Effect of different forearm positions on fragment rotation in extra-articular distal radius fractures: A cadaveric study

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ABSTRACT

Objective: The aim of the study was to investigate the effect of different arm positions (hand pronation/supination and elbow flexion/extension) on fragment rotation in extra-articular distal radius fractures in a cadaveric model.

Methods: In this study, ten fresh-frozen cadaveric upper extremities from five donors with a mean age of 69 ± 12 years were used. Two cortical pins were inserted in the radius and the ulna. In a custom-made device, different forearm positions (30°, 60°, and 90° of pronation and supination) and elbow positions (full extension) were tested, using a fluoroscopic analysis. The degree of rotation between the two pins was measured in these positions. At the last test sequence, the tendon of the brachioradialis muscle was released.

Results: A significant difference was found in concerns of the rotational angle between the distal fragment and the radial shaft at different degrees of pronation and supination if the elbow joint was in an extended and flexed position. The release of the brachioradialis tendon did not show any effect.

Conclusion: The results of this study supported that rotational malpositions in distal radius fractures can be decreased if the forearm is in a neutral position. Accordingly, the forearm should be in a neutral position while initially immobilization in a plaster splint is performed.

Introduction

The incidence of distal radius fractures has changed in the last decade, but they are still the most common upper extremity fractures. There are a number of options for stabilisation and treatment of these fractures, including conservative management with cast immobilisation, external fixation and different types of internal fixation. Unstable AO-type A3, B and C fractures often require open reduction and internal fixation. The correct repositioning of fragments and the congruency of the ulna and radius play an important role in the postoperative outcome. Malunion has been described as the most common complication following such fractures, including the loss of length and metaphyseal angulation. The most common malunion of extra-articular fractures emerges from incorrect placement of the Distal Radioulnar Joint (DRUJ). There is a comparatively large number of malunions, which require a corrective osteotomy. The clinical and radiological outcomes after corrective osteotomy following failed internal fixation were comparable with those reported after initial non-operative treatment, in terms of the modified Mayo Wrist Score and the point-score system of Fernandez.

In conservative cast therapy, closed reduction can be required by indirect fragment manipulation using or finger-trap traction and flexion or direct pressure. Accurate hands-on manipulation is challenging as closed reduction offers only limited visibility by radiographic imaging. The position and rotation of the wrist and arm prior to cast application may result in improved fracture alignment; however, rotational malpositioning should be avoided. It has been shown that positioning of the forearm influences fragment configuration. However, there were no differences in clinical outcomes when analysing forearm positioning during cast immobilisation.

The purpose of the study was to gain anatomical knowledge on the behaviour of fragments in a simulated distal radius fracture model during forearm rotation (pro- and supination) and in different degrees of flexion of the elbow joint. If forearm positioning affects fragment rotation, the correct position-
ing prior to the application of a cast for conservative treatment might provide better fragment alignment.

Materials and Methods

Ten fresh-frozen cadaveric upper extremities from five donors with a mean age of 69 ± 12 years were used in this study. All specimens consented in writing during their lifetime to the use of their body for research and education. The study was approved by the ethics committee of the medical faculty. Standard lateral and anteroposterior radiographs of the elbow and the wrist of each specimen were taken to exclude any joint pathology. Prior to the day of testing, the arms were thawed overnight at room temperature.

Two 5 mm conical bone pins were inserted within the dorsal aspect and perpendicular to the humeral shaft in line with the forearm within the mid-portion of the humerus. The specimens were secured to a mounting device, which allowed the arm to be placed in 90° of elbow flexion or full extension and with the forearm resting on a radiolucent working bench (Figure 1A and B). Under fluoroscopic control, a 3 mm pin was placed through the base of the 2nd to 5th metacarpal to control the rotational position of the forearm during testing. A steel bar was attached perpendicular to the pins and was designed to be locked in a semi-circular template, which allowed fixation of different forearm rotational positions with increments of 30°. With the arm in the neutral rotation, 2.5 mm steel pins with an exact length of 16.8 mm were introduced to the epiphysis and the shaft of the radius. The pins were positioned 15 and 40 mm proximal to the radial styloid process. The same procedure was used for insertion of two ulnar intraosseous pins, which were placed 10 and 35 mm proximal to the ulnar styloid process. The position of the pins was radiographically validated and recorded (Figure 2). In the first sequence, the intact specimens were mounted to the testing fixture. One set of fluoroscopic digital images was obtained with the elbow joint positioned in both full extension and 90° of flexion, while the forearm was rotated from the neutral position to 30°, 60°, and 90° of pronation and to 30°, 60°, and 90° of supination. In the second sequence, a radio-palmar approach to the distal radius was created and the pronator quadratus muscle was incised. A palmar mono-cortical osteotomy was performed proximal to the DRUJ, and the dorsal cortex was manually fractured to imitate an extra-articular extension fracture of the radius (AO-type 23 A2.2) (Figure 3). The distal radial pin (15 mm proximal from the styloid process) was set in the fragment.

Testing was performed by rotating the forearm from the neutral position to 30°, 60°, and 90° of pronation and supination to measure the rotation angle from the distal to the proximal pin. Therefore, a malrotation during changing of pronation and supination of the forearm and elbow flexion or extension was observed. In each position, digital fluoroscopic images were obtained, and the same procedure was repeated with the elbow in full extension. In the third sequence, a small incision was created 20 mm proximal to the radial styloid process, and the tendon of the brachioradialis muscle was released. With the elbow joint flexed by 90° and the forearm in neutral rotation, the fracture was reduced and testing was performed as described previously.

Data analysis

All fluoroscopic images were digitally processed and calibrated to a radiographically captured reference using imaging software (Image J, NIH). The absolute radiographic length of each pin was measured digitally. Using the law of tangent, the angle by which each pin had rotated in the various forearm positions was calculated (Figure 3). For each specimen and each position, the absolute value and differences between the rotational angle of the proximal and distal radial or ulnar pin, reflecting the rotational difference between the diaphysis and the fractured fragment, were calculated. Images obtained from intact specimens were measured once by three independent observers to analyse the accuracy of the measurements.

Statistical analysis

The normal distribution of the experimental data was validated using the Kolmogorov–Smirnov procedure. A one-way analysis of variance was used to compare the rotational angles at each forearm position in the intact specimens, as measured by the three observers. For each forearm position, a one-way analysis of variance was conducted to evaluate differences in the rotational angle of the radial pins between the different sequences. When overall differences between the sequences were observed, the Scheffé procedure was used as a post-hoc test to identify the specific location of statistically significant differences. The threshold of statistical significance was set at \( P < 0.05 \).

Ethical approval

All procedures using human specimens were performed in accordance with the institutional ethics research committee with reference number 15-289.

Results

In the intact setting, 90° of pronation of the hand and extended elbow joint rotation of the radius resulted in 62.2 ± 17.1° and 58.2 ± 13.4° with the elbow in 90° of flexion. With 90° of supination of the hand, the average rotation of the radius was 48.6 ± 8.8° with the elbow extended and 51.6 ± 13.0° with the elbow in 90° of flexion. After simulation of an extra-articular distal radial fracture, the rotation of the radial shaft decreased with the hand in 90° of pronation, averaging 45.1 ± 13.2° and 39.8 ± 11.0° with the elbow extended and flexed, respectively. In accordance with this result, the rotation of the radial shaft decreased with the hand in 90° of supination, averaging 34.8 ± 13.3° and 37.4 ± 8.9° with the elbow extended and flexed, respectively. Statistical comparison of measurements obtained from the three observers in the intact specimens revealed no significant differences \( (P > 0.05) \) (Figure 4).

The rotational difference between the radial shaft and the distal epiphyseal fragment differs between 25.4° with 90° of hand pronation and 20.8° with 90° of hand supination with full extension of the elbow (Figure 5). If the elbow was placed in 90° of flexion, the rotational difference between the radial shaft and the distal epiphyseal fragment averaged 29.1° with 90° of hand pronation and 18.8° with 90° of hand supination (Figure 6).

In the situation with an extended elbow joint, there was a significant difference in the rotational angle between the distal fragment and the radial shaft at 60° and 90° of pronation \( (P < 0.05) \) and 90° of supination \( (P < 0.05) \). If the elbow was in a flexed position at 90°, there was a significant difference in the rotational angle between the distal
fragment and the radial shaft at 60° and 90° of pronation \((P < 0.05)\) and 90° of supination \((P > 0.05)\). We did not observe any significant malrotation of fragments at 30° pronation \((P > 0.05)\) or 30° and 60° of supination \((P > 0.05)\) in both flexed (90°) and extended elbow positions.

Releasing the brachioradialis muscle did not significantly increase the rotational difference between the radial shaft and the distal epiphyseal fragment in any position of pronation or supination of the hand \((P > 0.05)\).

Discussion
In this anatomical study, we investigated the effect of several forearm (pro- and supination of the hand) and elbow positions (90° flexion and full extension) on fragment malrotation in an extra-articular distal radius fracture.

The study showed statistically significant differences between the intact setting and the simulated fracture setting in forearm pronation of 60° and 90°, and 90° of supination of the forearm in the flexed as well as extended position of the elbow joint. Therefore, applying a certain forearm position in distal radius fractures can reduce further malrotation.

Closed reduction and immobilisation in a cast remains an accepted method for stable distal radius fractures. Several studies have identified risk factors for the loss of reduction, such as age over 60 years, a dorsal angulation greater than 20°, 5 mm radial shorting, dorsal and ulna fracture, and intra-articular radiocarpal involvement.\(^8,9\) Leone et al. separated the predictors for re-dislocation into predictors for early (1 week) and late (6 weeks) instability.\(^10\) Especially in elderly patients, the distal radius fracture is the most common fracture, and the majority can be treated conservatively with acceptable results. Because of the lower bone mineral density, up to 60% of the distal radius fractures result in a secondary displacement after closed reduction, and functional recovery is frequently poor.\(^11,12\) In a prospective cohort study of 74 patients older than 50 years, Jarrenko et al. showed that self-reported outcomes in older adults were not associated with the “acceptability” of radiographic fracture reduction.\(^13,14\)

However, differences in pro- or supination during cast immobilisation therapy have been shown in previous studies.\(^15,16\) This is also seen in our findings, with pronation showing higher rates of malrotation compared to supination. Moreover, Wahlström showed less redislocation in immobilisation in supination compared to pronation in 42 extra-articular fractures of the distal radius, supporting our
findings. While radiographic control of retained alignment might be beneficial in pronation, numerous studies support that radiographic outcome did not correlate with clinical outcomes and the clinical impact may be limited. Fragment malrotation is not necessarily linked to the post-treatment range of motion, as Tynan showed that, even in 45° rotational malunion, forearm rotation is not decreased by more than 20°. In conclusion, several studies have shown a relationship between fragment malrotation in distal radius fractures and forearm position; however, in the clinical setting, the therapeutic consequences might be limited as the outcome scores show no significant differences.

Regarding the role of the brachioradialis muscle, this anatomical study did not show a significant impact of the brachioradialis muscle on fragment rotation. This is in contrast to previous studies; especially in surgical therapy, the brachioradialis muscle is regularly released for greater reduction. However, in this cadaveric study, this may be explained by the use of fresh-frozen specimens without active muscle tonus.

Several limitations apply to our results. As mentioned above, the effects of motoric functions can only be simulated in a diminished way when using cadaveric specimens. Furthermore, even with radiographic control of osseous structures before and after pin placement and fracture application, a possible bias caused by these procedures cannot be excluded completely.

In the given in vitro setting, the study results support that fragment rotation in distal radius fractures can be reduced if the forearm is in a neutral position. In pro- and supination, especially from 60° to 90°, the malrotation of fragments in distal radius fractures is observed, with pronation showing higher malrotation. As a consequence, the forearm should be in a neutral position or low-grade supination while...

Figure 3. A, B. (A) Fluoroscopic image of pins inserted into the ulna and radius in 90° supination of the left wrist with an extended elbow in an intact specimen. (B) Fluoroscopic image of pins and their rotation after induction of fracture and closed reduction in supination and with extended elbow.

Figure 4. Radial shaft rotation during different positions of the elbow in degrees and at different forearm and elbow joint positions. Abbreviation: Pro, Pronation; Sup, Supination.
initial immobilisation in a plaster splint is performed. Only clinical investigations will be able to determine the superiority of this position over different techniques.

Ethics Committee Approval: Ethics committee approval was received for this study from the Ethics Committee of the Medical Faculty of the University of Cologne (Reference number: 15-289).

Informed Consent: Written informed consent was obtained from the patients.

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