Indirect reduction and percutaneous fixation 

*versus* open reduction and internal fixation for displaced intra-articular fractures of the distal radius

**A RANDOMISED, CONTROLLED TRIAL**

A total of 179 adult patients with displaced intra-articular fractures of the distal radius was randomised to receive indirect percutaneous reduction and external fixation (*n* = 88) or open reduction and internal fixation (*n* = 91). Patients were followed up for two years. During the first year the upper limb musculoskeletal function assessment score, the SF-36 bodily pain sub-scale score, the overall Jebsen score, pinch strength and grip strength improved significantly in all patients. There was no statistically significant difference in the radiological restoration of anatomical features or the range of movement between the groups.

During the period of two years, patients who underwent indirect reduction and percutaneous fixation had a more rapid return of function and a better functional outcome than those who underwent open reduction and internal fixation, provided that the intra-articular step and gap deformity were minimised.

Fractures of the distal radius are the most common fracture in adults younger than 75 years of age. In order to restore function and prevent long-term disability, their management depends on their individual characteristics, with the options varying widely from immediate functional bracing to open reduction and internal fixation.

While most studies have been of retrospective case series, several randomised clinical trials have been undertaken to clarify treatment. Most have compared immobilisation in a cast with external fixation, or different methods of external fixation. One small trial compared external fixation with open reduction and internal fixation. Based on a comprehensive review of the available information, Haddow and Madhok concluded that there was insufficient evidence to determine the appropriate methods of treating these fractures. We know of no published clinical trials which have compared indirect reduction and primary external fixation with formal open reduction and internal fixation for severely comminuted fractures with incongruity of the joint.

Most authors consider displaced intra-articular fractures separately from extra-articular injuries with a congruous joint because the outcome is different and their management varies. The purpose of this study was to compare indirect reduction and percutaneous fixation with open reduction and internal fixation for displaced intra-articular fractures of the distal radius.

**Patients and Methods**

The internal review boards of all participating institutions approved the trial.

All skeletally-mature patients between the ages of 16 and 75 years with displaced intra-articular fractures of the distal radius who were seen at the three participating centres were screened for entry into the trial after initial closed reduction in the emergency department. Those who then had a minimum of 2 mm of either step-off or gap were eligible for the trial. This included fractures with dorsal angulation of greater than 10°, or comminution of more than one-third of the anteroposterior diameter of the radial shaft. The attending surgeon made the decision about joint congruity based upon assessment of the injury and the immediate radiographs after reduction. Patients were excluded if they had a history of a previous fracture of the wrist, a congenital anomaly or other severe problems of the wrist, if they were not fit for surgery, if definitive treatment could not be administered within one week of injury, if they were mentally incompetent or if they were unable to answer a written questionnaire in English. Those with an open fracture, associated injuries of the ipsi-
lateral upper limb or other significant systemic injuries were also excluded.

A total of 1269 patients was screened. Of these, 247 with an isolated displaced intra-articular fracture met the inclusion criteria. Nineteen eligible patients were missed and 49 others refused to participate, leaving 179 in the study. Most treated fractures of the distal radius were associated with multiple other injuries, making them ineligible for participation in the study. Of the 179 patients initially randomised, 166 returned for follow-up at six months (93%), 140 at one year (78%) and 118 at two years (66%).

A calculation of sample size suggested that, based on the Musculoskeletal Functional Assessment (MFA) questionnaire, approximately 90 patients in each group would be required to detect a difference of ten points in the mean function of the upper limb with 80% power and alpha equal to 0.05.

When possible, an independent research assistant approached the patients about the trial. Otherwise consent was obtained by the treating surgeon. Using sequentially-marked envelopes based upon computer-generated number sequences, the patients were randomly assigned to receive either indirect reduction with percutaneous fixation or open reduction and internal fixation. Assessment at follow-up was undertaken by an independent research assistant who was not blinded as to the treatment since we felt that any means of masking the method of management would interfere with measurement of movement and functional testing. All patients were evaluated according to the ‘intention-to-treat’ principle. Consequently, all outcomes were analysed according to the group to which patients were randomised even though they might cross over to the other treatment group. Thus, a patient who had been randomised to have indirect reduction but needed an open procedure to achieve adequate reduction continued to be assessed in the indirect group.

**Indirect reduction.** Under general or regional anaesthesia, closed reduction was performed and evaluated using image intensification (Fig. 1). Percutaneous Kirschner (K-) wires, or a small elevator inserted through a limited incision were used to manipulate the fragments. An arthrotomy was not performed. Bone grafting was carried out through a small incision at the discretion of the treating surgeon. Fixation was limited to percutaneous K-wires, cannulated or regular small- or mini-fragment screws and/or external skeletal fixation, using a small AO fixator. A successful reduction was defined as a step deformity of 2 mm or less, neutral palmar tilt or better and radial shortening of less than 5 mm as compared with the opposite side. The fixators and percutaneous pins were removed in the clinic between six and eight weeks after surgery.

**Open reduction.** All fractures randomised to open reduction received primary internal fixation, usually involving an arthrotomy (Fig. 2). The operation was performed through either an extended carpal tunnel approach on the volar side or between the third and fourth compartments on the dorsum of the wrist. The volar approach was chosen when closed reduction revealed instability of the volar ulnar corner of the radius. All other fractures were approached dorsally. Volar instability was assessed using the reduction manoeuvre described by Agee in which length was restored by longitudinal traction, palmar tilt by volar translation of the carpus and radial inclination by combining slight ulnar deviation with pronation of the hand relative to the forearm. The surgical approach was left to the discretion of the surgeon and was directed towards the area with the most displacement and comminution. If necessary, fixation by small- or mini-fragment plates and screws was supplemented with K-wires or an external fixator.

The patients were reviewed at weekly intervals up to six weeks and then at the discretion of the treating surgeon. All were evaluated and data collected according to a standardised protocol at the first post-operative visit and at six weeks and at six, 12 and 24 months. Specific complications included wound infection, loss of reduction and/or sympathetic-mediated pain.
The patients received supervised physiotherapy, including digit range of movement using ‘six-pack’ exercises and forearm rotation$^{20}$ until a maximum range of movement was achieved.

**Primary outcome.** At the first visit after operation a sensory and motor examination was recorded. All patients were asked to complete the MFA$^{15-18}$ and the SF-36 questionnaires.$^{21}$ The first allowed modular scoring of the function of the upper limb separately. The SF-36 questionnaire allowed subscale scoring of bodily pain separately from the other general considerations of health. Only these two individual aspects were noted since they were the most relevant. A pre-injury baseline assessment cannot be obtained after a fracture except by the recollection of the patient. The first post-operative functional scores represented a combination of function before injury and the acute effects of the trauma. Functional questionnaires were repeated at six, 12 and 24 months after the injury.

**Secondary outcomes.** Objective measurements, including the hand function test of Jebsen et al.$^{22}$ grip strength, lateral pinch strength, three-jaw chuck and pad-to-pad pinch strength tests were recorded at each interval. The seven individual components of the Jebsen test$^{22}$ were administered according to the recommended protocol. A Jamar grip dynamometer (Jamar, Jackson, Mississippi) was used to measure grip strength and a B & L pinch gauge (B & L Engineering, Santa Fe Springs, California) to measure lateral, three-jaw chuck and pad-to-pad pinch strength. The tests were repeated three times on both the affected and unaffected sides, and the mean of the latter subtracted from that of the former to measure the deficit between the two. All measurements were made in ft/lb.

The range of movement (ROM) on both sides was recorded for forearm supination/pronation, wrist flexion/extension and radial/ulnar deviation of the wrist and for flexion and extension of the metacarpophalangeal (MCP), proximal interphalangeal and distal interphalangeal joints. With the fingers in maximum flexion, the distance from the tip of the middle finger to the distal palmar crease was recorded. Flexion and extension at the MCP and inter-
phalangeal joints of the thumb were recorded, as were radial and palmar abduction.

Pre-operative radiographs of the affected and unaffected distal radius were obtained. Anteroposterior (AP) and lateral radiographs were obtained on the affected side at each subsequent follow-up. Healing was documented by obliteration of fracture lines and calcification of callus. At the conclusion of the study, all the available radiographs were reviewed and the radial angle, radial length, ulnar variance, radial shift, palmar tilt, dorsal shift, step, gap, patterns of intercarpal instability and reduction of the distal radio-ulnar joint were recorded.23 Post-traumatic osteoarthritis, defined as the presence of narrowing of the joint space or of osteophytes, was documented as ‘yes/no’ at each of the intervals.24,25

Statistical analysis. Repeated-measures analysis of variance was used to compare the two groups over time with respect to the primary and secondary outcomes. This allowed overall comparisons to be made between both groups observed over time, and was more powerful than multiple single-time comparisons. Group comparisons at the different time periods were made only when the overall repeated-measures tests were statistically significant (p < 0.05). All scale variables were tested for normality using the Kolmogorov-Smirnov test. Parametric variables were compared using independent groups employing Student’s t-test. The Mann-Whitney U statistic was applied to non-parametric scale variables and ordinal variables. Nominal variables were compared across independent groups using the chi-squared test or Fisher’s exact test. Homogeneity of variance was assessed using Levene’s test. Fisher’s exact test was used to compute the p values for all two-by-two tables. Relative risk and 95% confidence intervals (CI) were reported for two-by-two tables evaluating the association between step or gap deformity and radiological arthritis.

All tests between both groups were corrected for multiple comparisons using the simple Bonferroni correction which involved multiplying the p value by the number of comparisons to determine the adjusted p value (i.e. if 11 comparisons were made a p value of 0.0045 would be adjusted to 0.05). The adjusted p value is presented throughout the text. CIs have also been adjusted to account for multiple comparisons (i.e. a 99.55% CI is used when adjusting for 11 multiple comparisons).

Results

Patients and loss to follow-up. There were 88 patients in the indirect group and 91 in the open group. The characteristics of the patients were similar in both (Table I). More than 50% of those undergoing open reduction and internal fixation received bone grafting compared with 13% in the indirect reduction group (p < 0.001). Statistically significant baseline differences were noted, however, there was a trend toward more work-related injuries in the indirect group (p = 0.053). No other statistically significant baseline differences were noted (Table I).

Eight patients randomised to the indirect reduction group eventually had open reduction and internal fixation because an acceptable position could not be achieved with closed or minimal open manipulation (Table I). Three of these had volar shearing fractures in which the volar component could not be reduced satisfactorily by percutaneous or limited open attempts. Partial articular injuries with displaced volar shearing fractures were added to the exclusion list later in the study. One patient randomised to open reduction requested indirect reduction (Table I). All patients were analysed in the group to which they were randomised according to a strict ‘intention-to-treat’ principle.26

Primary functional outcome. The repeated-measures analysis considers the overall difference between treatment groups over the entire period of evaluation rather than an isolated comparison at a given point in time (Table II). Patients receiving indirect reduction had better function overall, scoring a mean of 6 points (95% CI 4.1 to 33.0) better on the upper limb module of the MFA function test,
than those with open reduction and internal fixation. The pain scores were better overall for patients in the indirect reduction group, although the result fell just below statistical significance (p = 0.052) (Table II). The function of the upper limb and the degree of pain improved significantly over time in both groups.

At the first post-operative review and after six weeks, all showed marked impairment of upper limb MFA function and considerable pain (Table III). At six weeks those with indirect reduction had significantly more bodily pain on the SF-36 assessment compared with patients who had an open procedure (corrected p = 0.041). The pain scores did not differ significantly between groups beyond six weeks after correcting for multiple comparisons (corrected p > 0.05).

By six months, patients in the indirect group had significantly better MFA function (lower scores) in the upper limb compared with those treated by open reduction (corrected p = 0.037). After six months there was no statistically significant difference in MFA function between the two groups.

**Secondary outcomes: Jebsen score, grip strength, pinch strength and ROM.** Repeated-measures analysis showed that patients who had improved grip strength by a mean of 10.1 lb overall (95% CI, 1.9 to 18.3) after indirect reduction compared with open reduction and internal fixation. Testing of grip strength showed statistically significantly less deficit (corrected p = 0.05) after indirect than after open reduction and internal fixation. Although grip strength favoured the indirect group at all times, there was no statistically significant difference between the groups after six months after correcting for multiple comparisons (corrected p > 0.05). There was no overall statistically significant difference between the two groups with respect to the Jebsen, grip and pinch strength testing (p < 0.05) (Table IV).
Repeated-measures analysis showed an improved ROM in all functions measured over time ($p < 0.05$). There was no statistically significant difference in any ROM between the groups on overall repeated testing ($p > 0.05$).

At six months the mean wrist flexion on the injured side was almost 20° less than on the normal side in both groups (Table V). Other than four patients with reflex sympathetic dystrophy, all patients regained ROM in their fingers within six weeks. The ROM in the forearm was regained within six months and there were no significant differences between the two treatment groups (Table V).

**Complications.** There were five (6%) superficial pin-track infections in the indirect reduction group and two (2%) in the open group. There were two (2%) superficial wound infections in the indirect reduction group requiring local care and one (1%) in the open group. Two patients in the indirect group and two in the open group developed pin-track infections which were deep enough to require operative intervention and debridement. One in the open group was treated with antibiotics for an infected bone-graft site at the iliac crest. One broken fixator pin required removal under general anaesthesia in the indirect group, and two patients underwent arthroscopic debridement for a tear of the triangular fibrocartilage complex, with partial resolution of their symptoms. One patient in the indirect group and three in the open group received treatment in the pain clinic for reflex sympathetic dystrophy. There were two ruptures of extensor tendons requiring repair in the open group.

**Radiological findings.** All fractures had united by six months. Twelve patients (14%) had an intra-articular step deformity after indirect reduction compared with 13 (14%) after open reduction and internal fixation. Three patients in the indirect group (3%) and two in the open group (2%) had a step deformity of more than 2 mm ($p = 0.679$) (Table VI). Thirteen patients (7%) developed radiological evidence of osteoarthritis within two years; seven had been treated by indirect reduction and six by an open procedure. Those with any residual step deformity were 9.9 times (95% CI 3.5 to 27.7) more likely to develop arthritic change than those without such deformity (Table VII). When the step deformity was greater than 2 mm the risk of developing arthritis was 10.4 times (95% CI 4.1 to 26.6) greater than when it was less than 2 mm. The risk of arthritis was 3.7 times (95% CI 1.3 to 11.0) greater in the presence of any residual gap compared with no gap. A gap greater than 2 mm was associated with a risk of arthritis which was eight times (95% CI 2.6 to 24.7) higher than that for patients with a gap less than 2 mm. Given the low level of deformity and arthritis, we were unable to demonstrate a statistically significant association between function and these circumstances.

**Limitations.** Loss to follow-up was a significant problem. In most cases, patients were completely out of the medical care system by three months. When contacted they noted that their fractures had healed, they had returned to their pre-injury activities and had no reason to return for medical care. At two years, their interest in returning for follow-up on a fracture which appeared to have no significant impact on their lives was minimal. The functional outcome was stable after one year for those who were assessed further at two years.

When this study started, the disability of arm-shoulder-hand (DASH) questionnaire did not exist. It is possible that it might have given greater discrimination than the upper limb module of the MFA in terms of functional recovery.

**Discussion**

Our study compared the results of fractures of the distal radius treated by indirect as opposed to open reduction. We did not intend to compare specific implants or fixators. The choice of implant was dictated by the surgeon and included small- and mini-fragment plates, and plates specifically designed for these fractures. They could be supplemented by a bone graft and external fixation at the surgeon’s discretion. Common to both groups was the agreement that at the end of the initial operation the length of the radius would be restored to neutral, palmar tilt to neutral and radial inclination to at least 7° to 10°; there would be no articular gaps and step-offs greater than 2 mm, and the distal radio-ulnar joint would be reduced. If these criteria could not be met after closed or percutaneous manipulation in the indirect group, the fracture was treated by an open procedure.

Anatomical restoration of these fractures is the key to a good functional outcome if all other factors are equal. A step-off in the articular surface of greater than 2 mm has

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**Table VI. Step and gap deformity for both groups, by number and percentage**

<table>
<thead>
<tr>
<th>Deformity</th>
<th>Indirect reduction</th>
<th>Open reduction/ internal fixation</th>
<th>$p$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step deformity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any step</td>
<td>12 (14)</td>
<td>13 (14)</td>
<td>0.910</td>
</tr>
<tr>
<td>&gt; 2 mm</td>
<td>3 (3)</td>
<td>2 (2)</td>
<td>0.679</td>
</tr>
<tr>
<td><strong>Gap deformity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any gap</td>
<td>11 (13)</td>
<td>8 (9)</td>
<td>0.421</td>
</tr>
<tr>
<td>&gt; 2 mm</td>
<td>3 (3)</td>
<td>1 (1)</td>
<td>0.362</td>
</tr>
</tbody>
</table>

**Table VII. Step or gap deformity related to radiologically apparent arthritis in both groups, by number and percentage**

<table>
<thead>
<tr>
<th>Deformity</th>
<th>Arthritis</th>
<th>No arthritis</th>
<th>Relative risk ratio (95% CI*)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Step deformity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No step</td>
<td>5 (3.2)</td>
<td>149 (98.8)</td>
<td></td>
</tr>
<tr>
<td>Any step</td>
<td>8 (32.0)</td>
<td>17 (68)</td>
<td>9.9 (3.5 to 27.7)</td>
</tr>
<tr>
<td>&gt; 2 mm</td>
<td>3 (60.0)</td>
<td>2 (40)</td>
<td>10.4 (4.1 to 26.6)</td>
</tr>
<tr>
<td><strong>Gap deformity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No gap</td>
<td>9 (5.6)</td>
<td>151 (94.4)</td>
<td></td>
</tr>
<tr>
<td>Any gap</td>
<td>4 (21.1)</td>
<td>15 (78.9)</td>
<td>3.7 (1.3 to 11.0)</td>
</tr>
<tr>
<td>&gt; 2 mm</td>
<td>2 (50)</td>
<td>2 (50)</td>
<td>8.0 (2.6 to 24.7)</td>
</tr>
</tbody>
</table>

* CI, confidence interval
been found to correlate with the development of degenerative arthritis of the wrist. Others have noted that residual angular deformity of greater than 20° is a critical factor in a poor outcome. A laboratory study has shown that the contact area of the articular surface decreases with progressive amounts of angular malunion. Thus, most surgeons are not willing to accept more than 2 mm of articular incongruity, 20° of angulation or shortening of greater than 5 mm, although these guidelines are based exclusively on retrospective data.

In practice, we must consider the possible side-effects and iatrogenic trauma involved in achieving these aims, especially in severe fractures with considerable concomitant soft-tissue injury. Gerber, Mast and Ganz outlined the goals of treatment as "indirect reduction without further devascularization of bone, aiming at perfect alignment rather than anatomical reduction of extra-articular fractures, and optimal rather than maximal internal fixation". While a full open reduction in conjunction with an arthrotomy and direct visualisation of the articular surface may represent the most reliable means of obtaining an anatomical reduction, indirect reduction involves less soft-tissue violation and may be preferable in some situations. One author noted that arthroscopy of the wrist was preferable to open reduction but gave no details as to the standard achieved.

Kinast et al noted a lower rate of complications with the use of indirect reduction techniques for treatment of fractures of the distal femur as compared with full open reduction, but no such studies have been described for fractures of the distal radius. While several authors have developed comprehensive treatment algorithms based on their experience, none of these has been tested experimentally.

We have demonstrated that if displaced intra-articular fractures of the distal radius can be treated by indirect reduction and percutaneous fixation a more rapid return to function and a superior functional outcome within two years of injury will be obtained than by open reduction and internal fixation, provided that the intra-articular step and gap deformity is minimised. We noted that little change in function occurred after one year in patients from either group. Functional outcomes are stable after one year and further follow-up is not necessary. There is nothing in the literature at this time that demonstrates a deterioration of function after one year. Thus, two- to five-year follow ups are not indicated in this population.

We recommend that open reduction be preceded by an attempt at minimally invasive percutaneous reduction. If an acceptable reduction is achieved then open reduction is unnecessary and function will be superior.

Despite randomisation, there were significantly more workers’ compensation patients in the indirect reduction group. It has been shown that such patients generally have poorer outcomes. It is, therefore, possible that our better functional results in the indirect reduction group are an underestimation of the difference between the two groups.

References


