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Biomechanical Analysis of Capsular Repair Versus Arthrex TFCC Ulnar Tunnel Repair for Triangular Fibrocartilage Complex Tears

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Abstract

Background: This study compares the effectiveness of a peripheral capsular repair with a knotless arthroscopic transosseous ulnar tunnel repair (TR) in restoring distal radioulnar joint (DRUJ) stability and stiffness in the setting of a massive triangular fibrocartilage complex (TFCC) tear. **Methods:** Eight matched pairs of fresh-frozen cadaveric forearms were tested. Each forearm was tested in supination and pronation using 3-dimensional (3D) optical tracking devices prior to any intervention. Each specimen then underwent a diagnostic wrist arthroscopy and sectioning of the TFCC's deep and superficial fibers. All specimens were then retested to assess instability secondary to the tear. The TFCC was repaired with either a peripheral capsular repair (CR) using three 2-0 polydioxanone sutures or a transosseous ulnar TR using a 2-0 FiberWire, and then retested (statistical significance; $P < .05$). **Results:** After TFCC arthroscopic sectioning, all specimens were unstable with a significant increase in translation and a significant decrease in stiffness. TFCC repair with TR resulted in displacement and stiffness similar to the native tissue. CR specimens were found to have significantly greater displacement and significantly decreased stiffness compared with the intact state. **Conclusions:** Arthroscopic sectioning of the TFCC resulted in DRUJ instability, as measured by stiffness and ulnar translation. TR effectively restored DRUJ stability and demonstrated no significant difference in postoperative stiffness or maximal displacement when compared with the intact specimen in pronation and supination. This study provides biomechanical evidence that an arthroscopic ulnar tunnel technique can restore stability to the DRUJ after a massive TFCC tear.

Keywords: wrist, arthroscopy, peripheral capsular repair, suture anchor, triangular fibrocartilage complex tears

Introduction

The triangular fibrocartilage complex (TFCC) is an intricate combination of soft tissue stabilizers on the ulnar side of the wrist, composed of the articular disk, the ulnocarpal ligaments, and the superficial and deep radioulnar ligaments.[10] Ulnar-sided wrist pain often results from injury to the TFCC,[15] and this most commonly occurs due to forced wrist extension or rotational injury to the wrist with distraction along the ulnar border.[8] This can result in chronic pain and is associated with increased scores on the patient reported Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire.[3,12]

Several groups have performed biomechanical analyses of a number of different repair techniques of peripheral TFCC injuries.[1,6,7,11,13,19] Ruch et al performed a biomechanical comparison of open transosseous repair versus capsular repair of TFCC tears in cadavers using a traction model to stress the TFCC.[13] They simulated a Palmer I-B injury using an ulnar-sided capsulotomy and disrupted all ulnar and dorsal attachments of the TFCC under direct visualization. The resultant displacement in the palmar and dorsal directions was measured before and after TFCC repair. They found no statistical difference in translation between the two repair groups. Importantly, however, they did not assess the relative stability of the ulna in varying positions of forearm rotation (supination and pronation), which can alter distal radioulnar joint (DRUJ) stability.

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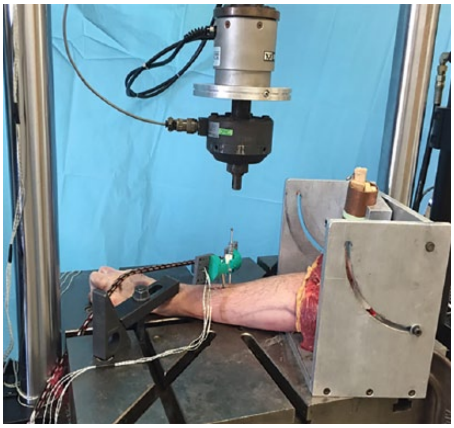

Figure 1. The experimental setup, showing the specimen was intact distal to the midhumerus.
Note. The arm was secured to the testing table by a mount fastened to the humerus. The distal radius was clamped to the table with a block under the radius to allow for motion on the ulna in the volar and dorsal direction while maintaining the radius stationary. A cortical bone screw was placed in the ulnar shaft 10 cm proximal to the ulnar styloid. The ulnar bone screw was then connected to the Instron ram and loaded with 5 cycles of ±40 N of force. An optical tracker was attached to the ulnar screw to measure displacement. A second screw was placed in the radius for an additional optical tracker to be attached. The radial tracker served as constant reference point to measure ulnar displacement.

The Ruch et al study has been cited as justification for arthroscopic capsular repair of the TFCC, and this was confirmed in multiple subsequent clinical series.[2,14,18] However, no study has directly compared arthroscopic capsular repair with arthroscopic transosseous fixation. Biomechanical comparisons that closely simulate the clinical load experienced by the joint are particularly lacking, as the DRUJ and TFCC must resist both translation and rotational forces. A better representation of the stresses applied in the clinical situation has been described by Dy et al in a cadaver model using cyclical loading that more accurately simulates the ulnar ballottement test performed clinically.[7] In addition, newer generation optical tracking systems have been used in various biomechanical joint studies and orthopedic applications,[4,5] providing submillimeter accuracy of translational and rotational motion as a function of force applied.

We hypothesize that using a biomechanical model that more accurately represents physiologic loading—combined with highly sensitive optical tracking devices—will demonstrate increased load to failure of the arthroscopic transosseous ulnar tunnel repair when compared with the arthroscopic peripheral capsular repair.

Materials and Methods

We prepared 8 matched pairs (16 specimens) of fresh-frozen cadaveric forearms for biomechanical testing of the TFCC using a servohydraulic load frame (Instron 8821s, Norwood, Massachusetts). The average age of the specimens was 67 years; there were 2 females and 6 males. Each specimen was intact distal to the midhumerus.

The biomechanical setup was similar to the method described by Dy et al with some important modifications (Figure 1).[7] The soft tissue proximal to the elbow was stripped in each specimen to allow mounting of the humerus to the testing table. The ulnar styloid was identified and marked with a stitch. A long cortical bone screw was placed 10 cm proximal to the stitch in the ulna. A second cortical bone screw was placed in the radius 10 cm proximal from a line drawn perpendicular to ulnar axis at the ulnar stitch. These cortical screws were approximately 100 mm long and 4.5 mm in diameter. The screw diameter was downsized to 3.5 mm for smaller ulnar diaphyses. Each cortical screw was placed bicortically through the ulnar or radial diaphysis with several threads past the far cortex. The remaining screw length allowed the 3-dimensional (3D) optical trackers (Certus, NDI International, Waterloo, Ontario, Canada) to be attached directly to each cortical screw.[9,16] In addition, the cortical screw served as the attachment of the ulna to the Instron.

Two cortical screws were necessary; the first was placed through the ulna and attached to the load and then cycled in the volar and dorsal plane. The second, placed in the radius, served as an attachment site for the optical tracker. The radius was held stationary with a clamp secured to the testing table with a block beneath it, while the ulna remained free to move in the volar and dorsal plane. When the specimens were tested in supination, the cortical screws were placed in a volar to dorsal direction. Conversely, when the specimens were tested in pronation, the screws were placed in a dorsal to volar direction.

Each forearm was tested in supination and pronation prior to any intervention to establish baseline motion of the wrist. As mentioned previously, the radius was clamped to the table of the Instron using a custom setup (Figure 1). The ulnar cortical screw was attached to the ram of the loading machine such that volar and dorsal loading could be applied. The ulna was cycled in the volar to dorsal direction for 5 cycles between ±30 N-40 N while translational displacement and stiffness was measured with 3D optical trackers attached to each bone screw as described. Multiple cycles allowed for the creep in the soft tissues to reach a steady state to minimize error. The 3D positioning of the optical trackers was interpreted by the Optotrak position sensor (Certus, NDI International, Waterloo, Ontario, Canada) (Figure 2).

Each specimen then underwent a diagnostic wrist arthroscopy using a 3-4 portal for camera placement and a 6R working portal. The TFCC was identified in each specimen and the deep and superficial radioulnar ligaments were sectioned with a scalpel introduced into the joint through the 6R portal. The TFCC capsular and foveal attachments were sectioned from an ulnar to radial direction, taking care

Figure 2. Picture of the NDI Certus Optotrak position sensor which determines the 3-dimensional spacial positioning of the optical trackers attached to the ulna and radius via cortical bone screws (Certus, NDI International, Waterloo, Ontario, Canada).

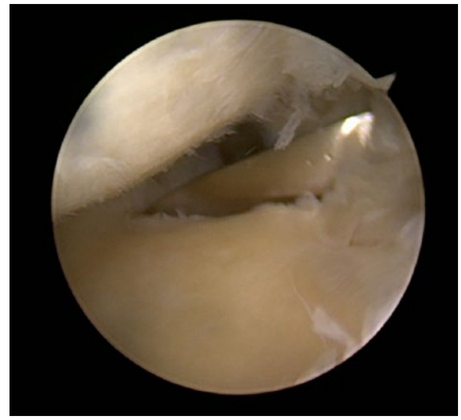

Figure 3. A representative arthroscopic image depicting a scalpel sectioning of all ulnar attachments of the triangular fibrocartilage complex.

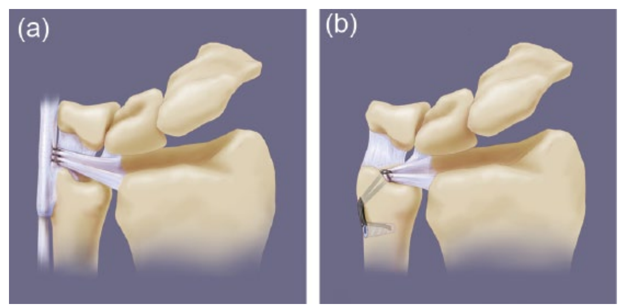

Figure 4. (a) Illustration of peripheral capsular repair and (b) illustration of transosseous ulnar tunnel repair. All ulnar attachments of the triangular fibrocartilage complex were divided arthroscopically as depicted in this illustration.

to keep the articular disk intact while elevating it and the distal radioulnar ligaments (Figure 3). All radial attachments were maintained. The specimens were then retested in the manner described above to assess instability secondary to the iatrogenic tear.

The TFCC in each specimen was then repaired with one of two techniques. The first technique was a peripheral capsule repair and the second was a transosseous ulnar tunnel technique. We randomly assigned the right arm to undergo one of the two repairs. The left arm of each matched pair was repaired using the technique not used on the right. For example, if the right arm was randomly assigned to undergo peripheral capsular repair, the left side underwent a transosseous ulnar tunnel technique. The opposite is true if the right arm was assigned to the transosseous ulnar tunnel technique. Eight specimens were repaired with a peripheral capsular technique using three 2-0 polydioxanone sutures, as described by Ruch and Papadonikolakis.[14] A meniscal mender kit was used to place each suture in a horizontal mattress fashion, securing the torn TFCC to the capsule. A small incision was made just volar to the extensor carpi ulnaris subsheath and the sutures were tied directly onto capsule (Figure 4a and Supplemental Figure 1).

The remaining 8 specimens were repaired with a transosseous ulnar tunnel technique using a 2-0 FiberWire. The 2-0 FiberWire was passed through the TFCC via the 6R portal using a scorpion suture passer (Arthrex, Inc, Naples, Florida), with the tails brought out the 6R portal. Then, a guidewire was inserted at a 45° angle from the lateral aspect of the ulna, just proximal to the ulnar neck, and entering into

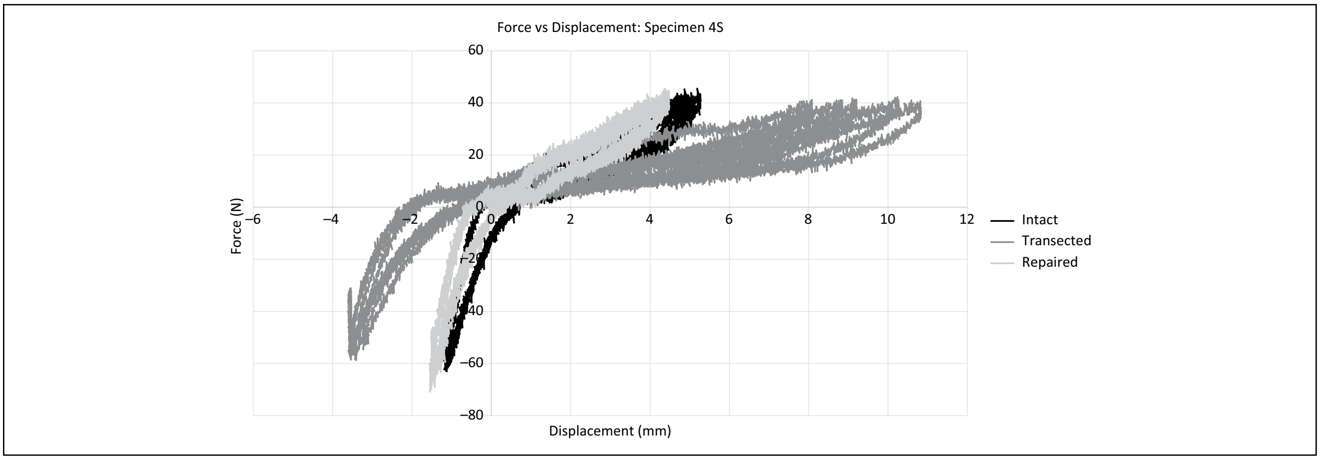

Figure 5. Results of biomechanical testing in pronation. Maximal ulnar displacement in millimeters with the wrist in pronation. Distal radioulnar joint stiffness in N/mm with the wrist in pronation.

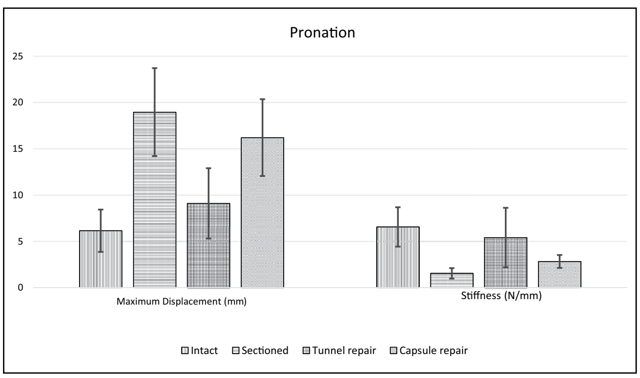

Figure 6. Results of biomechanical testing in supination. Maximal ulnar displacement in millimeters with the wrist in supination. Distal radioulnar joint stiffness in N/mm with the wrist in supination.

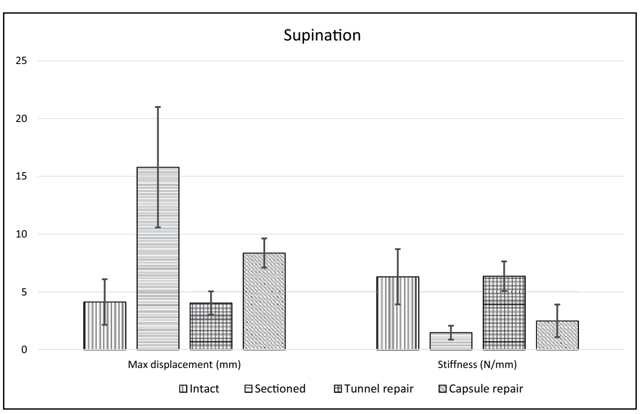

Figure 7. Sample force versus displacement curve for specimen repaired with transosseous ulnar tunnel technique tested in supination.

the joint through the fovea. An ulnar tunnel was created along the path of the K-wire with a 3.0 mm cannulated drill. Care was taken not to penetrate the TFCC with the drill. A suture lasso was then fed through the ulnar tunnel into the joint and brought out the 6R portal. Sutures were then shuttled into the tunnel and brought out the lateral side. These were secured 1 cm proximal to the ulnar tunnel with a 2-mm Push Lock anchor (Arthrex, Inc, Naples, Florida) (Figure 4b and Supplemental Figure 2). The two repair methods and materials were chosen based on current clinical practice.

After the repair each specimen underwent final testing. Force vs displacement (Figure 5) data were analyzed to determine maximal displacement and stiffness. Maximal displacement was determined to be the magnitude of the difference between the maximum anterior and posterior displacements of the ulna relative to the radius with radius held constant and the ulna being loaded by the Instron. Stiffness was determined as the slope of a linear fit of the force vs displacement curve between −20 N and +20 N. A Student *t* test was used to determine statistical significance in maximal displacement and stiffness among the two repair techniques in pronation and supination compared with the intact state. A $P < .05$ was considered significant.

Results

After arthroscopic sectioning of the TFCC, all specimens were unstable with a significant increase in translation when compared with the intact state. Maximal ulnar displacement in pronation increased from 6.15 mm to 18.96 mm on average ($P < .01$). In supination, the displacement increased from 4.13 mm in the intact state to 15.80 mm in the sectioned wrists ($P < .01$) (Figures 6 and 7). Stiffness significantly decreased after sectioning the TFCC. In pronation, the stiffness decreased from 6.57 N/mm in the intact wrist to 1.55 N/mm after sectioning the TFCC. In supination, the stiffness decreased from 6.32 N/mm to 1.48 N/mm after sectioning the TFCC (Figures 6 and 7).

Table 1. Average Maximal Displacement and Stiffness of Capsular Repair Versus Transosseous Tunnel Repair.

Position	Capsular repair	Transosseous repair	*P* value
Pronation			
Maximal displacement (mm)	16.21	9.11	.01
Stiffness (N/m)	2.84	5.42	.02
Supination			
Maximal displacement (mm)	8.37	4.05	<.01
Stiffness (N/m)	2.50	6.36	<.01

Note. P values of capsular repair compared with transosseous repair.

Triangular fibrocartilage complex repair with the transosseous ulnar tunnel technique resulted in displacement similar to the native tissue. There was no significant difference in maximal displacement in pronation or supination when compared with the intact wrists. Displacement of the ulna in pronation after the ulnar tunnel repair was 9.11 mm (P = .09) when compared with the intact state. Displacement of the ulna in supination after the ulnar tunnel repair was 4.05 mm (P = .95) when compared with the intact state.

Triangular fibrocartilage complex stiffness was not significantly different from the intact state after repair of the TFCC with the transosseous technique. Stiffness in pronation after ulnar tunnel repair was 5.42 N/mm (P = .41) and in supination the stiffness was 6.36 N/mm (P = .95).

Capsular repair specimens were found to have displacement significantly greater than the intact state. Maximal displacement in pronation after capsular repair was 16.21 mm ($P < .01$). Maximal displacement in supination after capsular repair was 8.37 mm ($P < .01$).

Stiffness was significantly decreased in the capsular repair when compared with the intact state. In pronation, the capsular repair had a stiffness of 2.84 N/mm ($P < .01$). In supination, the capsular repair had a stiffness of 2.50 N/mm ($P < .01$).

A Student *t* test comparing the capsular repair in relation to the transosseous repair demonstrated a significant difference in the maximal displacement in both supination and pronation. Maximal displacement of the ulna in pronation was 9.11 mm for ulnar tunnel repair and 16.21 mm with capsular repair (P = .01). DRUJ stiffness in pronation was 5.42 N/m with ulnar tunnel repair and 2.84 N/m with capsular repair (P = .02). Maximal displacement of the ulna in supination was 4.05 mm for ulnar tunnel repair and 8.37 mm with capsular repair ($P < .01$). DRUJ stiffness in pronation was 6.36 N/m with ulnar tunnel repair and 2.50 N/m with capsular repair ($P < .01$) (Table 1).

Discussion

Triangular fibrocartilage complex injuries can result in instability, particularly if the foveal attachments of the ligamentum subcruentum are torn. While many arthroscopic repair techniques have been used successfully to improve pain after a peripheral TFCC tear, it is unclear whether these are suitable to address DRUJ instability associated with a massive TFCC tear. This study sought to address this question by testing the ulnar stiffness and maximal displacement before and after arthroscopic repair of a Palmer I-B TFCC tear.

A novelty aspect of this study was the quantification of the effects of a Palmer I-B lesion of the TFCC on wrist kinematics in both supination and pronation in a cadaver model. Precise 3D optical tracking devices were used to achieve a higher degree of accuracy of ulnar translation and stiffness than that used in prior studies.[13]

This study demonstrated that arthroscopic sectioning of all ulnar attachments of the TFCC resulted in DRUJ instability, as measured by stiffness and ulnar displacement. This instability was found in both supination and pronation. These results also lend credibility to the biomechanical model, indicating that the model described above was able to detect a significant change in DRUJ stiffness and ulnar translation after sectioning the superficial and deep fiber of the TFCC. Transosseous ulnar tunnel repair effectively restored DRUJ stability and demonstrated no significant difference in postoperative stiffness or maximal displacement when compared with the intact specimen. Maximal displacement in pronation after ulnar tunnel repair—when compared with the intact state—trended toward significance. With a larger sample size, this may have become significant.

However, the stiffness and maximal displacement of those specimens undergoing peripheral capsular repair remained significantly different from the intact state, with increased displacement and decreased stiffness. Previous studies have shown no difference in ulnar displacement after transosseous or peripheral capsular repair through an open approach,[13] but these did not use optical tracking methods. Of note, prior studies also loaded the wrist with weights, as opposed to the materials testing system described above.

A strength of the current study includes a novel application of an optical tracking system to determine maximal ulnar displacement and stiffness. This allowed for

submillimeter accuracy in identifying displacement, potentially increasing the ability to detect subtle differences in outcome not previously appreciated.

Another difference between our study and prior literature is that the above specimens were tested in both supination and pronation. Patel et al compared an all-inside arthroscopic repair to an extensor retinaculum capsulorrhaphy (Herbert sling) as treatment for peripheral TFCC tears on cadavers.[11] They found a 21% decrease in ulnar translation with the Herbert sling, a 12% decrease with the arthroscopic repair, and 26% decrease in ulnar translation with both the Herbert sling and arthroscopic repair. Importantly, however, the specimens were tested in pronation only.

Limitations remain in the present study, particularly with regard to sample size. The relatively small sample size of 8 matched pairs from 16 cadavers limits the conclusions that can be drawn from this analysis. In addition, we did not control for age of the specimens. However, displacement and stiffness measurements of each specimen were compared with the intact state.

Future areas of research include comparison of arthroscopic transosseous tunnel to open TFCC repair. Controversy remains as to whether an arthroscopic approach is adequate to treat a TFCC tear with concurrent DRUJ instability.[14] Stable peripheral TFCC tears have traditionally been thought to be amenable to peripheral capsular repairs. However, if the deep fibers are torn from the foveal attachment, and result in an unstable DRUJ, then an open repair may be chosen by the surgeon.[17] The result of this research suggests that an arthroscopic ulnar tunnel repair of a peripheral TFCC tear may be sufficient to restore DRUJ stability. However, more work is needed to compare these methods directly.

The current standard of care for TFCC repair with an unstable DRUJ is an open approach with repair of the TFCC that uses a suture anchor. This creates significantly more scarring and potentially greater morbidity compared with arthroscopic repairs. Arthroscopic peripheral capsular repairs are commonly used in TFCC repairs, particularly for peripheral tears without evidence of instability. While this method enjoys great clinical success in relieving pain, our data suggest that it is insufficient to address instability. Furthermore, this study provides the biomechanical evidence that an arthroscopic ulnar bone tunnel technique could restore stability to the DRUJ comparable with a preinjury state, potentially increasing the patient's surgical options.

Ethical Approval

Our institution does not require approval for cadaver studies.

Statement of Human and Animal Rights

This article does not contain any studies with human or animal subjects.

Statement of Informed Consent

Informed consent was obtained when necessary.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: D.M.B.: Arthrex—medical education consultant and research support; American Society for Surgery of the Hand—board or committee member; Axogen—other financial or material support.

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