Effect of Wrist Position on Distal Radioulnar Joint Stability: A Biomechanical Study

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RUNNING HEAD:

Wrist position on DRUJ stability

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ABSTRACT

Purpose To investigate distal radioulnar joint (DRUJ) stability in different wrist positions, and to examine the relative contribution of each ligamentous component of the triangular fibrocartilage complex (TFCC) to DRUJ stability.

Methods We used nine fresh-frozen cadavers. The humerus and ulna were fixed at 90° elbow flexion. The radiocarpal unit was translated relative to the ulna in dorsopalmar directions with the wrist in five positions. Displacement of the unit was measured by an electromagnetic tracking device. Magnitudes of displacement were compared between different wrist positions in various sectioning stages: ulnocarpal ligament (UCL) sectioning, radioulnar ligaments (RUL) sectioning and extensor carpi ulnaris (ECU) floor sectioning.

Results Wrist position and sectioning stage significantly influenced the displacement. In intact wrists, the displacement in wrist extension was significantly lower than that in neutral. However, after UCL sectioning, there were no longer any significant differences. After RUL sectioning, the displacement in radial deviation was significantly lower than that in neutral. Following ECU floor sectioning, there were no longer any significant differences.

Conclusions In intact wrists, DRUJ stability in wrist extension is likely due to tightening of the UCL. After complete RUL sectioning, DRUJ is stabilized in radial deviation due to tightening of the ECU floor.

KEY WORDS:

biomechanics, distal radioulnar joint, wrist position, triangular fibrocartilage complex

INTRODUCTION

Instability of the distal radioulnar joint (DRUJ) is a relatively common clinical problem. Anatomical stability of the DRUJ is achieved through ligamentous structures [1,2,3,4,5], the DRUJ capsule [6], and musculotendinous structures [7,8]. The dominant structures stabilizing the DRUJ are the ligamentous components of the triangular fibrocartilage complex (TFCC), and the primary stabilizers are the dorsal and volar radioulnar ligament (RUL) [4]. The other ligamentous components of the TFCC are the ulnocarpal ligament (UCL) and the floor of the extensor carpi ulnaris (ECU) [2, 9]. The ulnar collateral ligament consists of a component of the floor of the ECU [10].

The UCL arises from the ulnar fovea and palmar RUL and inserts distally into the palmar aspects of the lunate, capitate, and triquetrum [11]. The UCL supports the ulnar carpus from the palmer aspect, stabilizing the ulnocarpal joint. Several biomechanical studies revealed that the UCL does not contribute significantly to DRUJ stability in wrist neutral position [4, 5, 13]. Although the UCL itself does not stabilize the DRUJ, there is a possibility that the UCL contribute to stability of the DRUJ in specific wrist positions [11, 12]. Moritomo et.al investigated the lengths of the UCL in wrist radial deviation and extension with three-dimensional in vivo analysis using computed tomography [14]. They found that the UCL elongates and are likely to be stretched more in these positions. Therefore, we speculated that the UCL may possibly stabilize the DRUJ in wrist radial deviation and extension. Moreover, the ECU floor includes fibers of ulnar collateral ligament, contributing ulnar collateral stability of the ulnocarpal joint. Therefore, we also speculated that when the wrist is radially deviated, increasing tension of the floor may possibly stabilize the DRUJ by radial shift of the distal ulna.

To our knowledge, there is only a single previous clinical study investigating DRUJ stability during different wrist positions [15]. They found that DRUJ mobility in normal wrists decreased in radial deviation compared with the neutral position, and was likely due to tightening of the UCL [15]. These findings indicate that tension on the ulnar wrist components changes during specific wrist positions, affecting DRUJ stability. However, other previous cadaveric studies investigating DRUJ stability were conducted only in the wrist neutral position, and there are no reports to our knowledge focusing on the effect of change in wrist position on DRUJ stability. The purpose of this study was to investigate DRUJ stability in different wrist positions and to examine the relative contribution of each ligamentous component of the TFCC to DRUJ stability.

MATERIAL AND METHODS

Specimen preparation

We used twelve fresh-frozen cadaver upper extremities for this study. Because of relatively elderly subjects of the cadavers we used, we investigated articular pathology and integrity of ligament structures of the TFCC (radioulnar ligament, ECU floor and ulnocarpal ligament) before experiment and had excluded 2 specimens with radioulnar ligament tear and one specimen with the DRUJ osteoarthritis. Then, we investigated nine specimens with no articular pathology, no gross bony deformities, and no ligament disruptions about the DRUJ (7 male specimens and two female specimen; average age, 85 years). All specimens were amputated above the elbow and thawed at room temperature before use. Specimens were kept constantly moist by spraying with normal saline during the experiment. Skin, muscles of the arm and forearm, and the DRUJ capsule were removed sparing the interosseous membranes and the TFCC.

Experimental setup

The humerus and ulna were solidly fixed to the testing apparatus, which was made of wood and titanium screw, with the elbow at 90° flexion (Figure 1). The radius, carpus, and metacarpal bones were fixed with the wrist in five positions (neutral; 70 degrees of extension;

70 degrees of flexion; 25 degrees of radial deviation; 40 degrees of ulnar deviation) using titanium Kirschner wires, and the radiocarpal unit was allowed to translate in palmar and dorsal directions freely relative to the ulna. We used a three-dimensional space electromagnetic tracking device (3SPACE FASTRAK; Polhemus, Colchester, VT, USA). One of two sensors was placed on the ulna, and the other was placed on the radius. A 4-mm-diameter screw was inserted into the ulnar corner of the distal radius and connected to a thread to apply load for passive mobility testing in the dorsal and palmar directions.

Radiocarpal unit passive mobility testing and data acquisition

We performed passive mobility testing by moving the radiocarpal unit relative to the ulnohumeral unit with a load of 20 Newtons in palmar and dorsal directions. A custom-made plastic devise was applied to prevent rotational movement of the radiocarpal unit during passive mobility testing. In addition, we inserted a Kirschner wire in the radial head perpendicular to the longitudinal axis of the radius and put the Kirschner wire between two other Kirschner wires inserted in the humerus to keep the radius in neutral rotation while leaving distal radius dorsopalmer translation. The loading was continued for 20 s in each test, and data from the last 10 s were recorded.

We measured changes in the location of the radius relative to the ulna during passive mobility testing, monitored by the three-dimensional space electromagnetic tracking device.

The ulnar fovea was labeled point F and designated as the fixed point of the ulna. The same reference point was labeled point F′ and designated as part of the radius. Before passive mobility testing, we positioned points F and F′ to completely overlap in the forearm neutral rotation. Simulated instability was expected to impinge the radius against the ulna and simultaneously shift point F′ away from point F. This divergence between the radius and ulna was designated as the F-F′ distance [16] (Figure 2). The total dorsopalmer movement was interpreted as the magnitude of displacement of the radiocarpal unit relative to the ulna during passive mobility testing.

Sectioning of DRUJ stabilizers

We simulated DRUJ instability in wrists with the TFCC intact and by sequential sectioning of the following components of the TFCC (Figure 3): stage 1: wrists with the distal attachment of the UCL sectioned; stage 2: wrists with the foveal and styloidal attachment of the radioulnar ligaments sectioned; stage 3: wrists with transverse sectioning of the ECU floor including the ulnar collateral ligament at the top of the ulnar styloid. In wrists with the TFCC intact and each sectioning stage, the F-F′ distances were measured during passive mobility testing and repeated in five different wrist positions.

Statistical analysis

The F-F′ distances during passive mobility testing were analyzed using two-way analysis of variance (ANOVA) for repeated measures, and analyses were followed by the Bonferroni-Holm method for post hoc comparisons.

RESULTS

The F-F' distances had statistically significant differences among different sectioning stages ($p<0.0001$) and different wrist positions ($p<0.0001$). (Table 1)

Wrists with the TFCC intact: In the TFCC intact wrists, the F-F′ distance was significantly lower in wrist extension than that in the neutral position (1.9mm smaller than neutral) and had a trend to be lower in wrist radial deviation (1.5mm smaller than neutral).

Stage 1 (Wrists with the UCL sectioned): In the UCL sectioned wrists, the F-F′ distance in wrist extension was significantly increased from intact wrists. However, there were no longer any significant differences between different wrist positions in this stage.

Stage 2 (Wrists with the UCL and radioulnar ligaments sectioned): After sequential complete sectioning of the radioulnar ligaments, the F-F′ distances significantly increased compared with those in intact wrists.

The F-F′ distances in radial deviation and extension were significantly lower than that in neutral position (3.7mm and 1.6mm smaller than neutral).

Stage 3 (Wrists with the UCL, radioulnar ligaments, and ECU floor sectioned): In the wrists with all components of the TFCC sectioned, the displacement significantly increased compared to stage 2 regardless of wrist positions. However, no differences were found in the F-F′ distances among different wrist positions. There were no longer any significant differences between various wrist positions in this stage.

DISCUSSION

We found that in the TFCC intact wrists, dorsopalmar stability of the DRUJ increased in wrist extension and had a trend to increase in radial deviation compared to neutral position. These results are comparable to clinical observations by Sanz et al., who found that DRUJ mobility in normal wrists decreased in radial deviation compared with the neutral position [15]. Despite the relatively small change, our study quantified a significant increase in DRUJ stability during wrist extension and tendency of increase in radial deviation from a biomechanical point of view. However, after sectioning of the UCL, the stabilizing effect of wrist extension and radial deviation on DRUJ stability disappeared, and there was no longer statistically different in any wrist position. In addition, DRUJ instability following the UCL sectioning was significantly increased compared to intact wrists only in a wrist extension position. These results suggest that DRUJ stability in wrist extension and radial deviation is likely due to tightening of the UCL. We speculate that because the UCL arises from the fovea and palmar RUL [11], the palmar RUL may be tightened in wrist extension and radial deviation, stabilizing the DRUJ.

After additional complete sectioning of the radioulnar ligaments (Stage 2), DRUJ instability generally increased when compared with the intact wrist. This result is comparable with previous biomechanical studies, indicating that the RUL is a primary stabilizer of the DRUJ. We considered that stage 2 simulated a complete ulnar tear of the TFCC while preserving the continuity of the ECU floor and was similar to a foveal tear of the TFCC [17]. DRUJ instability was significantly lower in wrist extension and particularly in radial deviation than that in neutral position. These results indicate that the DRUJ is stabilized in extension and radial deviation when the ECU floor is preserved. Tightening of the ECU floor, which corresponds to the ulnar collateral ligament, may have contributed to DRUJ stability in wrist radial deviation. Tightening of the palmer portion of the ulnar collateral ligament may have contributed to DRUJ stability in wrist extension. In the stage 2, the DRUJ instability in wrist flexion was almost the same as that in neutral position. This suggests that the ECU floor does not contribute to DRUJ stability in flexion. After the ECU floor sectioning (stage 3), the stabilizing effect of the DRUJ in wrist extension and radial deviation disappeared. This indicates that total sectioning of the TFCC including UCL, RUL, and the ECU floor results in gross instability of the DRUJ in any wrist position.

Clinically, a manual stress test is used to diagnose the specific location of the TFCC tear. Provocative maneuvers of the DRUJ stress test were introduced for determining palmar or dorsal radioulnar ligament injury in pronation and supination in a previous study [18]. The clinical significance of our study may be as follows: First, in diagnosing TFCC injury, when DRUJ instability decreases in wrist extension compared with the neutral position, continuity of the UCL may have been preserved. When DRUJ instability decreases in wrist radial deviation compared with the neutral position, the continuity of the ECU floor may have been preserved. The use of additional DRUJ manual stress test in wrist extension or radial deviation may be useful to detect loss of integrity of the UCL or ECU floor. Second, when a surgeon repairs the TFCC, in cases where DRUJ instability does not change in wrist extension compared with the neutral position, the volar approach may be preferable for detecting possible UCL injury, because the UCL consists of the volar structure of the TFCC and may be better visualized by volar approach. In cases where gross DRUJ instability is found regardless of wrist position, the dorsal approach may be recommended for detecting ECU floor injury, because the ECU floor consists of the dorsal structure of the TFCC and is easily observed by dorsal approach.

This study has several limitations. First,we removed DRUJ capsule before testing which affects DRUJ stability. While DRUJ capsule contributes to DRUJ stability in forearm maximum pronation and supination, DRUJ capsule does not contributes to DRUJ stability in forearm neutral rotation [6]. Because this study was performed only in forearm neutral rotation, removal of DRUJ capsule did not affect the DRUJ stability. Second, the sequence of sectioning stages may differ from clinical TFCC injury. We modified the sequence of ligament sectionings from a previous biomechanical study [4]. We simulated Palmer type 1C in stage 1, and simulated Palmer type 1B in stage 2 and 3 [19]. A randomized or different sequence of ligament sectioning would provide additional information. Third, the magnitude of the F-F' distance may have been affected by rotational movement of the radius. To minimize this measurement error, we prevented the rotational movement of the radius by a custom-made plastic jig at the top of the testing apparatus as well as supplemental Kircshner wires inserted in the radial head and humerus. Another limitation is the use of relatively elderly cadaveric specimens. Although we had excluded 3 specimens with TFCC degenerative tears or DRUJ osteoarthritis before the experiment, potential degeneration of the ligamentous or cartilaginous structures could have affected DRUJ stability.

In summary, stability of the DRUJ changed in different wrist positions. In intact wrists, the stability increased in wrist extension. This stability could be due to possible tightening of the UCL. Although DRUJ instability occurred following a simulated radioulnar ligament tear, the DRUJ was mainly stabilized in radial deviation when the continuity of the ECU floor was preserved. The ECU floor stabilized the DRUJ in radial deviation in the wrists with complete radioulnar ligament tears.

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FIGURE LEGENDS

Figure 1: Experimental setup.

The humerus and ulna were solidly fixed to the testing apparatus with the elbow at 90° flexion. The radius, carpus, and metacarpal bones were fixed with the wrist in extension, flexion, radial deviation, and ulnar deviation using Kirschner wires, and the radiocarpal unit was allowed to translate in palmar and dorsal directions freely relative to the ulna. A custom-made plastic devise was applied to reduce rotational movement of the radiocarpal unit. In addition, we inserted a Kirschner wire in the radial head and put the Kirschner wire between two other Kirschner wires inserted in the humerus to prevent rotational movement of the radiocarpal unit. A three-dimensional space electromagnetic tracking device was used. One of two sensors was placed on the ulna, and the other was placed on the radius.

Figure 2: Schematic drawing of the measurement of the distance F-F′.

The ulnar fovea was labeled point F and designated as the fixed point of the ulna. The same reference point was labeled point F′ and designated as part of the radius. Before passive mobility testing, we positioned points F and F′ to completely overlap in the forearm neutral rotation. Simulated instability was expected to impinge the radius against the ulna and simultaneously shift point F′ away from point F. This divergence between the radius and ulna was designated as the F-F′ distance.

a: Normal articulation between the radius and the ulnar head. The ulnar fovea was marked as a reference point on both the distal radius and the ulnar head.

b: Displaced articulation between the radius and the ulnar head. The reference point of the radius is displaced volarly against the ulnar head.

Figure 3: Schematic drawings of sequential sectioning of the TFCC.

Sectioning of the TFCC is shown as follows. Stage 1: distal attachment of the UCL sectioning; stage 2: foveal and styloidal attachment of the radioulnar ligament sectioning; stage 3: transverse sectioning of the ECU floor including the ulnar collateral ligament at the top of the ulnar styloid.

Table 1

Magnitude of Dorsal/palmar translation (Mean±SD)

	Neutral	Extension	Flexion	Radial deviation	Ulnar deviation
Intact	6.7±2.3	4.8±2.0 §	6.9±2.4	5.2±2.3	5.9±2.6
UCL cut	6.7±2.5	6.6±3.0 †	7.1±2.2	6.2±2.8	6.9±2.8
RUL cut*	13.3±3.5	11.7±3.2 §	13.6±3.4	9.6±3.5 §	13.5±3.4
ECU floor cut**	20.4±6.5	20.9±6.7	20.6±6.8	20.5±6.9	21.0±6.5

UCL: ulnocarpal ligament, RUL: radioulnar ligament, ECU: extensor carpi ulnaris

§ Indicates data that are significantly different from that of neutral in the same row

† Indicates data that are significantly different from that of intact in the same column

* Indicates data that are significantly different from that of intact in all wrist position

** Indicates data that are significantly different from that of RUL cut in all wrist position

Figure 1

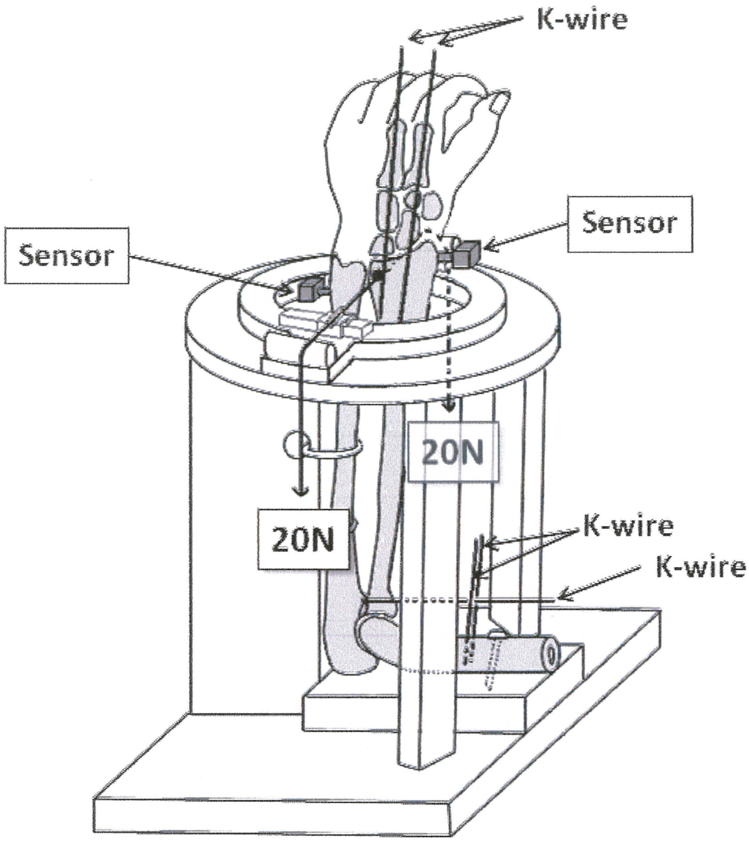

Figure 2

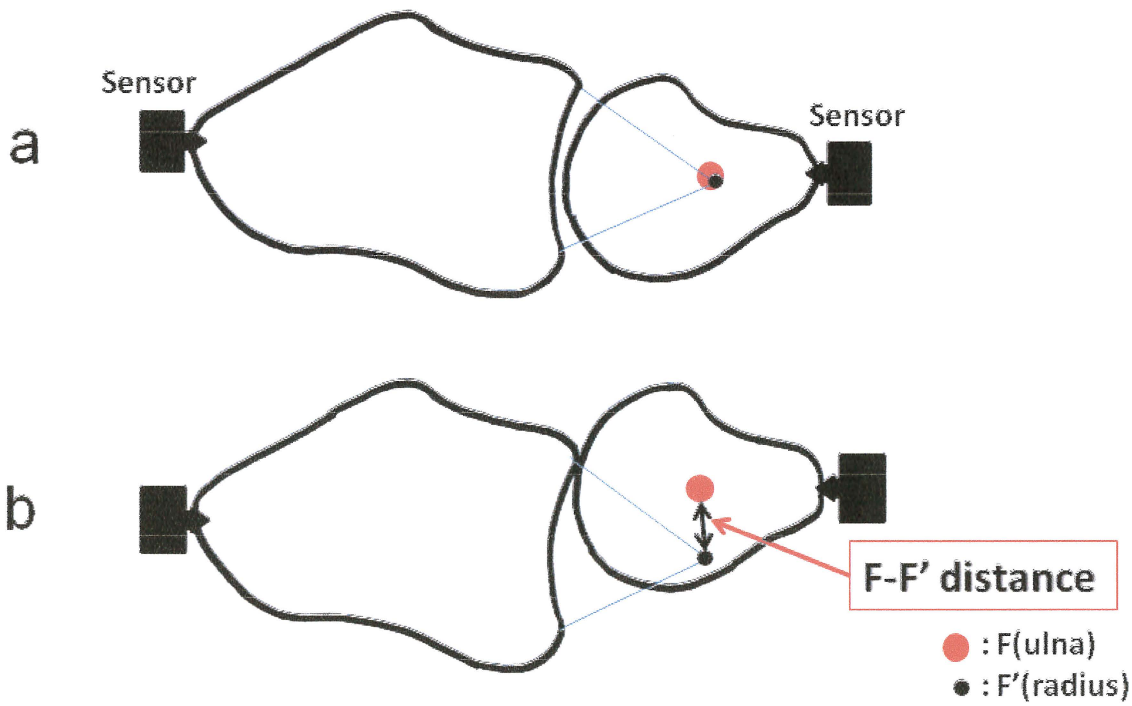

Figure 3