-weighted image4,5 combined with a high signal on T2 indicated hypervascularity. The bone was considered normal if it showed isodensity with the head of the capitate on both T1- and T2-weighted views, indicating the return of normal fat to the medullary cavity of the scaphoid.

Results

The patients were followed for a mean of 30 weeks (12 to 78). The fractures were seen only on MRI in five, were undisplaced in 28 and were displaced more than 2 mm in 13. There were two cases of nonunion, both in waist fractures and both displaced more than 2 mm. One was of the vertical oblique pattern and the other was a transverse waist fracture.

We found four types of MRI pattern in the early images (Table I). We interpreted these on the basis of the known vascular supply of the scaphoid6,7 which is from two sets of vessels. One enters the dorsal side through the scaphoid ridge, and the other, more distal, the laterovolar aspect near the tuberosity.
Type 1. Both fragments retain their vascularity (Fig. 1). The fracture line appears to run between the vascular territories of the vessels of the dorsal ridge and those of the volar tuberosity. A hypervascular healing response was seen involving both fragments. We defined this response as a signal intensity of -2 or -3 on T1- and of +2 or +3 on T2-weighted images. There were eight patients with this type of fracture.

Type 2. The proximal fragment shows signs of avascularity and the distal fragment a hypervascular healing response (Fig. 2). A signal intensity of -1 or less on both the T1- and T2-weighted images indicates avascularity. The fracture line interrupts the blood supply to the proximal fragment by the vessels of the dorsal ridge and healing has therefore to occur from the vascularised distal fragment. We noted the presence of a revascularisation front (Fig. 3) progressing from the fracture line into the avascular fragment. This was characterised by extension of the hypervascular tissue into the avascular segment with a clear dividing line at the interface. This process continued until the entire avascular segment had been crossed except in those cases which went on to nonunion. In these the front stopped. With time, as the hypervascularity subsided and normal marrow-containing fat was formed, the signal behind the front slowly returned to normal. We measured the distance between the midpoint of the fracture line and the midpoint of the front as shown on the T2-weighted image (Fig. 4). There were 35 fractures of this type, of which two went on to nonunion.

Type 3. The distal fragment shows signs of avascularity and the proximal fragment a hypervascular healing response (Fig. 5). The fracture line interrupts the blood supply to the distal fragment from the vessels of the volar tuberosity. Healing occurs only by invasion of the distal fragment from the proximal fragment. There was only one such case in our series.

Type 4. Both fragments are avascular. Radiologically, these show extensive comminution on the radial side (Fig. 6). Both sets of vessels are interrupted by the fracture. Healing occurs only by invasion of fronts from the point of entry of the vessels into the avascular proximal and distal fragments. There were two such patients.

<table>
<thead>
<tr>
<th>MRI pattern classification</th>
<th>Number of cases</th>
<th>Number of cases of nonunion</th>
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<tbody>
<tr>
<td>1</td>
<td>8</td>
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<tr>
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Avascular necrosis in either part of the scaphoid is indicated on plain radiographs by a relative increase in density in two or more views. There were only ten cases in our series, with radiological evidence of a revascularisation front being seen in six.

We measured the rate of progress of the front by serial MRI and found it to be a fairly constant 0.7 mm per week (Fig. 7). We believe that we can predict nonunion of fractures of the scaphoid by the lack of progression of the front. No fracture in which the front was within 2 mm of the fracture line at eight weeks went on to nonunion except for one which had delayed union.

MRI showing a revascularisation front as a white line on the T2-weighted image.

Type-2 fracture, MRI shows a) the T1- and b) the T2-weighted images. Diagrams (c) show that healing can only occur from distal to proximal. The key is as in Figure 1c.

Diagram showing the measurement of the progress of a revascularisation front.
Type-3 fracture. MRI shows a) the T1-and b) the T2-weighted images. The diagrams (c) show that healing can only occur from proximal to distal. The key is as in Figure 1c.

Type-4 fracture. MRI shows a) the T1-and b) the T2-weighted scans. Diagrams (c) show that healing can only occur by revascularisation of the two fragments separately. The key is as in Figure 1c.
Discussion

We deliberately limited the number of variables in this study. We excluded those fractures not freshly diagnosed or those associated with a carpal dislocation or instability. We did not exclude comminution or displacement of more than 2 mm, both of which have been cited as indications for immediate internal fixation. We defined displacement as being more than 2 mm since we did not feel able to measure within 1 mm of accuracy on standard radiographs. Both of our two cases of nonunion were in the displaced group, although the other 13 cases of displacement went on to union and would therefore have been operated on unnecessarily using standard criteria. We believe that our treatment regime has been reasonable in that our overall incidence of nonunion was 4%, which is similar to or lower than comparable series of fractures treated conservatively.

The duration of immobilisation is critical for healing and depends on the location of the fracture. Leslie and Dickson and Russe showed that different types of fracture of the scaphoid heal at different rates, although their criteria for healing were not exactly defined. Some take up to nine months to heal, especially those of the proximal pole, but neither of our cases of nonunion was in that area. We adopted a set period for this study of MRI, believing that after failure to heal following 12 weeks of immobilisation, patients would not tolerate further immobilisation when alternative treatment in the form of internal fixation and a bone graft was available.

A number of radiological classifications of fractures of the scaphoid have been described. That of Compson is the most recent and is based on fresh fractures as opposed to nonunions. We could not directly correlate his groupings with our MRI classification. One of our two cases of nonunion was of the vertical oblique variety, described by Trojan and De Mourges as being prone to fail to unite.

MRI of acute fractures of the scaphoid is confusing because of the different patterns encountered, and because the appearance of T1-weighted scans is based on the presence of fat in the marrow cells which can remain for some weeks after the death of lipocytes. The MRI appearance of healing in scaphoid fractures was discussed by Imaeda et al but without a description of the revascularisation front. At first we thought that it represented a ‘double’ fracture of the scaphoid, but the observation that it moved, combined with our failure to detect such a fracture on detailed CT of the scaphoid, led us to our conclusion regarding its nature. We believe that our interpretation of the MR findings correlates with the histological findings in bone biopsies from fractures of the scaphoid at the time of internal fixation. The double line seen at the healing front of avascular hips is, we believe, analogous to the front which we observed in the scaphoid. The same phenomenon can occasionally be seen on plain radiographs.

Not all of our patients had a clear-cut outcome at 12 weeks. One showed lack of advancement of the front past 2 mm but, when freed of the cast, slowly started to show progression, with healing at 28 weeks. Many patients had irritability of the wrist after removal of their cast as described by Dias et al. We believe this to be due to disuse, stiffness from immobilisation, and possibly some delay in healing. Some patients in this group took a long time to become asymptomatic. Serial MRI in this group showed steady advancement of the front until complete healing had occurred, even without immobilisation in a cast. Confirmed failure of the front to proceed was always associated with eventual nonunion. Confirmation of our findings needs MRI of higher resolution with more frequent scanning, neither of which was available to us, but we believe our approach to be logical and to be based on the known patterns of vascularisation of the scaphoid. In particular, it is important to study the entire series of MR images, as partial volume effects can be misleading.

It should be possible to predict which fractures will proceed to union while being treated by this regime from the appearances of MRI at six weeks. This should define a subgroup which will benefit from early internal fixation.

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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


