Biomechanical Study of Distal Radioulnar Joint Ballottement Test

Running title: Biomechanical study of DRUJ instability

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Authors Contribution Statement

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Akio Iida contributed to the biomechanical study and the analysis and interpretation of data.

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Abstract

We investigated the reliability and accuracy of the distal radioulnar joint (DRUJ) ballottement test using five fresh-frozen cadaver specimens in triangular fibrocartilage complex (TFCC)-intact and TFCC-sectioned wrists. The humerus and proximal ulna were fixed. The ulna was allowed to translate in dorsopalmar directions without rotation, and the radius was allowed to move freely.

Four sensors of a magnetic tracking system were attached to the radius and ulna and the nails of each examiner's thumbs. Five examiners conducted the DRUJ ballottement test before and after TFCC sectioning. We used two techniques: with holding and without holding the carpal bones to the radius (holding and non-holding tests, respectively). We compared the magnitudes of bone-to-bone (absolute DRUJ) movement with that of the examiner's nail-to-nail (relative DRUJ) movement. The intrarater intraclass correlation coefficients (ICCs) were 0.92 (holding) and 0.94 (non-holding). The interrater ICCs were 0.84 (holding) and 0.75 (non-holding). Magnitudes of absolute and relative movements averaged 11.5 and 11.8 mm, respectively ($p<0.05$). Before TFCC sectioning, the DRUJ movement during the holding and non-holding techniques averaged 9.8 and 10.8 mm, respectively ($p<0.05$). The increase in DRUJ movement after TFCC sectioning was greater with the holding technique (average 2.3 mm) than with the non-holding technique (average 1.6 mm). The DRUJ ballottement test with magnetic markers is relatively accurate and reliable for detecting unstable joints. We recommend the holding technique for assessing DRUJ instability in clinical practice.

Keywords: biomechanics; distal radioulnar joint; ballottement test; human cadaver

INTRODUCTION

The distal radioulnar joint (DRUJ) relies heavily on soft tissue support for stability, with dorsal and volar radioulnar ligaments being its primary stabilizers. Injury of the deep radioulnar ligament at the ulnar fovea and base of the ulnar styloid may result in DRUJ instability.[1] Untreated instability often causes wrist pain and/or weakness of grip strength. Thus, accurately diagnosing DRUJ instability is clinically important.

Because of inherently unstable and complicated soft tissue structures of the DRUJ, the diagnosis and treatment of the instability remain challenging. In the clinical field of hand surgery, DRUJ instability is assessed by several manual stress tests, such as the ballottement test, ulnocarpal stress test, and piano-key test. A previous biomechanical study using cadaver wrists demonstrated that, compared with other manual stress tests, the DRUJ ballottement test was the most accurate for evaluating the instability.[1]

The DRUJ ballottement test is usually conducted in forearm neutral rotation and interpreted as positive if the examiner identifies conspicuous displacement of the radius relative to the ulnar head or lack of end-point resistance.[1,2] Examiners may recognize DRUJ instability depending on the magnitude of movement of the examiners' fingernail grasping the ulnar head and the radius. During the testing, however, the magnitude of movement of the radius and the ulna may be different from that of examiner's fingernail. When the fingernail movement is larger than the bony movement, examiners may overestimate the extent of DRUJ instability. Also, there is no established maneuver for the DRUJ ballottement test, although two have been reported: one with and one without holding the carpal bones to the radius during the testing.[3,4] There are no reports available, however, that have claimed that one of these maneuvers is more reliable or more accurate than the other for detecting DRUJ instability.

The purpose of this study was to investigate the reliability and accuracy of the DRUJ ballottement test with these two techniques in triangular fibrocartilage complex (TFCC)-intact wrists and in TFCC-sectioned wrists using cadaver specimens. We hypothesized that examiners could over- or under-estimate DRUJ instability because they must rely on the test's reliability and accuracy, which may be different for the two techniques.

MATERIAL AND METHODS

Specimen Preparation

We used five fresh-frozen cadaver upper extremities. All specimens were amputated above the elbow and thawed at room temperature before use. Specimens were kept constantly moist by spraying them with normal saline during the experiment.

Experimental Setup

The humerus and proximal ulna were fixed on the testing apparatus (composed of wood and titanium screws) using Kirschner wire, with the elbow at 90° of flexion and the forearm in neutral rotation. The ulna was allowed to translate in palmer and dorsal directions without rotation, and the radius was allowed to move freely (Figure 1). Two sensors of a magnetic tracking system (3SPACE FASTRAK; Polhemus, Colchester, VT, USA) were attached directly in the distal aspect of the radius and ulna after injecting silicone rubber (Blue Mix (50g) two-part silicon mould / mold making material. Silicone rubber, Agsa Japan Co., Ltd) into the bone holes. The sensors were then rigid in the bone holes after rubber polymerization. The other two sensors were attached to the nails of the examiner’s thumbs, with which the examiner would perceive instability (Figure 2).

Sectioning the DRUJ Stabilizers and Data Acquisition

Five examiners (two board-certified hand surgeons and three board-certified orthopedic surgeons) conducted the DRUJ ballottement test before and after sectioning the ulnar insertion of the TFCC. TFCC was sectioned at its foveal and styloidal attachments to the deep and superficial fibers of radioulnar ligaments and ulnocarpal ligaments (UCLs).

DRUJ capsules and the floor of the extensor carpi ulnaris (ECU) tendon sheath were preserved to simulate a real clinical case. We used two techniques: with and without holding the carpal bones to the radius during the testing (holding technique and non-holding technique, respectively) (Figure 3). We measured the magnitude of the movement between the radius and ulna (absolute DRUJ movement) and that between the examiner’s nails (relative DRUJ movement) using the electromagnetic tracking device. Each test was repeated three times. The values of the three tests were averaged and used to compare the magnitude of the DRUJ movement among different conditions.

Data Analysis

We determined the intra-rater and inter-rater reliability of the DRUJ ballottement test by calculating the intraclass correlation coefficient (ICC) for dorsopalmar movement of the DRUJ for the two manual testing techniques. ICCs were interpreted to be slight at ICC >0 but <0.2, fair at ICC >0.21 but <0.4, moderate at ICC >0.41 but <0.6, substantial at ICC >0.61 but <0.80, and almost perfect at ICC >0.81 but<1.00 by Landis and Koch’s criteria.[5] We compared the magnitude of the dorsopalmar real DRUJ movement with that of the relative DRUJ movement to determine how the nail movement approximates the bone movement. The magnitudes of the dorsopalmar movement of the DRUJ were compared before and after TFCC sectioning in order to simulate clinical testing of both injured and contralateral healthy wrists, and the two techniques were compared regarding the holding and non-holding conditions.

Paired *t*-tests were used to determine the accuracy of the DRUJ ballottement test for the holding and non-holding techniques and for the intact and TFCC-sectioned wrists. Statistical significance was accepted at the $P<0.05$ level.

RESULTS

We conducted a total of 300 DRUJ ballottement tests by five examiners in five cadavers. The mean values of three examinations were used for data analysis, and 100 bone-to-bone and nail-to-nail movements were analyzed to compare the magnitude of DRUJ movement, including 25 values of intact and TFCC sectioned wrists with holding and non-holding techniques.

Intrarater and Interrater Reliability of the DRUJ Ballottement Test

The intra-rater reliability values, identified using the ICC of bone-to-bone movement during the holding and non-holding techniques, were 0.92 (almost perfect) and 0.94 (almost perfect), respectively. Inter-rater reliability with different wrists and techniques were 0.89 (almost perfect) for TFCC-intact wrists with the holding technique, 0.8

(substantial) for TFCC-intact wrists with the non-holding technique, 0.74 (substantial) for TFCC-sectioned wrists with the holding technique, and 0.68 (substantial) for TFCC-sectioned wrists with the non-holding technique (Table 1).

Magnitude of DRUJ movement

Magnitudes of bone-to-bone and examiner's nail-to-nail movements averaged 11.5±4.4 and 11.8±4.2 mm, respectively. There was a statistically significant difference between these magnitudes ($p<0.05$) regardless of the TFCC sectioning status or whether they were tested using the holding or the non-holding technique.

Both techniques showed that real DRUJ instability was significantly increased after TFCC sectioning. In TFCC-intact wrists, the magnitudes of the DRUJ movement with the holding and non-holding techniques were 9.8±4.1 and 10.8±4.6 mm, respectively. The magnitude of DRUJ movement with the holding technique, however, was significantly lower than that with the non-holding technique ($p<0.05$). After TFCC sectioning, the DRUJ movements increased to 12.1±4.1 and 12.4±4.3 mm, respectively. Regardless of the technique used (holding or non-holding), the magnitude of DRUJ movement in the TFCC-sectioned wrist was significantly greater than that in the TFCC-intact wrist ($p<0.05$). The increased DRUJ instability after TFCC sectioning was greater with the holding technique (average 2.3 mm) than with the non-holding technique (average 1.6 mm) (Table 2).

DISCUSSION

The manual DRUJ ballottement test is widely used by hand surgeons to assess joint instability. In clinical practice, it is important to compare DRUJ laxity between injured and contralateral wrists instability. [2] Based on the results of this study, intra-rater and inter-rater reliability of the DRUJ ballottement test was almost perfect or substantial. Also, the magnitude of DRUJ movement in the TFCC-sectioned wrist was significantly greater than that in the intact wrist regardless of the technique used to assess it (holding or non-holding). The current comparison between the intact and TFCC sectioned wrists can be interpreted as comparison of clinical testing between intact and injured wrists. Thus, these results suggest that the DRUJ ballottement test with magnetic markers has a sufficiently high diagnostic performance to discriminate joint instability.

Clinical evaluation of joint instability during the manual stress test depends on subjective judgment by each examiner. We interpreted the magnitudes of movement between examiners' thumbs as relative DRUJ instability and those of bony movement as absolute instability. The relative DRUJ instability was significantly increased when compared to absolute DRUJ instability. We think that this difference was due to the soft tissue that intervened between the nail and the bone during the testing maneuver. Despite a significant result, there was minimal difference (0.3mm) between the nail to nail and bone to bone movement, and we interpret the clinical significance of this difference to be relatively small.

Several studies have investigated the accuracy of manual stress testing using fresh cadaver specimens.[6-8] Little, however, has been reported on comparing the testing techniques. Based on the current results, the inter-rater reliability of the DRUJ ballottement test using the holding technique was greater than that for the non-holding technique. Also, after TFCC sectioning, the increase of DRUJ movement with the holding technique was greater than that with the non-holding technique. Thus, we recommend use of the holding technique in the clinical setting to achieve more accurate examinations. With intact wrists, the magnitude of the DRUJ movement is significantly less with the holding technique than with the non-holding technique. We considered that this difference of DRUJ movement was due to a difference of ligaments contributing to the DRUJ stability between the holding and non-holding technique. Because the holding technique holds the radius with the carpus firmly, the radiocarpal unit would be stabilized by connections of the ulnocarpal ligaments and the floor of the ECU tendon to the ulnar head. Three-dimensional ligamentous structures, which include not only the radioulnar ligaments but the ulnocarpal ligaments and the floor of the ECU tendon, may have constrained the DRUJ. [9,10] Meanwhile, in the non-holding technique, the ulnocarpal ligaments and floor of the ECU tendon may have not supported the DRUJ, because the carpal bones moved during the testing (Fig. 4).

This study has several limitations. First, the magnitude of the nail and bone movements gave much useful data, but the direction of the displacement and rotational movement of the radius against the ulna was not fully evaluated. In future studies, we need to evaluate the three-dimensional movements including rotation. Second, we used relatively elderly specimens in the experiment. Potential degeneration of the ligamentous or cartilaginous structures could have affected the DRUJ instability. Third, the magnitude of DRUJ movement may not reflect the true instability after a TFCC injury because of the inherent stiffness in cadaveric specimens. Fourth, the pain inhibition mechanism is absent in cadaveric studies. Thus, associated soft tissue injuries, such as capsular rupture and tendon injury, may contribute to the magnitude of instability. Fifth, this study was performed only in forearm neutral rotation. Evaluating DRUJ instability in supination and pronation will be warranted in the future study.

Lastly, although we found a significant difference following TFCC sectioning, we have no data if the examiners could actually appreciate the 2mm difference. There was no test performed to determine whether this statistically significant difference can be detected clinically without magnetic tracking.

In summary, we consider that the DRUJ ballottement test with magnetic markers is able to detect an unstable joint relatively accurately and reliably. The inter-rater reliability of DRUJ ballottement testing was higher with the holding technique than with the non-holding technique. The increase in bone-to-bone movement after TFCC sectioning was larger with the holding technique than with the non-holding technique. We therefore recommend holding technique and to compare the laxity between affected and the opposite wrists in diagnosing DRUJ instability in clinical practice.

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Figure 1. Humerus and proximal ulna were fixed to a testing apparatus using Kirschner wire, with the elbow at 90° of flexion and the forearm in neutral rotation. Four sensors of a magnetic tracking system were attached directly to the distal aspect of the radius and ulna and to the nails of the examiner's thumbs.

Figure 2. (Left) Two sensors were attached to the nail of examiners' thumbs, by which the examiner would perceive a sense of instability. (Right) The other two sensors of the magnetic tracking system (3SPACE FASTRAK; Polhemus, Colchester, VT, USA) were attached directly to the distal aspect of the radius and ulna.

Figure 3. (Left) Distal radioulnar joint (DRUJ) ballottement test while holding the carpal bones to the radius (holding technique). (Right) Non-holding technique.

Figure 4. In the intact wrists, the magnitude of DRUJ movement using a holding technique was significantly smaller than that using a non-holding technique. This difference of DRUJ movement assumed to be due to a difference of ligaments contributing to the DRUJ stability between the holding and non-holding technique. In the holding technique, not only the Radioulnar ligaments: RULs (red), but the

Ulnocarpal ligaments: UCLs (green) and the floor of the ECU tendon（blue）may have constrained the DRUJ via the holded radiocarpal unit. Thus, these three-dimensional ligamentous structures may have supported the DRUJ during the holding technique. Meanwhile, in the non-holding technique, the UCLs and floor of the ECU tendon may have not supported the DRUJ, because the carpal bones moved freely during the test. Thus, two-dimensional ligamentous structures of the RULs only stabilized the DRUJ during the non-holding technique.