Reconstruction of a Mason type-III fracture of the radial head using four different fixation techniques

AN EXPERIMENTAL STUDY

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We have evaluated four different fixation techniques for the reconstruction of a standard Mason type-III fracture of the radial head in a sawbone model. The outcome measurements were the quality of the reduction, and stability.

A total of 96 fractures was created. Six surgeons were involved in the study and each reconstructed 16 fractures with 1.6 mm fine-threaded wires (Fragment Fixation System (FFS)), T-miniplates, 2 mm miniscrews and 2 mm Kirschner (K-) wires; four fractures being allocated to each method using a standard reconstruction procedure.

The quality of the reduction was measured after definitive fixation. Biomechanical testing was performed using a transverse plane shear load in two directions to the implants (parallel and perpendicular) with respect to ultimate failure load and displacement at 50 N.

A significantly better quality of reduction was achieved using the FFS wires (Tukey’s post hoc tests, \( p < 0.001 \)) than with the other devices with a mean step in the articular surface and the radial neck of 1.04 mm (SD 0.96) for the FFS, 4.25 mm (SD 1.29) for the miniplates, 2.21 mm (SD 1.06) for the miniscrews and 2.54 mm (SD 0.98) for the K-wires. The quality of reduction was similar for K-wires and miniscrews, but poor for miniplates.

The ultimate failure load was similar for the FFS wires (parallel, 196.8 N (SD 46.8)), perpendicular, 212.5 N (SD 25.6)), miniscrews (parallel, 211.8 N (SD 47.9), perpendicular, 208.0 N (SD 65.9)) and K-wires (parallel, 200.4 N (SD 54.5), perpendicular, 165.2 N (SD 37.9)), but significantly worse (Tukey’s post hoc tests, \( p < 0.001 \)) for the miniplates (parallel, 101.6 N (SD 43.1), perpendicular, 122.7 N (SD 40.7)). There was a significant difference in the displacement at 50 N for the miniplate (parallel, 4.8 mm (SD 2.8), perpendicular, 4.8 mm (SD 1.7)) vs FFS (parallel, 2.1 mm (SD 0.8), perpendicular, 1.9 mm (SD 0.7)), miniscrews (parallel, 1.8 mm (SD 0.5), perpendicular, 2.3 mm (SD 0.8)) and K-wires (parallel, 2.2 mm (SD 1.8), perpendicular, 2.4 mm (SD 0.7; Tukey’s post hoc tests, \( p < 0.001 \)).

The fixation of a standard Mason type-III fracture in a sawbone model using the FFS system provides a better quality of reduction than that when using conventional techniques. There was a significantly better stability using FFS implants, miniscrews and K-wires than when using miniplates.

“If in doubt, resect” was the old dogma regarding the treatment of fractures of the radial head which were first classified by Mason in 1954. This classification was modified by Broberg and Morrey in 1986. Good long-term results have recently been reported after resection of the radial head for Mason type-II fractures. Patients with more comminuted fractures and those with associated soft-tissue injuries of the elbow have a poor outcome if the radial head is simply resected. Complications include subsequent distal radioulnar pain, weakness and instability of the elbow, cubitus valgus and ulnar neuritis. The role of the radial head as an important stabiliser of the forearm and elbow is now better understood. It should not be resected without careful consideration. The treatment of Mason type-III fractures and those with associated ligamentous damage or dislocation (Mason type IV) is challenging. Several methods of reconstruction have been described and prosthetic replacement of the radial head is recommended for comminuted fractures, especially if the medial collateral ligament is disrupted. There are some concerns about the non-anatomical shape of the prostheses which may cause loosening, subsequent degenerative changes and instability of the elbow and several studies have indicated serious problems after resection of the radial head.
After initial experience of internal fixation of Mason type-III and type IV fractures using fine threaded wires (Fragment Fixation System, (FFS); Orthofix, Busselengo, Italy),

we have compared this system with three commonly used fixation devices for the reconstruction of a standard type-III fracture in a sawbone model. The outcome measurements were the quality of reduction, the failure load and the displacement of the reconstructed radial head at 50 N.

**Materials and Methods**

We used 96 sawbone radii of the same size and density. They were divided 5 cm distal to the radial tuberosity. The proximal radii were clamped and a standard Mason type-III fracture in each radius with a commercial saw with a blade thickness of 0.3 mm. The different fragments of the radial head were marked with a pen to their corresponding positions on the shaft of the radius in order to facilitate reconstruction. Figure 1 shows the typical Mason type III fracture model used for the experimental set-up.

Four different fixation devices were tested for reconstruction: 1) FFS, fine-threaded wires of a diameter of 1.6 mm, and 23 mm and 35 mm in length; 2) 2.0 T-miniplates with 2 mm miniscrews, 24 mm and 18 mm in length (Koenigsee Implantate, Aschau, Germany); 3) 2 mm miniscrews of 24 mm and 34 mm length (Koenigsee Implantate); and 4) 2 mm Kirschner (K)-wires (Koenigsee Implantate).

Reconstruction was undertaken by six orthopaedic surgeons (TCK, KM and four who are not authors) who had completed their training at least two years previously.

Mason type-III fractures are rare and therefore we required a minimum experience of 150 osteosyntheses per year as a prerequisite for these surgeons. Each reconstructed 16 radial heads, four with each device. Thus 24 reconstructions with each device were obtained from 96 specimens. The reduction was performed manually or with a Weber forceps (Koenigsee Implantate). The sawbone surfaces were smooth and the initial reduction was only accepted if it was anatomical. The quality of the reduction was measured after definitive fixation with the different devices. The clamps and drills were the same in all four experimental groups.

**Reconstruction of the radial head**

**Fragment fixation system.** Reconstruction began after manual reduction of the first fragment with one FFS wire, 35 mm in length, in an oblique direction. The second wire, 35 mm in length, fixed the second fragment, also in an oblique direction. The two remaining fragments were fixed to the first two with two additional wires, 23 mm in length. Finally, the wires were cut flush to the surface of the bone (Fig. 2).

**T-miniplate fixation.** As described in the AO manual, the radial head was reduced manually or with Weber forceps and temporarily fixed with 1.4 mm K-wires. Two K-wires were placed from one fragment into the shaft obliquely. The other two fragments were then similarly reduced and held with two more K-wires. The reconstructed radial head was definitively fixed with a T-miniplate. The plate was moulded to the shape of the radial head with two clamps. A 2 mm miniscrew was inserted into each hole after predrilling to 1.5 mm (two 18 mm screws for the shaft and two 24 mm screws for the head fragments). Finally, the K-wires were removed.

**Miniscrew fixation.** Temporary fixation was obtained with 1.4 mm K-wires as described above. Definitive fixation was obtained with four 2 mm miniscrews. Two 1.5 mm drill holes were made in an oblique direction from the first two fragments to the shaft, parallel to the K-wires. Two 35 mm miniscrews were inserted and the two remaining fragments fixed to the first two with two 24 mm miniscrews, again predrilling 1.5 mm. Finally, the K-wires were removed.

**K-wire fixation.** Definitive fixation was performed with 2 mm K-wires as for the FFS implants.

Figure 3 shows X-rays of the reconstructed radial heads with the four different fixation devices as described above.

The quality of reduction was measured twice by the first two authors (TCK, KM) using electronic calipers with an accuracy of 0.025 mm. The overall remaining intra-articular step was recorded including the step-off between the different fragments and the relationship of the head to the neck in terms of translation, rotation and angulation.

**Measurement of failure load.** For each fixation group, biomechanical testing was performed on the 24 specimens using a transverse plane shear loading model. Each specimen was mounted and fixed to a vice, which was attached.
to the base of a Zwick Z020 servohydraulic materials testing machine (Zwick, Ulm, Germany). All the specimens were aligned with the long axis of the radial shaft perpendicular to the axis of loading (Fig. 4). The distance from the articular surface to the bench was standardised at 40 mm.

A shear load was applied to the radial head through a semicircular plunger mounted on the mobile arm of the testing machine. As described by Giffin et al., the load was applied perpendicular to the radial shaft at an advancing speed of 2 mm/min. The specimens were randomised, and the rigidity of 12 specimens from each group was measured in two perpendicular directions of loading, one parallel to the fixation devices in the radial head and the other perpendicular to this (Fig. 4). The parameters of ultimate failure load and displacement at 50 N were calculated from the load-displacement curve. Failure load was defined as the point at which the shear load reached a maximum before decreasing due to failure of the osteosynthesis.

Statistical analysis. The quality of the reduction was subjected to a two-way analysis of variance (ANOVA) with fixed factors ‘surgeon’ and ‘fixation device’. Similarly, biomechanical measurements (ultimate failure load, displacement at 50 N) underwent a three-way ANOVA with fixed factors ‘surgeon’, ‘fixation device’ and ‘load direction’. Pairwise comparisons of means were assessed by Tukey’s post hoc tests, and a p-value ≤ 0.05 was considered to be statistically significant. All analyses were performed using SPSS 15.0 for Windows (SPSS Inc., Chicago, Illinois).

Results
The differences for the parameters fixation device (p < 0.001) and surgeon (p = 0.020) were significant in an ANOVA regarding the quality of reduction (interaction, p = 0.693). A significantly better quality of reduction was obtained with the FFS implants (Tukey’s post hoc tests, p ≤ 0.001) than with the other devices with a mean step in the articular surface and at the radial neck of 1.04 mm (SD 0.96) for the FFS, 4.25 mm (SD 1.29) for the miniplates, 2.21 mm (SD 1.06) for the miniscrews and 2.54 mm (SD 0.98) for the K-wires (Table I). The quality of reduction was similar for K-wires vs screws (Tukey’s post hoc, p = 0.688), but different for K-wires vs plates and screws vs plates (Tukey’s post hoc, p < 0.001).

Displacement of the miniplate-construct occurred after removal of the K-wire if it was not perfectly contoured in relation to the radial head and neck.

Biomechanical testing. Analysis of variance of ultimate failure load for the parameters fixation device (p < 0.001) and surgeon (p = 0.003) showed statistically significant differences, and that for load direction (p = 0.947) and interactions (p > 0.050) did not. The means and SDs are shown in Table II. The mean ultimate failure load was similar for FFS implants (parallel, 196.8 N (SD 46.8), perpendicular, 212.5 N (SD 25.6)), screws (parallel, 211.8 N (SD 47.9), perpendicular, 208.0 N (SD 65.9)) and K-wires (parallel, 200.4 (SD 54.5), perpendicular, 165.2 N (SD 37.9)), but significantly worse (Tukey’s post hoc, p < 0.001) for the plates.
The group differences for displacement at 50 N were significant in an ANOVA test for fixation device (Tukey’s post hoc, p < 0.001), but not for surgeon (p = 0.709), load direction (p = 0.761) and interactions (p ≥ 0.513). The mean displacement at 50 N (mm) was maximal for plate fixations (parallel, 4.8 mm (SD 2.8), perpendicular, 4.8 mm (SD 1.7)) and significantly greater (Tukey’s post hoc test, p < 0.001) than for FFS (parallel, 2.1 mm (SD 0.8), perpendicular, 1.9 mm (SD 0.7)), screws (parallel, 1.8 mm (SD 0.5), perpendicular, 2.3 mm (SD 0.8)) and K-wires (parallel, 2.2 mm (SD 1.8), perpendicular, 2.4 mm (SD 0.7)).

Discussion
Reconstruction of the radial head is usually performed using a miniscrew or miniplate system and has more recently been conducted with absorbable pins for Mason type-II fractures.1,4,14,18,24-26 Ikeda et al.18,27 were the first to report a high reconstruction rate and good clinical results using low-profile miniplates with 1.7 mm screws in comminuted fractures of the radial head. Koslowsky et al.21 recently reported a reconstruction rate of 100% and good clinical results using FFS wires with a diameter of 1.6 mm in 14 Mason type-III and 11 type-IV fractures.

We have compared this system with three other methods of fixation in a standard model of a Mason type-III fracture. The sawbone model was preferred to that of cadaver bone for several reasons. The large range of size of cadaver radial heads from 19 mm to 30 mm17,28,29 gives different sizes of fragment with consequences for the measurements of the quality of the reduction. The variable densities of cadaver bone depending on the age of the donor and their activity affect the testing of the stability of the osteosynthesis. Although, to our knowledge, no study using synthetic bone at the proximal radius has been previously performed other sites have been used. Landsman and Chang30 studied the validity of using sawbone models of the first metatarsal. They found that, although the sawbones did not simulate the mechanical properties seen in cadaver bone, they could be used in comparative studies of relative stability. Recently, Ali et al.31 described a solid foam sawbone tibial model with bicondylar plateau fractures and compared this with a cadaver tibial model. Double plating
was performed in both models and the failure load of the sawbone model had a lower variability than that of the cadaver bone model. They therefore recommended the sawbone model for the testing of different fixation devices.

The difference in training status was minimised since all the surgeons had operative experience of at least two years after completing their orthopaedic training. Variance analyses showed significant differences in the quality of reduction and ultimate failure load among the surgeons. However, the ranking of the fixation remained the same in the surgeons so that the results were validated. Standard operative procedures were used with the first two fragments being fixed to the radial neck followed by reconstruction of the whole head, so that restoration of the relationship of the radial shaft to the neck had the same priority as the reconstruction of the four head fragments.

Compared with the other forms of fixation the FFS system achieved the best quality of reduction. This was because no intermediate steps between the reduction of the fracture and definitive fixation were required. The poor quality of the reduction of the K-wire group is related to differences in rotational stability of the fragments during the first steps of fixation, which persisted until the complete head had been reconstructed. This also occurred in the miniscrew group in which the quality of fixation was the same as in the K-wire group. During miniscrew fixation, displacement of the radial head from the neck often occurred leading to poor reduction. The initial temporary reduction with K-wires was fixed with the miniscrew contoured to the bone. Minimal misalignment of the plate after removal of the temporary K-wire put the construct under tension. Incorrect contouring of the plate resulted in the poorest reduction with the largest incongruity between the radial head and neck. Successful reconstruction of the head alone would not restore full function, and correct alignment of the reconstructed radial head to the neck is the key prerequisite for normal rotation in the proximal radioulnar joint.

Giffin et al. and Patterson et al. tested the stability of isolated fractures of the radial head with different fixation devices in cadaver bone. In addition to a custom-designed blade plate and a 2.7 mm T-plate, Giffin et al. found that cross-cannulated 3 mm screws were superior to conventional T-plates. Patterson et al. tested four different T-plates and found that a modified 2.7 mm plate with a fixed-angle blade was superior to a normal T-plate. The thickness of the plate and incorporation of a fixed-angle blade have been found to be important variables affecting the stiffness of the constructs. Although we only used 2 mm T-plates and 2 mm screws we also found that the maximal holding power and displacement at 50 N of screws and FFS implants were superior to those using miniscrews. Interestingly, the K-wire construct achieved the same stability as the screws and FFS fixation and better stability than miniplates. However, this high primary stability is often followed by migration of the fragments.

The quality of reduction with plate fixation obtained in our study is in contrast to the clinical results described by Ikeda et al. They performed a demanding internal fixation technique not suitable for all fractures with double plating and additional interfragmentary fixation with Herbert screws. This minimised the risk of displacement of the fragments after plate moulding and fixation, but was not comparable to the conventional technique performed in our study. Ring reported a high early rate of failure, non-union and poor forearm rotation after miniscrew fixation of fractures of the radial head with more than three fragments, which is compatible with the results of our study.

### Table I. Mean (sd) quality of reduction for all four devices (mm)

<table>
<thead>
<tr>
<th>Device</th>
<th>Quality of reduction</th>
</tr>
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<tbody>
<tr>
<td>Fragment fixation system</td>
<td>1.04 (0.96)</td>
</tr>
<tr>
<td>Mini T-plate</td>
<td>4.25 (1.29)</td>
</tr>
<tr>
<td>Miniscrews</td>
<td>2.21 (1.06)</td>
</tr>
<tr>
<td>Kirschner wires</td>
<td>2.54 (0.98)</td>
</tr>
</tbody>
</table>

### Table II. Mean (sd) results for biomechanical testing for all four devices

<table>
<thead>
<tr>
<th></th>
<th>FFS*</th>
<th>Mini T-plate</th>
<th>Mini screws</th>
<th>K-wire†</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parallel direction</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultimate failure load (N)</td>
<td>196.8 (46.8)</td>
<td>101.6 (43.1)</td>
<td>211.8 (47.9)</td>
<td>200.4 (54.5)</td>
</tr>
<tr>
<td>Displacement at 50 N (mm)</td>
<td>2.1 (0.8)</td>
<td>4.8 (2.8)</td>
<td>1.8 (0.5)</td>
<td>2.2 (1.8)</td>
</tr>
<tr>
<td><strong>Perpendicular direction</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Ultimate failure load (N)</td>
<td>212.5 (25.6)</td>
<td>122.7 (40.7)</td>
<td>208.0 (65.9)</td>
<td>165.2 (37.9)</td>
</tr>
<tr>
<td>Displacement at 50 N (mm)</td>
<td>1.9 (0.7)</td>
<td>4.8 (1.7)</td>
<td>2.3 (0.8)</td>
<td>2.4 (0.7)</td>
</tr>
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</table>

* FFS, fracture fixation system  † K-wire, Kirschner-wire
The FFS system has also been used in the treatment of medial malleolar fractures.\textsuperscript{16,17} A biomechanical study with bovine cancellous bone has shown a superior holding power of the machine-threaded FFS wires compared with conventional cancellous screws.\textsuperscript{18}

In conclusion, we have described the experimental background for the good clinical results which have been obtained using the FFS system for the treatment of comminuted fractures of the radial head.\textsuperscript{21} Compared with the technically demanding double plating described by Ikeda et al,\textsuperscript{5} the FFS system is easy to use, provides a stable, one-step fixation technique and avoids the need to resect the radial head.

This study was supported by the companies Koenigsee (Koenigsee Implantate, Aschau, Germany) and Orthofix (Fragment Fixation System; Orthofix, Busso- lengo, Italy) which sponsored all the implants used. All results were obtained independently and without any critical comments from the companies. In addition to the two authors (TCK and KM), the reconstruction procedures have been performed by J. Heidman, A. Wulke, V. Boeher and S. Heck.

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References