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Biomechanical comparison of docking ulnar collateral ligament reconstruction with and without an internal brace

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Background: Current ulnar collateral ligament (UCL) reconstruction techniques are substantially less stiff and demonstrate lower load to failure compared with the native UCL. UCL repair with the addition of an internal brace has demonstrated superior biomechanical performance compared with docking UCL reconstruction, but internal bracing has not yet been used in UCL reconstruction.
Hypothesis/Purpose: To evaluate the time-zero biomechanical performance of a UCL docking technique reconstruction with and without an internal brace compared with native UCL properties.
Methods: Twelve matched pairs of cadaveric elbows were dissected and fixed at 90° for biomechanical testing. A cyclic valgus torque protocol was used to test the anterior band of the UCL in native specimens. After native specimens were failed, palmaris grafts were used for a docking reconstruction with or without internal brace and were subjected to the same valgus torque test protocol. Torsional stiffness, ultimate failure torque, and ulnohumeral gapping were determined.
Results: Stiffness in UCL reconstructions using a standard docking technique (3.0 ± 0.4 N m/deg) were significantly less stiff ($P < .001$) than native UCL (4.0 ± 0.8 N m/deg), whereas reconstructions using an internal brace (3.6 ± 0.6 N m/deg) were not different ($P = .120$) compared with native. Ultimate failure torque for standard docking (18.3 ± 4.1 N m) was significantly lower ($P < .001$) than native UCL (36.9 ± 10.1 N m), whereas the internal brace samples (35.3 ± 9.8 N m) were not different ($P = .772$) than native.
Conclusion: UCL reconstruction with an internal brace augmentation provides superior stiffness and time-zero failure strength when compared with the standard docking technique.
Level of evidence: Basic Science Study; Biomechanics

Keywords: Elbow; UCL reconstruction; internal brace

Institutional Review Board approval was not required for this basic science study.

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The last 2 decades have seen a drastic rise in the number of ulnar collateral ligament (UCL) reconstructions amongst baseball players in the United States.[2,11] According to one large questionnaire study, which included 2706 active major and minor league pitchers, the prevalence of UCL reconstruction in professional pitchers was 16%, with the prevalence rising to 25% in Major League pitchers.[3] Pitching places a valgus force across the elbow that is near the ultimate tensile strength of the UCL.[8] This results in microtrauma and subsequent chronic, attritional tearing of the ligament over time. In this setting, primary surgical repair is often not possible and would result in poor outcomes,[4] leading athletes who are limited by a UCL tear to undergo UCL reconstruction, a procedure introduced by Jobe over 30 years ago.[12]

A variety of different techniques for UCL reconstruction have been described, including the modified Jobe technique, the docking technique, the DANE technique, and the suture anchor/hybrid technique.[13] The docking technique has been shown to have a higher load to failure than the modified Jobe technique,[16] in addition to showing better clinical outcomes.[13,22] Regardless of the technique used, the outcomes of UCL reconstruction are generally favorable with 83% of athletes able to return to their sport at, or above, the preinjury level.[13,22] However, surgery requires a lengthy recovery and rehabilitation period with average time until return amongst major league pitchers reported from 15 to 18.5 months.[6,9,15] Furthermore, on return, pitchers have shown decreased performance metrics, although not statistically significant compared with age-matched peers who did not undergo surgery.[15]

Internal bracing describes a concept in which implant material, typically a collagen-coated suture tape, is fixed in the orientation of a ligament to serve as a checkrein, providing stability by reducing the stress applied to a repaired or reconstructed ligament once a certain threshold of strain is reached. Internal bracing has been applied to the repair or reconstruction of various ligaments within the body and has been shown to provide enhanced time-zero biomechanical stability.[10,19-21,24] Recently, Dugas et al[5] introduced a technique for UCL repair with internal bracing, which showed equivalent load to failure and greater resistance to gapping after cycling compared with UCL reconstruction. In a case series of 22 patients with internal brace and UCL repair, 96% of participants were able to return to play with a mean time of 5 months, drastically shorter than the average time to return after UCL reconstruction;[23] although another prior study of UCL repair without internal brace showed good to excellent outcomes in 93% of patients with 56 of 60 patients able to return to pitching by 6 months.[18] However, UCL repair is best suited for younger patients with acute or subacute injuries rather than a chronic attritional UCL tear. There have been no reported techniques for UCL reconstruction using internal brace augmentation.

The goal of this study was to compare the time-zero performance of a standard docking UCL reconstruction with an internal brace augmentation to that of a docking UCL reconstruction without internal bracing and to the native UCL. We hypothesized that the UCL reconstruction with internal bracing would demonstrate improved biomechanical performance that is closer to native ligament than reconstruction without brace, including greater stiffness, less joint gapping, and a greater maximal torque to failure.

Methods

To determine the number of specimens to include in our study, a power analysis was performed based on the primary outcome variable of ultimate failure torque. The effect size for our power analysis based on the difference in load to failure between native and UCL reconstructed elbows in the study by Paletta et al,[16] a beta of 0.2 and an alpha of 0.05. The power analysis indicated that 12 specimens per group were needed.

Twenty-four fresh-frozen unpreserved cadaveric upper extremities were obtained for this study (12 matched pairs; 12 male, 0 female; average age 52.4 ± 14.0 years [range, 28-66 years]). Elbows were randomized into the control or experimental group with an even distribution of laterality in each group, and each specimen was in the opposite group of its paired specimen. Specimens were amputated at the mid-humerus and stored at −20°C. After thawing overnight at room temperature, the palmaris longus tendon was harvested and kept moist in saline for later use in reconstruction. When the palmaris tendon was not present, a fresh frozen palmaris allograft was used. Specimens were then dissected down to the joint capsule and excess soft tissues including the posterior band of the UCL removed in order to isolate the anterior band of the UCL. The humerus, ulna, and radius were transected 15 cm away from the ulnohumeral joint line in 90° of flexion, and each side was embedded in fiberglass resin.

Biomechanical testing was performed on a materials testing system (Instron E10000 Electromechanical Dynamic Testing System; Instron, Canton, MA, USA) using a 10-kN/100-N m load/torque cell. Each specimen was secured to the tension-torsion testing frame using a custom fixture (Fig. 1). Specimens were fixed at 90° of flexion with the humerus positioned vertically and its long axis in line with the load cell. This joint position was chosen based on biomechanical research performed by Fleisig et al,[8] which showed that the elbow undergoes the highest valgus loads during pitching when the elbow is flexed to approximately 90°.

All specimens were preconditioned with 10 cycles of valgus torque between 2 and 5 N m at a cycling frequency of 0.5 Hz, then 1 cycle between 2 and 7.5 N m, followed by a 5-second hold at 7.5 N m to assess angular displacement and ulnohumeral gapping compared with the original reference position. Images acquired at 0 and 7.5 N m were used to measure joint gapping by measuring centroid distances between equally sized circles fit to the distal humerus and trochlear notch of the ulna. For load to failure, a valgus rotation was applied at a rate of 5°/s until the anterior band of the UCL failed or fracture occurred. Stiffness was calculated from the linear elastic portion of the torque-rotational displacement curve during the ramp-to-failure.

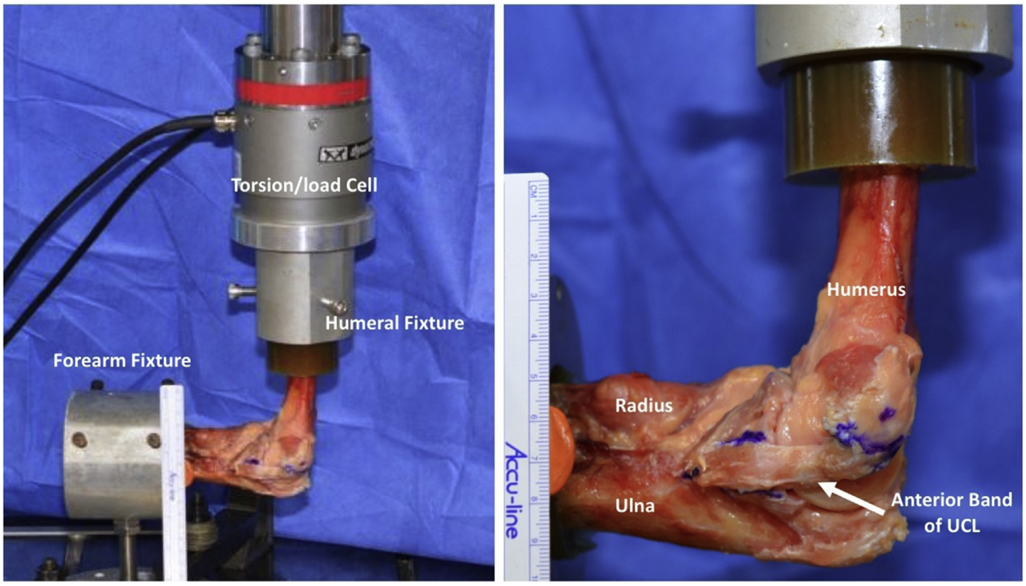

Figure 1 (*Left*) Biomechanical test setup for dynamic torsion and load to failure; (*right*) zoomed view showing anatomical features of tested samples. UCL, ulnar collateral ligament.

After the native specimens were failed, palmaris grafts were used for a docking UCL reconstruction with or without an internal brace. The docking reconstruction was performed using standard techniques previously described in the literature.[17] The internal brace reconstruction used the same bone tunnels as the docking technique but with a suture tape (FiberTape, Naples, FL, USA) also passed through the tunnels along the same course as the palmaris graft (Fig. 2). A 3.5-mm ulnar tunnel and 4.5-mm humeral socket were used for both techniques.

For the internal brace reconstructions, the palmaris graft was first tensioned in 30° of flexion with all slack removed from the tendon graft. Next, a 2-mm-thick shim was placed between the suture tape and the graft adjacent to the ulnar tunnels at the midpoint between the tunnels. The suture tape was tensioned over the shim and tied down over the humeral bone bridge at 30° of elbow flexion using a single surgeon and the same shim to standardize tensioning. The shim was used to provide some laxity in the internal brace to reduce stress shielding of the reconstructed ligament yet provide a checkrein to avoid excessive ulnohumeral gapping that might approach clinical failure. A 2-mm shim was selected as this represents the highest amount of laxity that should be allowed in the ligament to remain below the clinical failure threshold; thus, this tension provided the highest level of protection against stress shielding while still offloading the ligament. All reconstructed specimens were then subjected to the same valgus torque protocol as used for the intact native UCL.

Normal distribution of data was verified using Shapiro-Wilk testing. To check for statistical differences between biomechanical parameters among the 3 groups, analysis of variance was performed. When analysis of variance testing demonstrated statistical differences, the Student-Newman-Keuls method for multiple comparisons was used to detect significant differences amongst all pairwise combinations. Statistically significant differences were defined as $P < .05$.

Figure 2 Specimen with tensioned ulnar collateral ligament reconstruction with internal bracing.

Results

The mean stiffness of the standard docking reconstruction (3.0 ± 0.4 N m/deg) was significantly lower ($P < .001$) than native UCL (4.0 ± 0.8 N m/deg) (Fig. 3). There was no statistical difference ($P = .12$) between the stiffness of native UCL compared with reconstructions with the internal brace (3.6 ± 0.6 N m/deg). There was a statistical difference between stiffness of standard docking compared with internal brace ($P = .044$).

The mean ultimate failure torque for UCL reconstruction using the standard docking reconstruction (18.3 ± 4.1 N m) was significantly lower ($P < .001$) than the native UCL group (36.9 ± 10.1 N m) (Fig. 3). The mean ultimate failure torque for the internal brace reconstructions (35.3 ± 9.8 N m) was not different compared with native ($P = .77$).

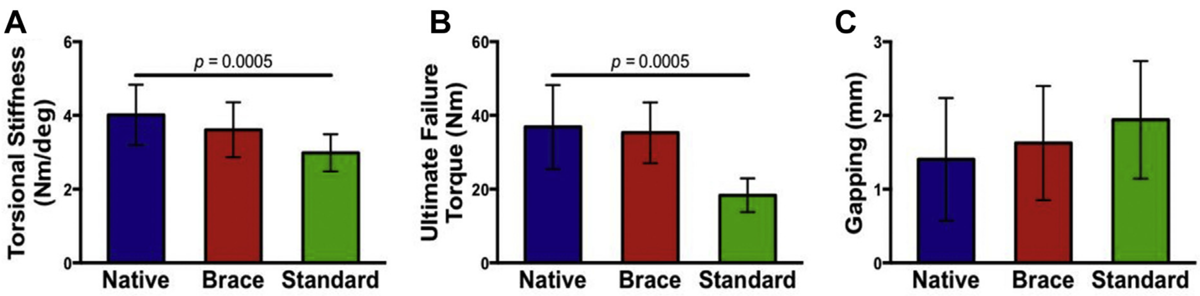

Figure 3 (**A**) Compared with native, torsional stiffness was significantly larger for standard docking, while the internal brace construct was not different. (**B**) Compared with native, ultimate failure torque was significantly larger for standard docking but not different for internal brace. (**C**) For gap formation, there were no significant differences compared with native for either standard docking or internal brace reconstructions. (Plots show mean ± standard deviation.)

Mean ulnohumeral gapping for the standard docking reconstruction (1.9 ± 0.8 mm) was not different (P=.12) compared with the native UCL (1.4 ± 0.8 mm) (Fig. 3). Gapping was also not different (P = .18) between the UCL reconstruction with the internal brace (1.6 ± 0.8 mm) compared with native UCL.

The mode of failure in UCL reconstructions with internal brace was ulnar tunnel fracture in 7 (58.3%) and failure of graft in 5 (41.7%), whereas for standard docking reconstruction, failure of graft occurred in 9 (75%), failure of knot occurred in 2 (16.7%), and ulnar tunnel fracture occurred in 1 (8.3%). Fisher's exact test did show significant differences in the occurrence of graft failure and tunnel fracture as mode of failure between reconstruction techniques.

Discussion

Our study demonstrates that UCL reconstruction with internal brace improved time-zero stiffness and maximal torque to failure compared with standard docking reconstruction. More importantly, the internal brace UCL reconstruction showed similar biomechanical performance to that of the native UCL even with 2 mm of laxity placed in the internal brace. Armstrong et al[1] evaluated the time-zero performance of different UCL reconstruction techniques; however, none of the techniques were able to restore native stiffness and gap formation. In fact, the time-zero ulnohumeral gapping of current reconstruction techniques was all greater than 2 mm, the threshold used by many to denote failure of the UCL.[1] The present study demonstrates that the addition of an internal brace to a docking technique helps restore mechanical properties closer to the native UCL and provides better time-zero stiffness and ultimate failure torque compared with the docking reconstruction technique.

Within the internal brace group there were only about half as many graft failures compared with the standard docking group (41.7% compared with 75%), suggesting that the internal brace is effectively offloading the ligament. From a clinical perspective, there is obvious concern about stress shielding with an internal brace that off-loads the ligament. In order to limit this response, we induced 2 mm of slack in the internal brace to allow the ligament to experience strain initially but then load share beyond what could be considered clinical failure, 2 mm of ulnohumeral gapping.[7] It is important to note that there were still graft failures within the internal brace group of samples, suggesting that the graft still experiences load with 2-mm slack within the internal brace. With improved biomechanical performance and graft protection of an internal brace with a docking UCL reconstruction at time zero, it may be appropriate to allow more aggressive rehabilitation and earlier return to athletic activities similar to what Walters et al[23] have supported for a UCL repair with internal brace.

This study is not without limitations. First, this is a time-zero biomechanical study to evaluate the performance of the internal brace with a docking UCL reconstruction. We are unable to provide any clinical outcomes data of UCL reconstruction with internal brace. Because this is a time-zero study, the osseous integration and healing process expected to occur with the ligament graft has not occurred, so measured biomechanical properties are likely different than those of a healed reconstruction in vivo. Also, as is often the case with biomechanical testing in cadavers, the specimens used in this study were older than the typical patient for which a UCL reconstruction is performed. Older age of cadaveric specimens may have resulted in an increased frequency of failure through graft tunnel fracture, which is an uncommon mode of failure in actual UCL reconstruction patients but common in cadaveric biomechanical testing.[2,14,16] We did observe more failures at the ulnar tunnel in the internal brace group, but it remains to be seen whether this same failure would occur in clinical application with younger, healthy bone. When transitioning this UCL reconstruction technique to clinical use, the potential for ulnar tunnel fracture should be considered because it would limit revision reconstruction options, with ulnar cortical button fixation potentially being the only revision option.

Although the absolute values for torsional stiffness and ultimate failure torque also may be affected by cadaver age, our torque and stiffness values for the standard docking technique and the native ligament agree with values that have been reported in other biomechanical studies.[1,5,16] In addition, this study was performed using matched pairs of cadaver elbows to minimize a biased comparison between study groups. Similar to other recent biomechanical evaluations of UCL reconstruction techniques,[1,5] we tested our specimen fixed in 90° of flexion to best simulate the late cocking/early acceleration phase of the throwing motion where the elbow is subject to the highest valgus torque during the throwing motion. As a result, we cannot comment on how internal brace UCL reconstruction performs at other degrees of flexion.

Another limitation is that power calculation for this study was performed based on ultimate failure torque, so it is possible that the study is underpowered to detect a difference in stiffness or ulnohumeral joint gapping between groups, although post hoc power analysis showed adequate power to assess stiffness. Finally, our testing setup did not have 3D motion capture capabilities and were unable to gather data necessary (eg, ligament cross-sectional area) to determine the stress-strain curves for our tested specimens. Further studies to examine the effect of internal bracing on the stress-strain curve of a reconstructed ligament would be helpful in order to ensure that the internal brace is effectively offloading the ligament while still allowing enough load transfer to the UCL to minimize stress shielding. As such, the optimum amount of slack in the internal brace has yet to be determined and is outside the scope of the current study.

Conclusion

UCL reconstruction with internal brace augmentation provided increased time-zero stiffness and failure torques when compared with the standard docking technique. However, there was no difference in ulnohumeral gapping. UCL reconstruction with internal brace augmentation more closely restored the biomechanical properties of the native UCL with the elbow at 90° of flexion.

Disclaimer

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