Biomechanical Comparison of UCL Repair Using Suspensory Fixation Versus UCL Reconstruction

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Background: Medial ulnar collateral ligament (mUCL) repair is growing in popularity as a treatment for younger athletes with mUCL tears. One of the most recent techniques utilizes a collagen-coated suture tape to augment the repair. The most popular repair technique uses a screw for proximal fixation in the humerus. We present an alternative technique that uses suspensory fixation in the proximal humerus.

Purpose: To biomechanically compare elbow valgus stability and load to failure of a novel alternative repair technique with suspensory fixation to an mUCL reconstruction.

Study Design: Controlled laboratory study.

Methods: Eighteen fresh-frozen cadaveric elbows were dissected to expose the mUCL. Medial elbow stability was tested with the mUCL in an intact, deficient—either repaired or reconstructed—state. The repair technique used a suspensory fixation with suture augmentation, and the docking technique was used on all reconstructions. A 3-N·m valgus torque was applied to the elbow, and valgus rotation of the ulna was recorded via motion tracking cameras as the elbow was cycled through a full range of motion. After kinematic testing, specimens were loaded to failure at 70° of elbow flexion.

Results: Both ulnar collateral ligament reconstruction and repair restored valgus stability to levels that were not statistically different from intact at all angles of flexion. There was no significant difference in the ultimate torque to failure between repaired and reconstructed mUCLs.

Conclusion: There was no significant difference in the valgus strength between the mUCL repair with suspensory fixation and the mUCL reconstruction.

Clinical Relevance: Suspensory fixation is an alternative method for proximal fixation in the mUCL without compromising the strength of the construct.

Keywords: medial ulnar collateral ligament; elbow; biomechanics; UCL reconstruction; UCL repair; suture augmentation

When Dr Frank Jobe developed the medial ulnar collateral ligament (mUCL) reconstruction, he discovered a solution to a seemingly insurmountable problem.[7] Before Dr Jobe's work, an mUCL tear was a career-ending injury for professional baseball pitchers. In his original 1986 publication, Dr Jobe reported returning 10 of 16 professional pitchers to their previous levels of play or better.[4,7] Over the years, the technique has undergone multiple iterations to meet various challenges, including fixation methods, approaches, postoperative ulnar nerve deficit, and revision of failed reconstructions.[1,14-16] These iterations have improved ulnar collateral ligament (UCL) reconstruction outcomes, evident by the current rate of return to previous level of play of 82%.[11]

The number of symptomatic mUCL injuries has dramatically increased among adolescent athletes.[9,17] Petty et al[13] observed a 50% increase in the number of mUCL surgeries performed by their group on high school baseball players from 1995 to 2005. Similarly, a retrospective review of mUCL surgeries in the state of New York reported 56% of all mUCL surgeries were performed on adolescents.[9] These trends have renewed interest in mUCL repair with the belief that adolescent mUCL tears typically occur in 1 location, leaving the remaining ligament healthy and capable of repair.[2,5]

Similar to UCL reconstruction, repair techniques will likely undergo multiple iterations to improve outcomes and meet new challenges. The most common repair technique

The Orthopaedic Journal of Sports Medicine, 9(9), 23259671211038992
DOI: 10.1177/23259671211038992

involves augmenting the repair with collagen-coated suture tape.[5,12] Dugas et al[5] described securing the proximal mUCL repair and the suture tape with a 3.5-mm screw in the original footprint at the medial epicondyle.

One of the senior authors (O.L.) began using suspensory fixation after observing variations in medial epicondylar size among patients. Differences in medial epicondylar morphology and size have previously been shown to depend on the type of sport played.[3,10] Makhni et al[10] measured the height, width, and thickness of medial epicondyles in baseball players compared with nonathletic controls and demonstrated that baseball players have significantly greater anterior-posterior thickness and superior-inferior height compared with controls. Likewise, Bamaç et al[3] observed that the volume of the medial epicondyle in volleyball players was significantly greater than age- and sex-matched controls who did not play volleyball. Since symptomatic mUCL injuries occur in adolescents who participate in a variety of sports (not just overhead throwing athletes), it is important to develop UCL repair techniques that can accommodate epicondyles of all shapes and sizes.[17]

We have recently developed a novel mUCL repair technique that utilizes suspensory fixation. The purpose of this biomechanical study was to compare elbow valgus stability and load to failure of this novel repair technique with suspensory fixation with that of the gold standard mUCL reconstruction, hypothesizing that both techniques would provide similar mechanical strength and stability.

METHODS

Specimen Preparation

Institutional review board approval was not required for this laboratory investigation, as it utilized deidentified cadaveric specimens. Nine matched pairs of fresh-frozen cadaveric upper extremities (from 5 male donors and 4 female donors), with a mean age of 51.4 years (± 10.5; range, 29-61 years), were procured from an institute-approved tissue bank and stored at -20°C. Left and right pairs were divided into 2 groups, (1) repair and (2) reconstruction, taking care to ensure laterality was equally divided between groups.

Specimens were thawed overnight at room temperature. The skin and subcutaneous tissue were dissected from the medial aspect of the elbow, and the distal and proximal extent of the mUCL was exposed with a flexor carpi ulnaris muscle-splitting approach. The flexor pronator origin and capsular tissue were preserved. The forearm was fixed in neutral rotation with a K-wire across the radius and the ulna perpendicular to their long axis. The skin and soft tissue were removed from the distal forearm to facilitate rigid fixation in a metal pot with a 2-part epoxy resin (Smooth-Cast 300; Smooth-On). Motion tracking diode sensors were then fixed to the humerus and ulna in line with the long axis of the bone per manufacturer's specifications (0.1 mm accuracy and 0.01 mm resolution; Optotrak Certus; Northern Digital).

Surgical Technique

A simulated UCL tear was created by splitting the proximal mUCL in line with its fibers to the level of the ulnohumeral joint. The insertion of the mUCL at the medial epicondyle was also elevated. Sufficient injury was confirmed as an increase in valgus rotation throughout flexion compared with the intact state that was recorded and displayed in real time using the motion-tracking cameras. Afterward, specimens were either repaired or reconstructed per the techniques described below.

mUCL Repair. A 2.4-mm guide pin was drilled through the medial epicondyle in line with the medial column from distal to proximal at the site of the mUCL footprint on the humerus (Figure 1A), and the pin was removed. A straight suture lasso was then passed through the hole on the medial epicondyle from proximal to distal. The straight suture passer was then loaded with 2 size zero looped sutures. One limb of each was then passed back through the hole in the medial epicondyle in a retrograde fashion.

Two simple interrupted size zero ultra—high molecular weight polyethylene (UHMWPE) sutures repaired the distal split in the ligament. The proximal portion of the ligament that had been detached in a T-shape fashion was repaired with the same size zero UHMWPE suture with the 2 limbs of the repair suture exiting from the proximal portion of the ligament. The limbs of the repair suture were then passed in a retrograde fashion via one of the looped passing sutures (Figure 1B).

A 1.5-mm tape containing a polyethylene core was then loaded onto a 2.6-mm button. Each limb of the repair suture was passed through an eyelet on the Endobutton (Arthrex) in the opposite direction of the limbs of the tape. The limbs of the tape were then passed through the medial epicondyle

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Final revision submitted April 8, 2021; accepted May 13, 2021.
One or more of the authors has declared the following potential conflict of interest or source of funding: A portion of this study was funded by a research grant from Arthrex. Arthrex also provided loaner sets for the medial ulnar collateral ligament reconstruction and repair. R.N.M. has received grant support from Arthrex and educational support from Arthrex and Smith & Nephew. O.L. has received educational support, consulting fees, and nonconsulting fees from Arthrex and consulting fees and royalties from Linvatec. N.S.E. has received nonconsulting fees and royalties from Arthrex. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.
Ethical approval was not sought for the present study.

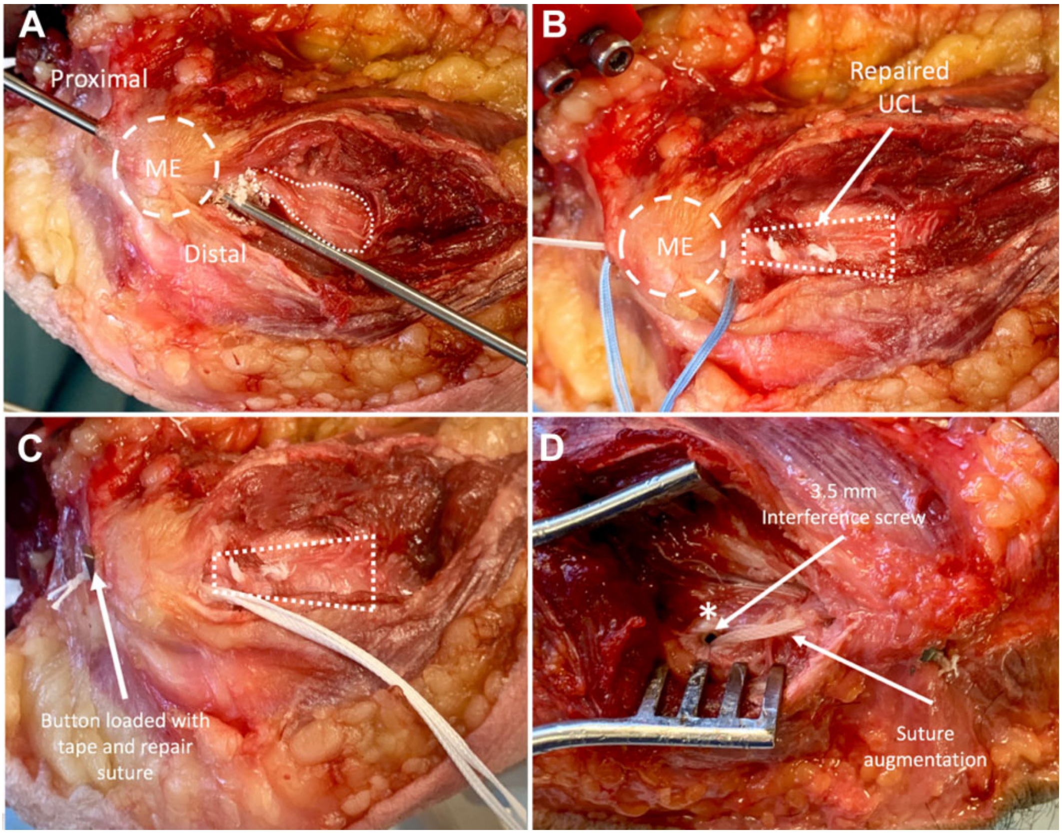

Figure1. The UCL repair technique. (A) The medial side of the elbow, with the torn mUCL outlined by the dotted line. The ME is outlined by the dashed circle. The pin is drilled from proximal to distal at the mUCL attachment site on the humerus. (B) The repaired mUCL (arrow) is outlined by the dotted line. The tails of the most proximal repair suture are seen after they have been brought through the ME from distal to proximal. (C) The repaired mUCL is outlined by the dotted line. The arrow is pointing to the repair suture tied over the 2.6-mm Endobutton. (D) The asterisk indicates the location of the sublime tubercle, and the 3.5-mm interference screw is just distal to this. The other arrow is pointing to the suture tape augmentation. ME, medial epicondyle; mUCL, medial ulnar collateral ligament; UCL, ulnar collateral ligament.

from proximal to distal via the remaining looped passing suture (Figure 1C).

A 2.7-mm hole was drilled just distal to the apex of the sublime tubercle on a 60° angle radial to a line drawn down the center of the ulnar shaft, and a 3.5-mm tap was used. The tape was then loaded onto a 3.5-mm bioabsorbable knotless anchor (SwiveLock; Arthrex) (Figure 1D). A freer elevator was placed between the tape and underlying ligament. The elbow was held in 20° of flexion, with a slight varus force applied while the anchor was advanced into the bone.

mUCL Reconstruction. Surgical reconstruction of the UCL was performed using an ipsilateral palmaris longus tendon graft and the standard docking technique. Grafts were sized to 3.5 mm, pretensioned to 20.34 N·m, and kept moist with saline-soaked gauze. The two 3.5-mm holes on the ulna were drilled at the sublime tubercle using a guide to ensure a sufficient bone bridge.

A 4.5-mm hole was drilled at the UCL origin on the humerus, aiming toward the intermuscular septum to a depth of 15 mm. An adjustable humeral guide was used to create two 2-mm additional humeral tunnels, so that the tunnels converged and had a 1-cm bone bridge.

The anterior limb of the graft was prepared with a No. 2 UHMWPE suture in a Krackow fashion. The graft was then passed through the ulnar tunnel from posterior to anterior. The anterior limb was docked into the humeral tunnel with the sutures exiting the posterior 2-mm tunnel. The elbow was ranged and held in 30° of flexion to determine how much of the posterior limb to remove, so that 1 cm would be docked into the humeral tunnel. A No. 2 UHMWPE suture (Arthrex) was then passed through the posterior limb in a Krackow fashion and passed through the remaining hole.

The sutures from the anterior and posterior limbs were then tied over the bone bridge while the elbow was held in 30° of flexion and a slight varus force was applied.

Kinematic Testing

Elbow kinematics were determined using a previously described method.[6] Briefly, the humerus was clamped parallel to the testing surface so that the weight of the potted forearm created a 3-N·m valgus torque on the elbow (Figure 2). The ulnar and humeral axes were defined by

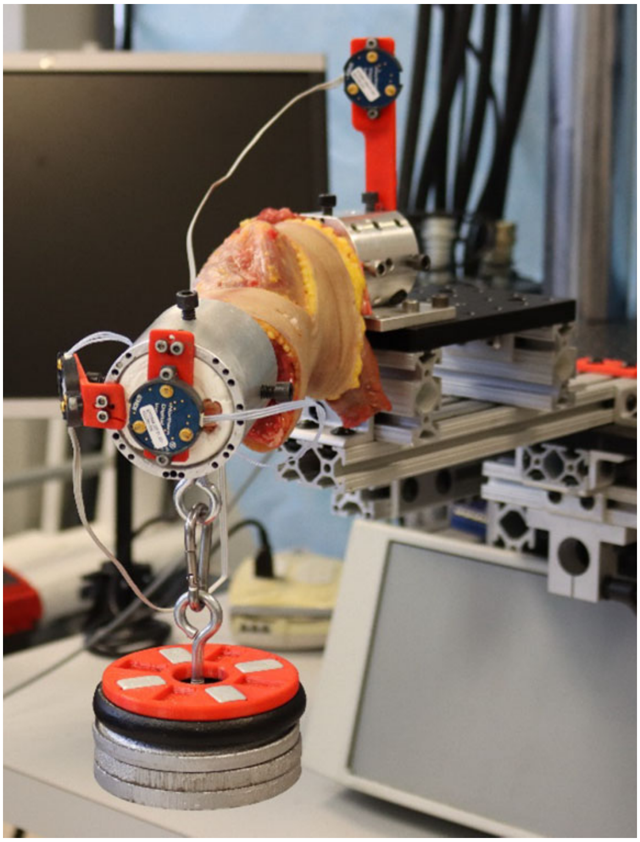

Figure 2. The humerus was secured with a clamp, and weights were applied to the distal forearm to generate a 3-N·m valgus load. The elbow was rotated from flexion to full extension while valgus rotation of the forearm relative to the fixed humerus was recorded using infrared diodes attached to the humerus and potted forearm.

digitizing 3 points in line with the long axis of each bone with a digitizing probe (Northern Digital Inc). Each specimen was cycled from 10° to 120° of flexion 5 times while the valgus rotation of the ulna relative to the humerus was recorded at a rate of 128 Hz via the motion-tracking cameras. Data were binned for each trial into flexion increments of 0.25° that were averaged across all 5 trials. The mean valgus values for 10° increments of elbow flexion were used in the statistical analysis.

Failure Testing

After kinematic testing, specimens were mounted onto the frame of a biaxial hydraulic testing machine (370.02 Bionix Testing System; MTS Systems) for failure analyses. The humerus was fixed to the MTS frame in 70° of elbow flexion, and the ulna was attached to the actuator of the testing machine, similar to previous studies.[6,8] After applying a 1-N·m preload, the ulna was loaded in the valgus at a rate of 0.5 mm/s, and the ultimate torque was determined, as previously described.[6] After failure, specimens were evaluated to determine the mechanism of failure.

Statistical Analysis

All data are presented as mean ± SD, and differences are presented with 95% CIs. Continuous kinematic data were binned in 10-degree increments of elbow flexion using MATLAB software (Mathworks). A repeated-measures analysis of variance model clustered within specimen predicting valgus, while adjusting for other variables, was used to analyze the effect of sex, age, treatment (intact, reconstruction, repair), flexion angle, and the interaction of treatment and flexion angle. The Tukey-Kramer test was used to adjust for multiple comparisons. Differences in load to failure and stiffness between the 2 surgical methods (repair vs reconstruction) were evaluated using the Student t test.

A post hoc power analysis based on our load to failure data was performed, and it demonstrated an effect size of 0.55 and a resultant power (1-β error) of 72% (G*Power 3.0.10). Analyses were performed using SAS statistical software (Version 9.4; SAS Institute), with statistical significance set at $P < .05$.

RESULTS

No gross evidence of abnormality was observed in any of the specimens upon inspection of the medial distal humerus, proximal ulna, flexor pronator mass, native UCL, sublime tubercle, or capsule. The resultant data from all 18 elbows were included in the kinematic and failure analysis.

Kinematic Testing

Left elbows had significantly lower mean valgus rotation compared with right elbows, with a mean overall difference across all angles of flexion of 0.93° (95% CI, 0.5°-1.4°; $P < .001$). Elbows from male donors had less valgus rotation compared with those from female donors (mean difference, 4.8°; 95% CI, 1.8°-7.8°; $P = .002$), and there was a mean 0.22° (95% CI: 0.1°-0.4°) decrease in valgus rotation per 1-year increase in age ($P = .004$).

UCL-deficient elbows demonstrated greater valgus laxity compared with intact elbows at every angle of flexion tested, which was significant at 20° and 120° of flexion ($P < .01$) (Figure 3). The greatest mean difference in valgus rotation between the intact and deficient state was 6.64° (95% CI, 4.34°-8.95°), recorded at 80° of flexion ($P < .0001$). UCL reconstruction and repair restored valgus stability to levels that were not statistically different from intact at all angles of flexion. UCL-reconstructed elbows were significantly more stable than UCL-deficient elbows from 60° to 120° of flexion ($P < .05$). Likewise, UCL-repaired elbows were more stable than UCL-deficient elbows from 50° to 120° ($P < .05$).

Failure Testing

There was no significant difference in the ultimate torque to failure between repaired and reconstructed mUCLs. The overall failure torque for all 18 specimens was 21.5 ± 6.1 N·m. The mean failure torque for reconstructed

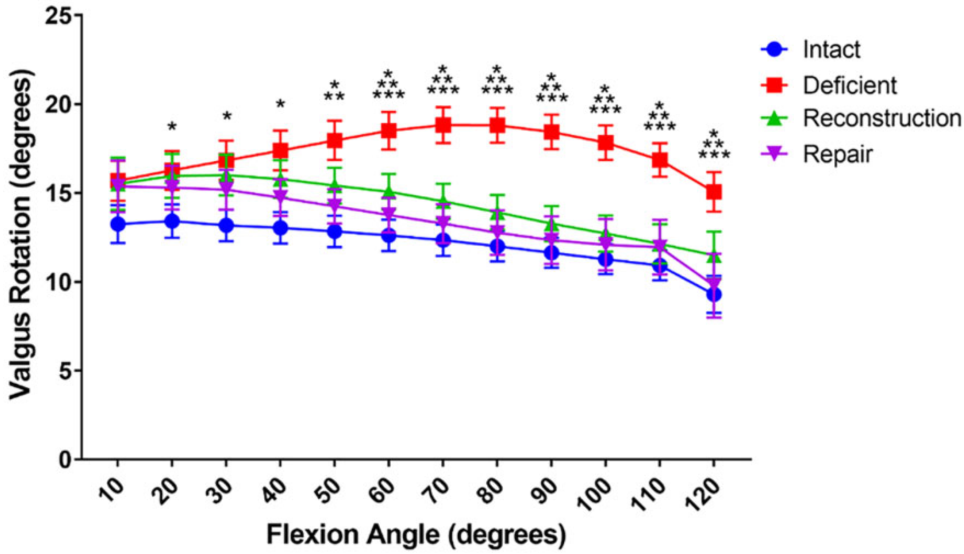

Figure 3. Mean valgus rotation as a function of elbow flexion angle for the intact, deficient, repaired, and reconstructed mUCL. Error bars represent the SEM. Valgus rotation in mUCL-deficient elbows was significantly higher than intact (20°-120°), repaired (50°-120°), and reconstructed (60°-120°) elbows ($P < .05$ for all). mUCL, medial ulnar collateral ligament. * indicates intact elbows; ** indicates repaired elbows; *** indicates reconstructed elbows.

TABLE 1
Modes of Failure for the Repaired and Reconstructed Specimens for Each Matched Pair[a]

Pair	Repair	Reconstruction
1	Anchor-suture interface	Graft/suture tore at humeral tunnel
2	Anchor-suture interface	Suture loosened
3	Anchor-suture interface	Graft slippage through humeral tunnel
4	Anchor-suture interface	Graft/suture tore at humeral tunnel exit
5	Anchor-suture interface	Graft tore in humeral tunnel
6	Anchor-suture interface	Graft tore in humeral tunnel
7	Anchor-suture interface	Graft tore in humeral tunnel
8	Anchor-suture interface	Suture tore at humeral tunnel
9	Anchor-suture interface	Graft pullout

[a]Anchor-suture interface indicates that the suture tape eventually pulled through the distal interlocking screw.

specimens was 23.3 ± 7.6 N·m compared with 19.7 ± 3.7 N·m for repaired specimens ($P = .30$). The mean stiffness of repaired elbows (3.4 ± 0.9 N·m/deg) was also not statistically different from reconstructed elbows (2.6 ± 0.8 N·m/deg) ($P = .12$). The repair consistently failed at the suture-interference screw interface by the suture's pulling through the eyelet of the interference screw (Table 1).

DISCUSSION

Faced with a growing number of young athletes presenting with UCL tears, we developed a novel mUCL repair that utilizes a suspensory fixation technique at the humerus. The biomechanical results of this study demonstrated that both this novel repair technique and the UCL reconstruction restored valgus stability toward that of the intact elbow. In addition, the torque at failure of the repaired specimens was not statistically different from specimens with a reconstructed UCL, and every repair construct tested failed at the anchor-tape interface in the ulna.

Dugas et al,[5] in their biomechanical analysis comparing a suture-augmented repair with the standard reconstruction, demonstrated that repaired specimens with repaired UCLs had comparable strength and less gap formation than those with reconstructed UCLs. [5,12] In the present study, we analyzed UCL repair with suspensory fixation that employed 1.5-mm tape instead of the collagen-coated internal brace used in the study of Dugas et al. This novel repair technique also restored valgus stability toward that of the intact state and was not statistically different from that of the reconstruction. Load to failure between the repair and reconstruction groups was not statistically different. However, the repair did have a lower mean failure torque, and because our data were powered to 72%, further clinical data are needed to verify that the repair is sufficiently strong in the immediate postoperative setting.

Proximal suspensory fixation is an attractive repair strategy because it can be performed on medial epicondyles of any size. The medial epicondyle does not have to have the volume to accommodate a 3.5-mm anchor when using suspensory fixation. A recent publication demonstrated the successful use of suspensory fixation proximally in revision mUCL reconstruction, where a lack of medial epicondylar volume is the issue.[8] Suspensory fixation requires less bone removal, which likely diminishes this risk by not compromising the structural integrity of the medial epicondyle. Suspensory fixation also does not require placement of the hardware within the medial epicondyle, thereby eliminating the presence of a stress riser. The counterargument to this is that suspensory fixation could actually create a larger stress riser because one has to violate both cortices. This debate requires further biomechanical investigation. An additional benefit of the lack of hardware is that it leaves more options if a reconstruction is required in the future. One theoretical concern is that the presence of the button could irritate the ulnar nerve. Anecdotally, the senior surgeon (O.L.) has not observed ulnar neuritis in the patients on which he has performed this technique. Furthermore, the proximity of the button to the ulnar nerve through full range of motion can be assessed during the surgery.

As with most cadaveric studies, there are several limitations that should be noted. First, the tissue quality of the cadaveric specimens used in this study does not accurately represent the tissue of a young athlete. The bone quality of the cadaveric specimens may also have caused the construct to fail at the anchor-tape interface, which may misrepresent the true weak point of the construct. The anchor may be failing because of the poor bone quality of the cadaveric specimens, which is not representative of the patients in whom this surgery will be performed. The data presented only reflect the immediate postoperative setting. As with any biomechanical cadaveric study, it is impossible to evaluate the strength of the construct after several years' worth of cyclical loading. The model also cannot account for progressive changes, such as tissue ingrowth into the tunnel that may positively or negatively affect the strength of the construct.

Our study evaluates an alternative method of mUCL repair. We compared our technique with that of an mUCL reconstruction and demonstrated that there was not a significance difference in the amount of valgus stability restored. However, a comparison between anchor fixation and suspensory fixation proximally needs to be further evaluated.

CONCLUSION

This time-zero biomechanical study provides initial evidence that an mUCL repair with a suspensory fixation and suture augmentation can effectively restore elbow valgus stability levels that are not statistically different from UCL reconstruction. This technique can be performed in all athletes, regardless of the medial epicondylar size. Further clinical studies that evaluate the construct overtime as the tissue begins to repair are needed to fully determine the long-term stability, advantages, and disadvantages of this novel technique. A study directly comparing proximal anchor fixation with suspensory fixation should also be pursued.

ACKNOWLEDGMENT

The authors thank Arthrex for its funding and in-kind donation of surgical supplies and Kevin Kennedy, MS, of Saint Luke's Hospital, Kansas City, Kansas, USA, for his effort and assistance with the statistical portion of the data analysis.

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