The effect of rotational malunion of the radius and the ulna on supination and pronation

AN EXPERIMENTAL INVESTIGATION

C. E. Dumont, R. Thalmann, J. C. Macy

From the University of Zürich, Switzerland

We have assessed the influence of isolated and combined rotational malunion of the radius and ulna on the rotation of the forearm. Osteotomies were made in both the radius and the ulna at the mid-diaphyseal level of five cadaver forearms and stabilised with intramedullary metal implants. Malunion about the axis of the respective forearm bone was produced at intervals of 10°. The ranges of pronation and supination were recorded by a potentiometer under computer control. We examined rotational malunions of 10° to 80° of either the radius or ulna alone and combined rotational malunions of 20° to 60° of both the radius and ulna.

Malunion of the ulna in supination had little effect on rotation of the forearm. Malunion of either the radius or of the ulna in pronation gave a moderate reduction of rotation of the forearm. By contrast, malunion of the radius in supination markedly reduced rotation of the forearm, especially with malunion greater than 60°. Combined rotational malunion produced contrasting results. A combination of rotational malunion of the radius and ulna in the same direction had an effect similar to that of an isolated malunion of the radius. A combination in the opposite direction gave the largest limitation of the range of movement. Clinically, rotational malunion may be isolated or part of a complex angular/rotational deformity and rotational malunion may lead to marked impairment of rotation of the forearm. A reproducible method for assessing rotational malunion is therefore needed.

Angular malunion after conservatively-treated diaphyseal fractures of the forearm causes limitation of rotation. The effect of isolated rotational malunion of the radius or ulna on the limitation of the range of movement (ROM) of the forearm is less well documented. Daruwalla described six children with rotational malunion out of 28 with malunion of the forearm, but mentioned difficulties in the assessment of rotational changes on radiographs. High-grade isolated rotational malunion is easily discernible, but low-grade rotational malunion or that combined with angular deformities is less noticeable and harder to quantify. Hence, clinically, rotational malunion should be borne in mind when angular deformities cannot fully explain the extent of limited rotation of the forearm. Although several studies have quantified the reduction of such rotation as a result of angular malunion, few have quantified it for isolated rotational malunion of both the radius and ulna.

We have studied fresh-frozen cadaver specimens with a device which allows simulation of rotational malunion of either the radius or ulna, or a combination of both. Our aim was to assess the influence of isolated and combined rotational malunion of the radius and ulna on the limitation of rotation of the forearm.

Materials and Methods

We used five fresh-frozen cadaver specimens of the forearm. All were transected at the glenohumeral joint with all bones, joints and soft tissues left intact. They were thawed at room temperature and all the measurements were performed consecutively for a given specimen. A medial approach was used for the midpart of the shaft of the ulna and a volar approach for the midpart of the shaft of the radius. Two external fixators were fixed rigidly to the radius and ulna to avoid angular or rotational deformities. Cuts were perpendicular to the mechanical axis of the respective bone. We performed diaphyseal bone resections with a hand-held oscillating saw. Custom-made cylindrical metal implants were introduced into the medullary canal. These were anchored rigidly in both the radius and ulna with cemented screws and sharp spikes which prevented rotation between the implants and bone surfaces, precisely preserving the length of the bone (Fig. 1). The implants were marked at 10° intervals for measuring rotational malunion.
in pronation and supination. The direction of the rotational malunion referred to the direction of the rotation of the distal fragment with regard to the proximal fragment. Anteroposterior and lateral radiographs were taken to control the position of the implant with respect to the anatomical axes of the radius and ulna (Fig. 2). The specimen was fixed rigidly to a freely adjustable carbon frame. The elbow was fixed in 90° of flexion by drilling two threaded pins into the shaft of the humerus and two through the metacarpal bones. The radiocarpal and midcarpal joints were locked with a 2.5 mm Kirschner (K-) wire through the radius. The forearm was positioned perpendicular to the floor and only pronation and supination were allowed to occur after the external fixator had been removed.

Rotation of the forearm was produced by applying to the two distal K-wires a torque of 0.5, 1 and 2 Nm through cables attached to pulley wheels. Each specimen was preconditioned through ten pronation-supination cycles. Rotation of the forearm was measured by a GL60 10K/M potentiometer (Contelec, Biel, Switzerland) and 20 Hz connected through a DAQCard-AI-16E-4 slot card (National Instruments, Austin, Texas) to a laptop computer (Fig. 3). Preliminary investigations with the device gave repeatability of measurements within 3° with the 0.5 Nm torque and 5° to 7° with torques of 1 and 2 Nm. Maximal pronation and supination reached a plateau after constant torque for 30 seconds indicating maximum tissue deformation. A set of measurements consisted of two pronation-supination cycles. Maximal values for pronation and supination were extracted using customised software written with Labview (National Instruments), and used for the analysis of data.

Maximal pronation and supination without malunion served as a control. ROM was defined as the arc of rotation between maximal pronation and supination. Osteotomies of the radius or ulna were rotated by 10° increments to evaluate the influence of rotational malunion of either the radius or ulna alone. Both were rotated by 20° increments to determine combined rotational malunion. Rotations were increased until resistance prevented further malalignment of the bone. All the measurements were normalised so that control values for maximal pronation and supination for each individual specimen were set to 90°. The data are presented as the mean ±SD.

Results

The maximal inducible rotational malunion in pronation or supination was 80° for either the radius or ulna alone and
the maximal rotational malunion was 60° for both radius and ulna in combined malunion. The ROM obtained for a given rotational malunion was dependent on the applied torque. Raising the torque from 0.5 to 1 Nm increased the maximum pronation or supination by 14 ± 4°. Raising the torque from 1 to 2 Nm increased maximum pronation or supination by 20 ± 4°. Data obtained with torques of 1 and 2 Nm are not shown because of redundancy with results obtained with a torque of 0.5 Nm. Limitation of the rotation of the forearm tended to correlate with the magnitude of the rotational malunion. Loss of movement was proportional to the magnitude of the malunion in the opposite direction.

Isolated rotational malunion of either the radius and ulna. Variations in the ROM resulting from the decrease in the movement opposite to the direction of malunion were balanced by an increase of movement in the direction of the malunion. In malunion of the ulna, increased movement in the direction of the ulna was constant for malunion greater than 20° (Fig. 4). By contrast, in malunion of the radius, the ROM increased in the direction of the malunion until a plateau was reached, followed by a progressive decrease (Fig. 5). Malunion of the radius in supination had the largest effect on reducing the ROM and malunion of the ulna in supination the least.

Combined rotational malunions of both the radius and ulna. The decrease in the movement opposite to the direction of malunion and the slight increase in movement in the direction of the malunion observed in combined malunion of both the radius and ulna in the same direction (malunion of either bone in pronation or of either bone in supination) had an effect on the ROM comparable to an isolated malunion of the radius (Table I).

Combinations of malunion of the radius and ulna in opposite directions (malunion of the radius in pronation and malunion of the ulna in supination, or malunion of the radius in supination and of the ulna in pronation) resulted in the highest limitation of the ROM because the decrease in the movement opposite to the malunion was produced in both pronation and supination movements of the forearm (Table I).

Discussion

Our study reports the limitations of pronation and supination observed in both isolated and combined rotational malunion of the radius and ulna. Modification of the alignment of the proximal and distal radio-ulnar joints in rotational malunion may account for limitations in rotation of

<table>
<thead>
<tr>
<th>Malunion in pronation (degrees)</th>
<th>Ulna (degrees)</th>
<th>Malunion in supination (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>29 ± 8</td>
<td>0°</td>
</tr>
<tr>
<td>40</td>
<td>36 ± 11</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>39 ± 11</td>
<td>40</td>
</tr>
<tr>
<td>0°</td>
<td>33 ± 16</td>
<td>60</td>
</tr>
</tbody>
</table>

Table I. Effect of combined rotational malunion of the ulna and the radius on supination and pronation of the forearm

Fig. 3

Diagram of the apparatus used to measure pronation-supination in cadaver forearms, which was connected to a laptop PC.
Fig. 4
Isolated malunion of the ulna. Histogram showing the effect of rotational malunion on supination and pronation. The vertical bars represent the ROM. The results are given as the mean ±sd.

Fig. 5
Isolated malunion of the radius. Histogram showing the effect of rotational malunion on supination and pronation. The vertical bars represent the ROM. The results are given as the mean ±sd.
In our study, the extent of the limitation of the ROM for a given malunion differed between the radius and the ulna as well as for malunion in pronation and supination. This suggests that the extent of radio-ulnar impingement or increased tension in the interosseous membrane depends on the involved bone and the direction of the axial malunion.

We developed an intramedullary cylindrical metal implant with an external diameter of less than the diameter of the shaft of the bone which allowed simulation of malrotation up to 80° in both directions. Reproducibility of the measurements was controlled in a pilot study. The results for isolated rotational malunion of the radius partly corroborated the findings by Tarr, Garfinkel and Sarmiento, who reported that this resulted in a loss of movement equivalent to the magnitude of the malrotation. We found that malunion of the radius in supination had a more significant effect on limiting ROM than malunion in pronation. The difference was particularly evident for malunion greater than 50°. Isolated rotational malunion of the ulna of less than 50° showed results similar to those recently reported by Tynan et al. They found that the loss of supination or pronation did not directly correlate with the magnitude of the malunion so that the ROM was reduced by 20% with malunion of 45° pronation or 45° supination. We found more limitation of the ROM with malunion of the ulna in pronation than in supination. The results of isolated malunion of either bone in pronation were similar.

Combined rotational malunion produced contrasting results according to the convergence or divergence of the malunion. Combining malunion in the same direction decreased the ROM similarly to that of isolated rotational malunion of the radius. This was thought to occur because the arc of rotation was shifted in the direction of the malunion of the ulna. By contrast, combining rotational malunion in an opposite direction had a synergistic effect with significant limitation of the ROM if one of the forearm bones already had a malrotation of 60°.

Clinically, surgical correction of rotational malunion of both bones is required to improve the ROM. Malrotation combined with angular deformities is probably underestimated and may partly explain the inconsistencies in outcome reported after the surgical treatment of malunion of fractures of the bones of the forearm. Although we did not study combined rotational and angular deformities, and limited our study to malunion of the mid-shaft, our data may contribute to a better understanding of this clinical problem. Further research is required to determine the effects of both rotational and angular deformities.

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References