The Effect of Supination and Pronation on Wrist Range of Motion

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Abstract

Wrist range of motion (ROM) is a combination of complex osseous articulations and intricate soft tissue constraints. It has been proposed that forearm rotation contributes significantly to carpal kinematics. However, no studies have investigated whether supination or pronation influence this course of motion. The purpose of this study is to examine whether supination and pronation affect the mechanical axis of the wrist. After being screened for gross anatomic abnormalities, six upper extremity cadaver specimens (three matched pairs) were fixed to a custom-designed jig that allows 24 different directions of wrist motion. Each specimen was tested in three separate forearm positions: neutral, full supination, and full pronation. Moments of ± 2 Nm were applied, and the applied moment versus wrist rotation data were recorded. Forearm position did not significantly ($p > 0.31$) affect the ROM values of the wrist. In forearm neutral, supination, and pronation positions the envelope of wrist ROM values was ellipsoidal in shape, consistent with prior neutral forearm biomechanical testing. The major axis of the ellipse was oriented in a radial extension to ulnar flexion direction, with the largest ROM in ulnar flexion. We hypothesized that forearm position would influence wrist ROM. However, our biomechanical testing showed no statistically significant difference in the orientation of the mechanical axis nor the passive ROM of the wrist. The primary passive mechanical axis in all three forearm positions tested (neutral, supination, and pronation) was aligned with radial extension and ulnar flexion. Although it has been shown that forearm position affects various radioulnar, radiocarpal, and ulnocarpal ligamentous tensions and lengths, it appears that wrist ROM is independent of forearm position. Consequently we feel our biomechanical testing illustrates that wrist ROM is primarily dependent on the osseous articulations of the carpus. Additionally, given that no change is observed in wrist ROM relative to forearm position, the significance of the contribution of the distal radioulnar joint (DRUJ) to wrist kinematics is debatable.

Keywords

- supination/pronation
- wrist kinematics

Advances in biomechanical research have led to an improved understanding of the complex mechanical properties of the human wrist. Wrist range of motion (ROM) is a combination of complex osseous articulations and intricate soft tissue constraints. It has been proposed that forearm rotation contributes significantly to carpal kinematics.^{1–3} Pronation

and supination are accomplished through the distal radioulnar joint (DRUJ). This joint allows the radius to revolve around a nearly fixed ulna. Numerous studies have demonstrated that the stability of the DRUJ and its articulation with the carpus is dependent upon multiple radioulnar, radiocarpal, and ulnocarpal ligaments.^{4–6} Recent computed

tomography (CT) analysis with 3-dimensional reconstruction of forearm rotation has begun to quantify the exact extent of changes in carpal ligaments and osseous articular translation as the wrist is moved through various positions of pronation and supination.⁷

Frequently, effective utilization of the wrist and hand requires a complex coordinated movement between the wrist and forearm. As the forearm rotates about its longitudinal axis, various degrees of pronation and supination enable the hand to be oriented for effective and efficient movements. Daily activities, from simple movements such as turning keys and opening doors to more complex movements such as throwing a baseball, all require a combined wrist and forearm ROM. Although significant investigation into the kinematics of wrist ROM has occurred, very little research has been done examining the effect forearm position will have on wrist ROM.

In several pathologies, forearm pronation and supination can be limited. For example, forearm fracture, injury of the DRUJ, and elbow impairment can all result in decreased forearm ROM. Clinically the functional impairment of reduced forearm pronation and supination is apparent. In reviewing the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire, multiple evaluation categories examine forearm ROM as a component of this score. The DASH questionnaire has been validated as an effective measure of health status in patients with various upper extremity injuries, underscoring the importance of forearm pronation and supination in determining clinical outcomes.⁸

Recent work by Crisco et al has shown that the primary mechanical direction of the wrist is one of radial extension and ulnar flexion, a direction along a path of the dart thrower's wrist motion.⁹ This track is guided by the direction of the least stiffness.¹⁰ However, this study examined wrist kinematics only with the forearms in a neutral position. The purpose of this study is to examine the contribution of forearm position to wrist ROM. We hypothesized that wrist range of motion would differ between forearm positions of supination, pronation, and neutral.

Methods and Materials

Six upper-extremity cadaver specimens (three matched pairs) were studied. Complete upper extremities were used. The specimens were maintained in a freezer at -20°C . Approximately 24 hours prior to mechanical testing, the specimens were removed from the freezer and thawed. Visual inspection and X-ray imaging was used to confirm the specimens were free from any anatomical abnormalities.

Proximally the elbow was mechanically fused at 90 degrees of flexion using four screws placed through the distal humeral olecranon joint. Soft tissues were removed over the posterior aspect of the humerus to allow appropriate screw placement and potting; care was taken not to violate the joint capsule with dissection. Distally the digits were disarticulated at the metacarpophalangeal joints. Screws were then inserted into the metacarpal heads and soft tissues were removed to allow secure fixation in the potting material. The distal and proximal screws were then potted in a urethane compound

(Smooth-On, Easton, Pennsylvania) in cylindrically shaped molds. The humerus was then transected through its distal one-third aspect to allow placement in the custom jig.

The finger flexors and extensors were removed. The extensor carpi radialis longus and brevis, extensor carpi ulnaris, flexor carpi radialis, and flexor carpi ulnaris were isolated, and each of these four tendon groups was whip-stitched for later attachment to constant-force springs on the specimen jig. Throughout preparation and testing, the specimens were kept moist with a wrapping of saline solution-soaked gauze. Care was taken to preserve all ligamentous attachments and preserve specimen integrity.

Neutral forearm rotation was obtained using the previously described method of placing the humerus and forearm flat on the dissecting table, flexing the elbow to 90 degrees, and then rotating the forearm so that the palm lay down flat on the dissecting table in the same plane as the forearm and humerus. Neutral forearm rotation was then further standardized under fluoroscopic examination by carefully pronating or supinating the forearm to maximize the distance between the radial and ulnar styloids on the anteroposterior (AP) view.⁹

First the specimens were pinned and tested in neutral forearm rotation, followed by full supination and then full pronation. For each forearm position, Kirschner wires (K-wires) were used to pin the radius to the ulna, thus locking the intended forearm position. The specimens were tested in a custom jig which would apply an unconstrained moment to the wrist in each of the 24 directions of wrist motion (model 8521S; Instron, Norwood, MA).⁹ Four constant-force springs (4.45 N each; McMaster-Carr, Robbinsville, NJ) were attached to each of the isolated tendons.

After the specimen had been run through all 24 directions of wrist range of motion, the specimen was removed from the jig. The K-wires used to fix the radius and ulna in a neutral forearm position were removed. The forearm was then placed in maximal supination, defined as the maximal amount the cadaver specimen could be supinated by two separate physician examiners before significant resistance was encountered. A goniometer was used to measure the supination; measurements were only considered accurate if both investigators agreed.¹¹⁻¹³ K-wires were placed through the radius and ulna to hold the forearm in the supinated position, the specimen was placed back in the jig, and the previously described testing sequence was repeated. After the specimens completed testing in the 24 directions of wrist ROM, they were removed from the jig. The forearm K-wires were removed. The forearms were placed in maximum pronation, using the same methodology as previously described for supination. The ROM for each specimen is illustrated in **Table 1**.

The moment-rotation behavior was determined from 0 to 2 Nm in 24 directions of wrist motion. Moment was applied as a sinusoidal wave in angular displacement control to a load limit of 2 Nm at a test frequency of 0.1 Hz. To mechanically precondition the specimens in each direction, they were cyclically loaded for a total of nine cycles. Throughout testing, the vertical movement of the actuator was held at a

Table 1 Summary of the ROM for each specimen in degrees at neutral, maximal supination, and maximal pronation

Specimen	Neutral	Supination	Pronation
1 R	0	84	80
1 L	0	90	88
2 R	0	78	80
2 L	0	82	80
3 R	0	93	85
3 L	0	88	88

constant position that was set to the neutral position of the wrist at the beginning of each directional test. Neutral wrist position was defined visually when the dorsal surfaces of the hand and forearm were flush and the long axes of the third metacarpal and the forearm were aligned. The vertical load, consisting of the weight of the distal potting fixture and wrist, was zeroed at the beginning of each directional test with the wrist in neutral position. Data was collected digitally at a rate of 25 Hz, with use of the test frame control system (FastTrack 8800; Instron, Norwood, MA). Only the loading portion of the last cycle was used in the data analysis. The moment-rotation behaviors were determined in the anatomically defined directions of flexion, extension, and radioulnar deviation, oriented 90 degrees relative to each other. The remaining 20 directions of wrist motion were defined at 15-degree increments within in these anatomical directions. Data was reduced to determine values of wrist

range of motion for forearm neutral, supination, and pronation positions.

Results

The mean ROM in extension was 71.6 ± 18.6 degrees in neutral, 68.3 ± 8.4 degrees in supination, and 74.2 ± 11.1 degrees in pronation. ROM for flexion was 101.4 ± 23.7 degrees in neutral, 106.8 ± 17.8 degrees in supination, and 104.1 ± 16.9 degrees in pronation. There was no statistically significant difference in the motion direction between the three different orientations: neutral, supination, and pronation ($p = 0.578$). The mean ROM in ulnar flexion was 122.3 ± 13.0 in neutral, 120.4 ± 12.6 in supination, and 108.9 ± 15.1 in pronation. Radial flexion value for ROM in neutral was 43.3 ± 8.3 degrees, compared with 46.9 ± 7.2 degrees in supination and 45.1 ± 9.8 degrees in pronation. There was no statistically significant effect of the forearm position on the result ($p = 0.305$). This is demonstrated in ►Fig. 1. There was a statistically significant difference in the direction of motion (ulnar deviation) between neutral and pronation orientations ($p < 0.0001$) at 120 degrees from the initial position of the forearms.

A two way analysis of variance (ANOVA) was performed to detect the differences between the motion direction (flexion, extension, radial deviation, ulnar deviation, etc.) orientations and forearm positions (neutral, pronation, and supination). Multiple comparisons were performed using Bonferroni post hoc analysis. Statistical significance was set to 0.05 *a priori*. Interaction between motion direction and forearm position accounted for 1.39% of the total variance (p value = 0.58),

Fig. 1 Graphical representation of ROM values in neutral, supination, and pronation. This demonstrates there was no significant difference in wrist ROM when looking at the different motions of the wrist in 15-degree increments.

indicating that if there were no interaction overall, there were a 58% chance of randomly observing so much interaction in an experiment of this size. The interaction was not statistically significant.

Forearm position accounted for <0.1% of the total variance (after adjusting for matching limbs; p value = 0.30), suggesting that the numbers were too small to make any significant conclusions. Motion direction accounts for 84.34% of the total variance (after adjusting for matching limbs; p value is <0.0001).

There were statistically significant differences between the matched limbs (right vs. left forearms; p = 0.0002).

Discussion

We hypothesized that forearm position would influence wrist ROM. However, our biomechanical testing showed no statistically significant difference in wrist ROM in our three tested forearm positions of neutral, maximum supination, and maximum pronation.

Motion of the wrist is achieved through an intricate interaction among multiple articulations and complex interosseous kinematics. Our understanding of this complicated carpal motion has advanced considerably through extensive investigational work. We have moved from “three-column” and “two-row” theories to an improved understanding of “coupled” wrist motions.^{14,15} Recently, the suggested dart thrower’s motion of the wrist has been proposed as a possible unifying explanation for observed wrist motion. Our findings would again tend to support this idea. In the three forearm positions tested—neutral, supination, and pronation—the envelopes of the average values for wrist ROM were generally elliptical in shape and oriented in a path of radial extension to ulnar flexion.

Recent work by multiple authors has shown that complex wrist ROM results in different tensions and lengths for various radiocarpal, radioulnar, and ulnocarpal ligaments.^{6,16,17} Our results challenge the significance of ligamentous contribution to the mechanical axis of the wrist. By testing our specimens at the extremes of forearm pronation and supination, the ligaments of the wrist and carpus were subjected to different elongation stresses secondary to test positions. With forearm pronation the dorsal superficial radioulnar ligament and palmar deep radioulnar ligament tighten, while in supination the palmar superficial radioulnar ligament and dorsal deep radioulnar ligament tighten.¹⁶ In our study no significant difference in wrist ROM was observed between pronation, supination, and neutral. If the aforementioned ligaments significantly contributed to the mechanical axis of the wrist, one would expect to see a difference in wrist ROM as they moved from a relaxed to a taut state. It is possible that the summation of the forces the ligaments exert over the carpus remains in relative equilibrium through wrist ROM; however, more reasonably, wrist ROM is determined primarily by the shape and contour of its contact surfaces and interosseous connections.

Specific analysis of the DRUJ has shown that forearm rotation causes proximal and distal translation of the distal

aspect of the radius relative to the ulnar head, which can be observed as increased ulnar variance in pronation versus supination.¹⁸ Additionally, forearm rotation produces translation between the sigmoid notch and the ulnar head in the sagittal plane, so that the ulnar head is somewhat palmar relative to the radius during supination and dorsal to it during pronation.^{5,19} However, since no change is observed in wrist ROM relative to forearm position, the significance of the contribution of the DRUJ to wrist kinematics is debatable. Although injuries to the DRUJ undoubtedly have clinical significance in patient symptomatology, the importance of DRUJ injury with relation to wrist kinematics may be less significant.

The dart thrower’s motion—the combination of radial deviation and extension with ulnar deviation and flexion—has been described as the predominant functional arc of wrist motion.²⁰ Prior imaging studies have illustrated that scaphoid and lunate motion is significantly less along this path of the dart thrower’s motion than in any other direction of wrist motion, with the investigators concluding that this path of wrist motion confers a unique degree of radiocarpal stability.²¹ Our results would tend to support these findings. Clinically, injuries and/or surgery to the radiocarpal joint are usually followed by periods of immobilization. Given the inherent stability of the dart thrower’s motion, it is possible to consider that starting early ROM along this axis would not deleteriously affect a prior injury or surgical repair. Additionally, it is possible to theorize that functional wrist motion would be maintained despite various injuries and pathologies affecting forearm rotation.

There are several limitations to this study. First, this is a cadaver study and consequently has all of the limitations of such methodology. It is impossible to truly foretell in vivo kinematics from the use of cadaver specimens; however, our goal was to further our understanding of the mechanical properties of the human wrist in relation to forearm position, and to this end we have succeeded. Additionally, it is understood that elbow position affects DRUJ kinematics.¹⁵ Our test methodology examined upper extremity specimens only with the elbow fused at 90 degrees. We acknowledge that testing the specimens at full extension might have theoretically produced different results. We choose 90 degrees of elbow flexion as an initial examination point. This study also combined both males and females. Several articles have suggested that, because women display more ligamentous laxity, they may consequently display different wrist ROM.^{22,23} We did not examine differences between males and females and recognize this as a possible limitation of our study. Finally, we examined wrist motion as defined by the metacarpals with respect to the forearm; consequently, we measured motion as a summation of radiocarpal as well as midcarpal motion. From our analysis we are unable to distinguish the individual contributions of each joint to ROM.

Conclusion

Wrist ROM is a combination of osseous articulations and soft tissue constraints. Although it has been shown that forearm

position affects various radioulnar, radiocarpal, and ulnocarpal ligamentous tension and length, it appears that wrist ROM is independent of forearm position. Consequently, we feel our biomechanical testing illustrates that wrist ROM is primarily dependent on the osseous articulations of the carpus.

Conflict of Interest

None

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