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Biomechanical assessment of lateral ulnar collateral ligament repair and reconstruction with or without internal brace augmentation

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Background: Surgical treatment of posterolateral rotatory instability (PLRI) using primary repair or reconstruction of the lateral collateral ligament complex have proven inconsistent. This study aimed to test the hypothesis that augmentation of LUCL repair or palmaris longus tendon reconstruction using a suture tape augmentation would be associated with less rotational displacement and greater torque load to failure (LTF) compared with nonaugmented constructs.
Methods: Cadaveric elbows ($n = 12$ matched pairs) were used. Baseline stiffness and displacement values were obtained. The LUCL was transected followed by repair alone, repair with augmentation, reconstruction with palmaris longus graft, or reconstruction with augmentation. Specimens were retested including torque LTF. Paired *t* tests were performed to assess the biomechanical effects of augmentation.
Results: Augmentation was associated with higher LTF than repair and reconstruction alone ($P = .008$ and .047, respectively). Displacement was less with augmentation in reconstruction groups ($P = .048$) but not in repair groups. Suture tape augmentation maintained rotational stiffness better than repair alone ($P = .01$). Although reconstruction with augmentation maintained rotational stiffness better than non-augmented reconstruction, the differences were not statistically significant ($P = .057$). Mode of failure for repair alone was predominantly suture pulling through repaired ligament. Augmented repairs primarily failed at the anchor-bone interface. Modes of failure for both reconstruction groups were similar, including graft tearing and/or slipping at the anchor.
Conclusion: When positioned in neutral forearm rotation and 90° of flexion to simulate postoperative conditions, augmentation of LUCL repair or tendon reconstruction using suture tape is associated with better resistance to rotational loads compared with nonaugmented repair or reconstruction, while maintaining near-native rotational stiffness.

Although most simple dislocations are managed conservatively, there is a subset of patients who experience recurrent instability and subluxation due to posterolateral rotatory instability (PLRI).[26,27] The elbow is second only to the shoulder in incidence of dislocations of the upper extremity, occurring at a rate of 5.2 per 100,000 people.[30] PLRI of the elbow was first described by O'Driscoll et al[27] in 1991 and thought to be caused by injury to the lateral collateral ligament.[26] Imatani and colleagues[19] described the macro- and micro-anatomy of the lateral collateral ligament and its subcomponents, which include the radial collateral ligament, the annular ligament, the lateral ulnar collateral ligament (LUCL), and the accessory posterior annular ligament. The authors reported that the LUCL blends into the capsuloligamentous complex, which helps to explain its role and importance to elbow stability throughout the arc of motion.

Prior to the studies by O'Driscoll et al and Imatani et al, lateral elbow constraint was believed to be primarily maintained by the bony anatomy and the dynamic stabilization provided by the common extensors and anconeus,[19] such that surgical treatment of LUCL injuries were not deemed necessary or effective. However, with increasing knowledge of the role the LUCL plays in the stability of the elbow and its role in the pathomechanics of PLRI,[9,16,18,20] surgical repair and reconstruction techniques have been

This study was conducted in accordance with University of Missouri institutional policies and guidelines on the use of cadaveric tissues. Institutional review board approval was not required for this basic science study.

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described. Currently, primary repair and single- and double-strand autograft and allograft reconstructions are used to address LUCL deficiency and resultant PLRI.[1,10–12,15,16,20–23,25] The goal of these procedures is anatomic reconstruction of the LUCL[1,11] for restoration of functional stability to the elbow.[4,6,8,10,11,15–17,22,23,26,28,31] However, outcomes after these treatments have not proven consistently effective.[5,29] As such, augmented primary repair or reconstruction of the LUCL using nonabsorbable suture tape as an "internal brace" has been described as a method for potentially improving these outcomes.[17]

Use of the internal brace technique has been studied and reported to be safe and effective in many different types of ligament repairs and reconstructions.[3,7,13,14,24,32] For the elbow, Dugas et al[13] performed a biomechanical evaluation of various reconstruction techniques for the ulnar collateral ligament and reported that augmentation of repair with internal brace resulted in less gapping than repair alone. Bernholt et al[2] compared the biomechanical properties of native ulnar collateral ligament ligament to reconstruction with and without internal brace and also found that internal bracing yielded superior results to reconstruction without augmentation. The reconstruction with internal brace was found to be equivalent to the native ligament. Recently, Greiner et al[17] published the results of a cohort of patients who underwent repair and augmentation with internal brace. However, to date and to the authors' knowledge, there have been no biomechanical studies evaluating the use of internal brace augmentation of repair or reconstruction of the LUCL. Therefore, the goal of this study was to test the hypothesis that augmentation of LUCL primary repair or tendon reconstruction using a suture tape internal brace would be associated with significantly less rotational displacement and significantly greater torque load to failure compared with repair or reconstruction without internal brace, while not compromising native elbow stiffness.

Materials and methods

Data collection

In accordance with our institutional policies and guidelines on the use of cadaveric tissues, we acquired 12 matched pairs of fresh-frozen cadaveric elbows (n = 24, average donor age: 55.42 ± 10.72; male n = 5; female n = 7). We stored the elbows at −20°C and then allowed them to thaw at room temperature for approximately 24 hours before dissection. Cadaver elbows were dissected of all soft tissue except for the joint capsule and ligaments connecting the humerus, radius, and ulna. No pre-existing capsular or ligamentous pathology was noted in any of the specimens. The proximal end of the humerus and distal ends of the radius and ulna were potted in fiberglass resin (3M Corp., St. Paul, MN, USA) in a neutral forearm rotation.

We randomly allocated each matched pair of elbows either to primary LUCL repair or to reconstruction with palmaris longus tendon treatment groups. The pairs were then randomly subdivided into repair/reconstruction with internal brace or without internal brace, determining left or right by coin flip, for a total of 6 elbows in each of 4 groups (Fig. 1). An ElectroPuls E10000 Instron Materials Testing Machine (Instron Corp., Norwood, MA, USA) with biaxial motion capabilities and a load cell capacity of 10 kN in linear force and 100 Nm in rotational force was used for mechanical testing. Each specimen was mounted in the Instron machine with the long axis of the humerus perpendicular to the testing surface and the elbow flexed at 90° as shown in Figure 2. A compressive load of 45 N was applied to the humerus, and a rotational preload of 2 Nm was applied to the lateral aspect of the elbow. The preload was followed by 500 rotational cycles between 2 and 10 Nm, at 1.5 Hz, to determine stiffness and resistance to rotational displacement in the intact state. This testing method was designed to simulate the immediate postoperative period when failure is most likely to occur by repetitive movements.[5,20]

The LUCL was then identified and sharply dissected from the lateral condyle of the humerus to simulate a proximal tear of the ligament. Based on previous assignments by matched pairs, 1 of 4 treatments were performed on each elbow as follows:

1. Primary repair (n = 6; Fig. 3): The humeral isometric point was located by identifying the intersection point in which the lateral condyle is bisected by a line from the center of the radial head both in 90° of flexion and extension. A 2.75-mm drill was then used to predrill a socket in the distal humerus while aiming in a slightly cranial direction. This hole was then tapped with a 3.5-mm tap. A 3.5-mm SwiveLock (Arthrex, Inc., Naples, FL, USA) loaded with a size 2 nonabsorbable suture was inserted. This suture was then passed through transected LUCL fibers in a locked mattress fashion directly re-pairing them to the native origin on the lateral condyle.
2. Primary repair with internal brace (n = 6; Fig. 4): The humeral portion was prepared in the same fashion as direct repair. The 3.55-mm anchor was placed into the humerus with a 2-mm FiberTape (Arthrex, Inc.) also loaded in the eyelet. The no. 2 sutures, along with the tape, were passed through the ligaments and fascia. The no. 2 sutures were passed in an identical manner to repaired specimens. The elbow joint was reduced and the no. 2 sutures tied. We located the supinator crest of the ulna just posterior to its proximal edge. At this level, the fascia was split with a stab incision down to bone, leaving most of the posterior tissues intact. The ulnar cortex was then drilled using a 2.75-mm

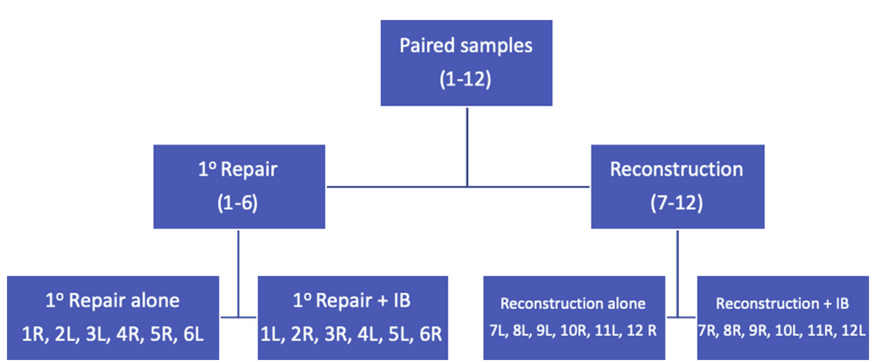

Figure 1 Cadaveric sample randomization. *R*, right elbow; *L*, left elbow; *IB*, internal brace.

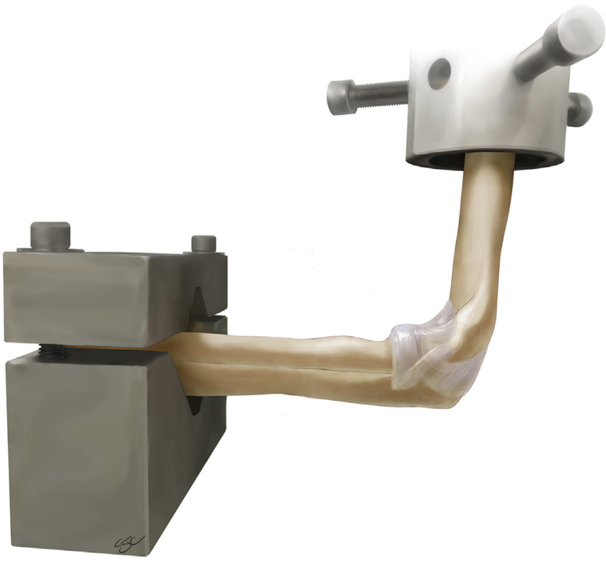

Figure 2 Intact specimen mounted on the Instron materials testing machine. *IB*, internal brace. © University of Missouri.

drill and tapped with a 3.5-mm tap. The tape was tensioned and a knotless 3.5-mm SwiveLock anchor was then docked into the ulna with the internal brace. The resultant internal brace was suprafascial to mimic the clinical scenario, allowing for removal or cutting.

3. Reconstruction (n = 6; Fig. 5): The isometric point of the lateral humeral condyle was located using the radial head bisector technique previously described. The cortex at this point was breached using a 5.0-mm drill angling slightly proximal. Another hole was drilled in the ulna just proximal and posterior to the supinator crest near the base of the annular ligament using the same 5.0-mm drill to a depth of approximately 2 cm. In the samples with ulnas thinner than 2 cm, the ulna was drilled bicortically to allow for complete docking of the anchor. The palmaris longus tendon was docked into the ulna using a 4.75-mm forked-tipped SwiveLock anchor. The elbow was then held in a reduced position while the proximal end of the graft was docked with another 4.75-mm forked-tipped SwiveLock anchor.

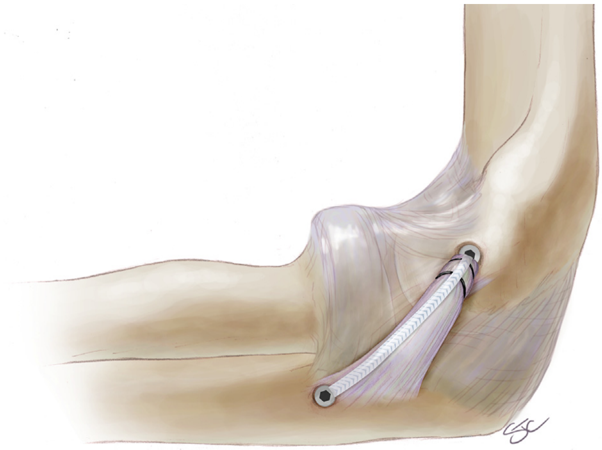

Figure 4 Illustration of primary repair with internal brace augmentation. © University of Missouri.

4. Reconstruction with internal brace (n = 6; Fig. 6): Ulnar and humeral tunnels were drilled with the same technique described above. Using 4.75-mm SwiveLock anchors, the palmaris longus tendon and internal brace of fiber tape was docked into each sample. Of note, the graft and internal brace was too thick to fit within the forked tip in 1 sample. For this sample, the construct was secured to the anchor via suture lasso. The matched pair in the reconstruction-only group was secured with the same anchor/lasso construct.

When the assigned surgical treatment was completed, the samples were remounted into the materials testing machine and the loading protocol was repeated, and for these treated specimens, cyclic loading was followed by torque to failure at 10°/s in order to ascertain the potential for catastrophic failure in the postoperative period. For all specimens, load, torque, linear displacement, and rotational displacement data were recorded at 1000 Hz. Using the torque–rotational displacement curves generated by each sample, we calculated the stiffness of each intact and repaired sample from the slope of the first cycle. The rotational displacement was measured between the first and last cycles at 2 Nm of torque. For treated specimens, we determined an additional stiffness measurement from the linear portion of the torque–rotational

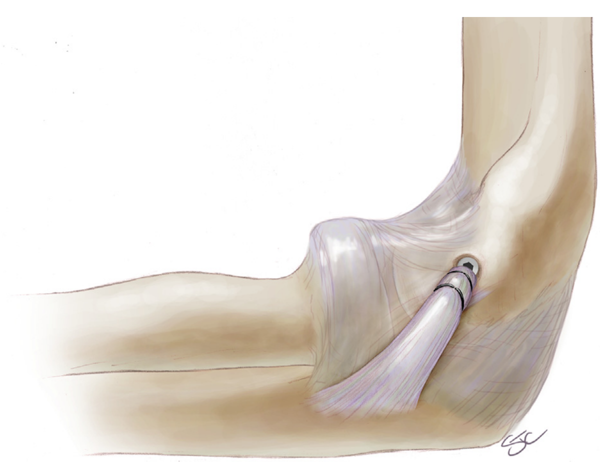

Figure 3 Illustration of primary repair alone. © University of Missouri.

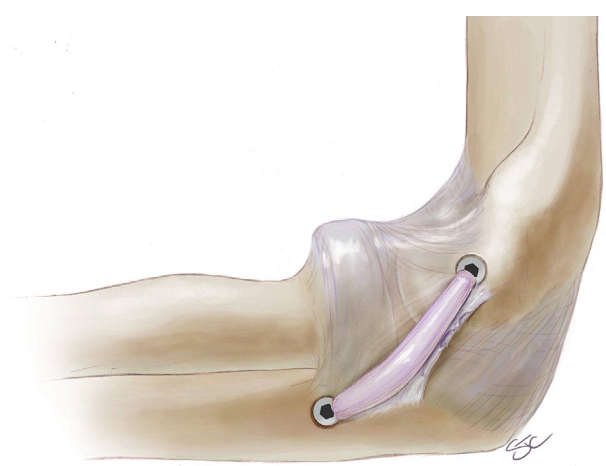

Figure 5 Illustration of tendon reconstruction alone. © University of Missouri.

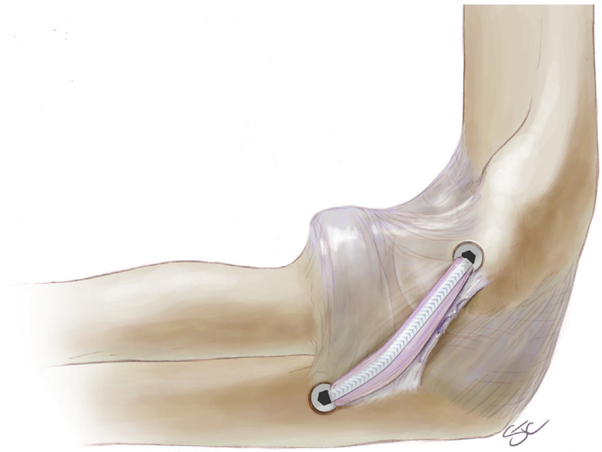

Figure 6 Illustration of tendon reconstruction with internal brace augmentation. © University of Missouri.

displacement curve during the torque to failure, and the failure torque was determined from the maximum torque recorded for each sample (Fig. 7). The mode of failure was documented for each specimen.

Data analysis

A prestudy 2-sided *t*-test power analysis to determine sample size was performed using biomechanical testing data from a previous study,[13] which suggested that 6 matched specimens per group would be sufficient to result in reaching the desired power of 0.8 with alpha = 0.05. Means and standard deviations were calculated for each outcome measure. We compared data for statistically significant ($P < .05$) differences within treatment category using paired *t* tests.

Results

No statistically significant differences were noted for intact-state rotational stiffness or rotational displacement data between

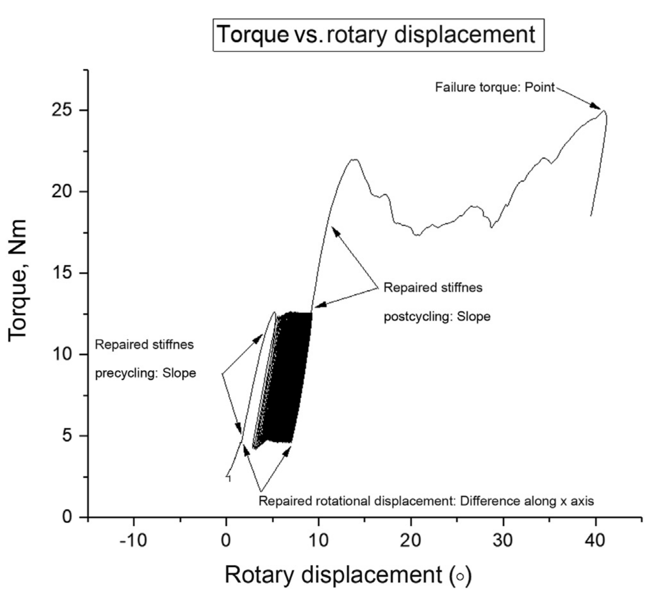

Figure 7 Load-displacement curve demonstrating where and how outcome measures were determined.

matched-pair specimens allocated to with or without internal brace augmentation groups for either treatment category ($P > .22$).

For primary repair (Fig. 8), augmentation with internal brace was associated with significantly higher torque LTF than repair alone ($P = .008$). Displacement after repair was not significantly different with augmentation; however, internal brace augmentation maintained rotational stiffness through testing significantly better than primary repair alone ($P = .01$). Mode of failure for primary repair alone was predominantly suture pulling through repaired ligament with 2 specimen failures before completion of 500 cycles. Internal brace–augmented repairs failed by anchor pullout at the anchor-bone interface (Fig. 9) or suture tape slippage through the anchor, except for 1 specimen that had an olecranon process fracture. All of these specimens completed cyclic testing.

For tendon graft reconstruction (Fig. 10), internal brace augmentation was again associated with significantly higher torque LTF than nonaugmented reconstruction ($P = .047$). Displacement after reconstruction was significantly less with internal brace augmentation ($P = .048$), and although internal brace augmentation maintained rotational stiffness through testing better than nonaugmented reconstruction, the differences were not statistically significant ($P = .057$). Modes of failure for both reconstruction groups were similar. The group undergoing reconstruction without augmentation primarily failed with the graft slipping or tearing at the humeral anchor, with 1 specimen failing by anchor pull out. Four of these specimens failed before completion of 500 cycles. The group undergoing reconstruction with internal brace augmentation failed by graft tearing and suture tape slipping in 4 specimens or pullout of the humeral anchor in 2 specimens. Two of these specimens failed before completion of 500 cycles.

Discussion

The results of this study allow us to accept the hypothesis that augmentation of LUCL primary repair or tendon graft reconstruction using a suture tape internal brace was associated with significantly greater torque load to failure for both repair and reconstruction and significantly less rotational displacement for reconstruction, while not compromising native elbow stiffness.

Sutures tearing through the ligament was the most common mode of failure in the repair-alone group. However, when repair was augmented with internal brace, the mode of failure shifted toward anchor pullout. According to this finding, it appears that the internal brace has a protective effect on the underlying repaired ligament. Posterolateral rotatory instability is a rare pattern of instability in the elbow. The use of the internal brace with nonabsorbable suture tape is becoming more common with a wide variety of ligamentous repairs.[5,8,25,29,32]

As mentioned previously, Greiner et al[17] published their results of 17 patients who underwent acute LUCL repair augmented with internal brace for treatment of PLRI following elbow dislocation. In this series, all patients were without recurrent instability at the time of final follow-up despite the presence and repair of concomitant injury to the same elbow. The authors also showed that their postoperative time to full mobilization was significantly less than that of other LUCL studies (3 days vs. 2 weeks and up to 6 months),[17] which is important given that persistent instability historically has been problematic following LUCL repair.[8,17,29] We believe our data confirm the biomechanics behind these clinical results by Greiner et al and that augmentation of a repair results in a greater construct stiffness that holds up better after cycling of the elbow. Taking our biomechanical results along with recent clinical data, we surmise that internal brace can be used to augment LUCL procedures in the following situations:

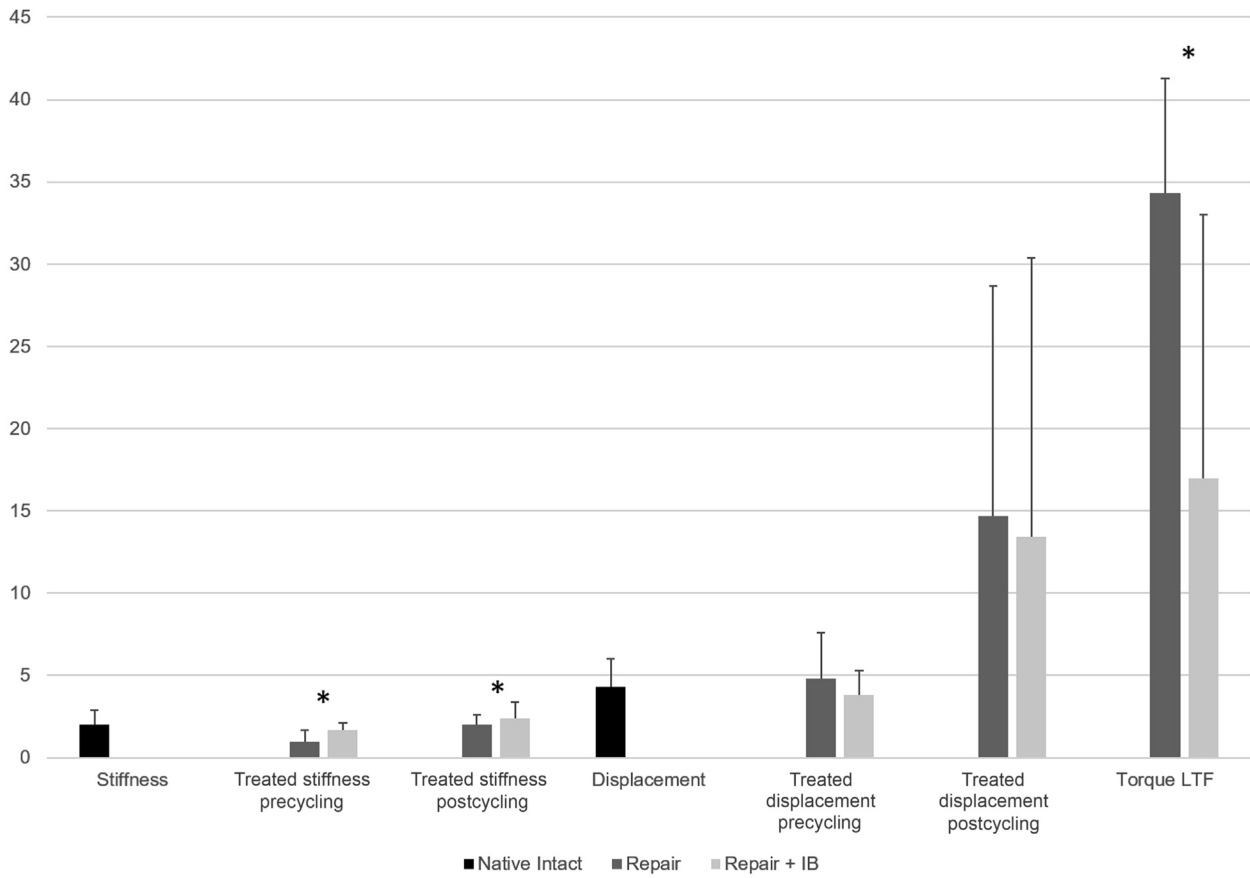

Figure 8 Biomechanical analysis of repair alone vs. repair with internal brace groups (stiffness measured in newton-meters/degree, displacement measured in degrees, and torque measured in newton-meters). *LTF*, load to failure; *IB*, internal brace. *Indicates statistically significant.

- poor local tissue quality
- when there is concern about the integrity of the available graft
- when complete protection of the elbow is not possible
- when the patient would benefit or requests an accelerated rehabilitation course

Of course, further studies are needed to validate these hypothetical indications.

Limitations of the current study include the use of a surgically induced injury model in cadaveric elbows and the applicability of the experimental testing. The surgical transection model allows for valid biomechanical testing of LUCL deficiency, but does not result in damage to the LUCL or surrounding tissues as would occur clinically such that only the biomechanical, and not the biological, aspects of treatment can be investigated. This may explain differences between primary repairs and allograft reconstructions in completing cyclic testing noted in the present study. Further, cyclic loading and load to failure testing in a single elbow position and single degree of freedom in cadaveric elbows does not fully recapitulate the clinical scenario. However, it was not feasible to test all possible scenarios in this first study, so the hypothesis-driven experimental design was focused on the most common position for postoperative splinting (90^o of flexion and neutral rotation) to examine repetitive motion and catastrophic material properties and potential mechanisms of failure. As such, the significant differences demonstrated in this head-to-head comparison study have valid application for these scenarios. In addition, these data do not account for the additional stability afforded by repair of capsular and muscular tissues or for effects of increased stability and stiffness on elbow function and range of motion. The effects of these factors on tissue healing and function after a period of immobilization in the patient should be considered. Further clinical studies are required to investigate these in vitro findings and translation of these data into clinical application.

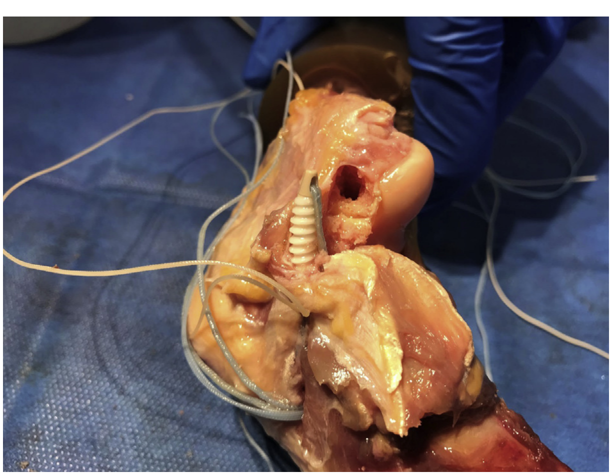

Figure 9 Primary repair with internal brace augmentation specimen failure.

Conclusion

With these limitations in mind, the results of the biomechanical testing study suggest that augmentation of LUCL primary repair or

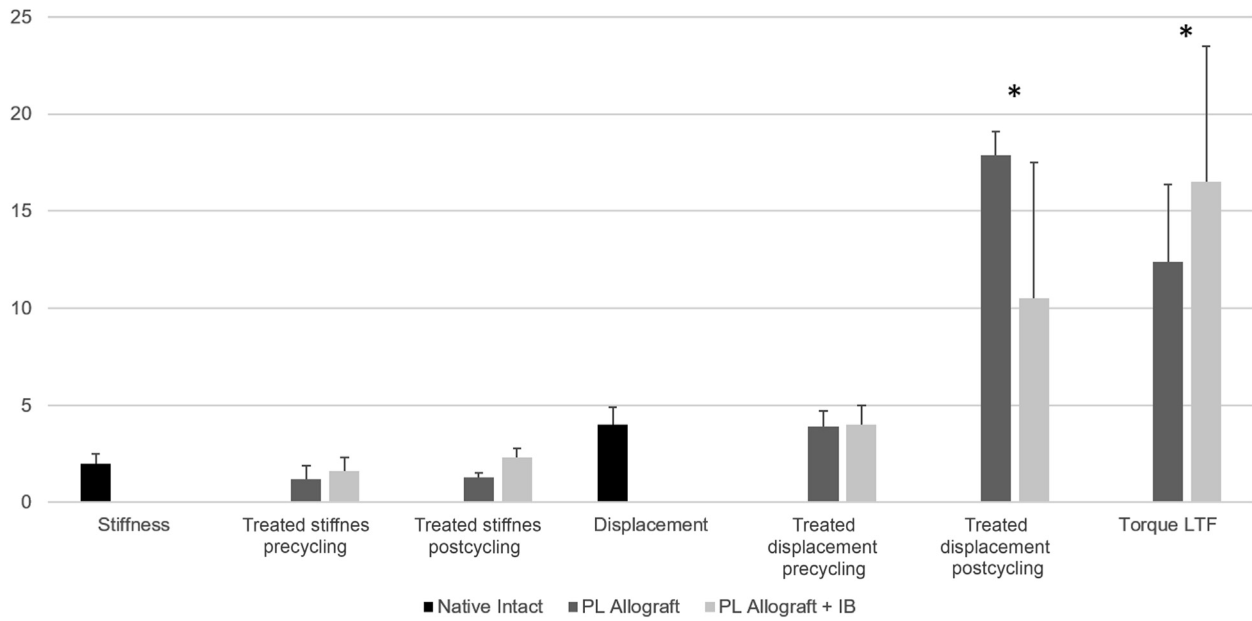

Figure 10 Biomechanical analysis of reconstruction alone vs. reconstruction with internal brace groups (stiffness measured in newton-meters/degree, displacement measured in degrees, and torque measured in newton-meters). *LTF*, load to failure; *PL*, palmaris longus; *IB*, internal brace. *Indicates statistically significant.

allograft tendon reconstruction using a suture tape internal brace is associated with better resistance to rotational loads compared to repair or reconstruction without internal bracing, while also maintaining rotational stiffness closer to native levels when the elbow is positioned in neutral forearm rotation and 90^{o} of flexion to simulate postoperative conditions. As such, this study provides clinically relevant biomechanical evidence for internal brace augmentation of LUCL repairs or reconstructions providing improved rotational stability and strength compared to non-augmented repairs or reconstructions. As such, internal brace augmentation may allow for more consistent restoration of functional elbow stability with less immobilization time and earlier return to function after surgical treatment of LUCL injuries.

Disclaimer

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