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Biomechanical Comparison of Ulnar Collateral Ligament Repair With Internal Bracing Versus Modified Jobe Reconstruction

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Investigation conducted at the American Sports Medicine Institute, Birmingham, Alabama, USA

Background: The number of throwing athletes with ulnar collateral ligament (UCL) injuries has increased recently, with a seemingly exponential increase of such injuries in adolescents. In cases of acute proximal or distal UCL insertion injuries or in partial-thickness injuries that do not respond to nonoperative management, UCL repair and augmentation rather than reconstruction may be a viable option.

Purpose/Hypothesis: The purpose of this study was to biomechanically compare a new technique of augmented UCL repair versus a typical modified Jobe UCL reconstruction technique. The hypotheses were that (1) the repaired specimens would have less gap formation and a higher maximal torque to failure compared with the reconstruction group, and (2) while both groups would show an increase in gap formation after the simulated tear, the repair group would return closer to the native values compared with the reconstruction group.

Study Design: Controlled laboratory study.

Methods: Nine matched pairs of cadaveric arms were dissected to expose the UCL. Each elbow was mounted on a test frame at 90° of flexion. A cyclic valgus rotational torque was applied to the humerus with the UCL in its intact state and repeated in its surgically torn state. Finally, each specimen received either an augmented repair or reconstruction and was again put through the cyclic protocol, followed by a torque to failure.

Results: Gap formation (0.51 ± 0.22 mm) in the torn state for the repair group was significantly higher (P = .04) than in the intact state (0.33 ± 0.12 mm). After the procedures, the repair group (0.35 ± 0.16 mm) showed greater resistance to gapping (P = .03) compared with the reconstruction group (0.53 ± 0.23 mm). No statistical differences were found for the maximum torque at failure, torsional stiffness, or gap formation during the failure test.

Conclusion: The current study shows that this novel technique of augmented UCL repair replicates the time-zero failure strength of traditional graft reconstruction and appears to be more resistant to gapping at low cyclic loads.

Clinical Relevance: This study demonstrates that this novel technique has important biomechanical properties, including time-zero strength and ultimate failure load, compared with the gold standard of UCL reconstruction. In some throwing athletes, this technique may supplant standard UCL reconstruction as the procedure of choice.

Keywords: ulnar collateral ligament; repair; reconstruction; augmentation; internal brace; biomechanical

The anterior bundle of the ulnar collateral ligament (UCL) is the primary restraint to valgus stress at the elbow during an overhead throwing motion.[22,27] Valgus loads produced during this motion have been estimated to approach the ultimate tensile strength of the UCL.[15,16] Hence, injury to the UCL most commonly occurs in overhead throwing athletes.[5,9,19,23,31,36] This injury can be treated nonoperatively initially, but it often leads to symptomatic valgus instability requiring surgical treatment for return to overhead sports. Initial reports focusing on direct ligament repair in male professional baseball players showed that results generally were not optimal, with an overall 0% to 63% return to previous or higher level of competition.[2,5,9,19,23] Dr Frank Jobe then pioneered the surgical technique of UCL reconstruction and reported his

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results in 1986.[19] Since that time, multiple modifications of this technique have been reported, with improved results (68%-95% return to play).[5,6,9-11,19,34] Early on, this procedure was limited to professional baseball players with chronic microtrauma and ligament attenuation, necessitating a graft-type reconstruction[9,19]; however, recently an increasing number of athletes have experienced UCL injuries, with a seemingly exponential increase of such injuries in adolescents.[6,24,26] Due to the success of UCL reconstruction relative to UCL repair in earlier studies, UCL repair has been largely abandoned.[5,6,9] In younger athletes without chronic attritional damage and secondary pathologic changes of the joint, one would expect that the native ligament tissue quality may be preserved.[21,23]

In the case of acute proximal or distal UCL insertion injuries, where a biomechanically stable joint is maintained, repair rather than reconstruction may be a viable option. Some recent clinical success has been gained with direct suture repair in young athletes with acute proximal or distal tears.[3,28,30] Studies have shown reliable and rapid return to overhead sports in this nonprofessional patient population. Given these early clinical outcomes, we have focused on developing a reliable ligament repair technique that will restore valgus stability, decrease soft tissue dissection, and preserve bone, to allow a more rapid return to play. The purpose of the current study was to compare the cyclic and failure biomechanical properties of a new technique of UCL repair augmented with a spanning tape anchored on each end (Internal Brace; Arthrex Inc) to those of a modified figure-of-8 UCL reconstruction technique. We hypothesized that the repaired specimens would have less gap formation and a higher maximum torque to failure compared with those undergoing modified Jobe reconstruction. In addition, we hypothesized that while both groups would show an increase in gap formation after the simulated tear, the repair group would return closer to the native values compared with the reconstruction group.

METHODS

Specimen Preparation

Eighteen fresh-frozen cadaveric upper extremities (9 matched pairs; 2 male, 7 female; mean age, 63 years; range, 55-71 years) were procured and stored at –20°C. After thawing overnight at room temperature, the specimens were disarticulated from the scapula. If present, the palmaris longus tendon was harvested and kept moist in saline for later use in reconstruction. In cases in which the palmaris longus was not present, one from the repair limb of another specimen pair was used. Each specimen was dissected to expose the UCL by use of a muscle elevating approach used by the senior author (J.R.D.) for UCL reconstructions.[5] The flexor pronator origin and all ligament and capsular tissues were preserved in the dissection. The humerus and forearm were then transversely sectioned at midshaft. Skin and soft tissue were removed on these ends, exposing sufficient bone ends to allow for rigid fixation in acrylic pipe with polymethylmethacrylate

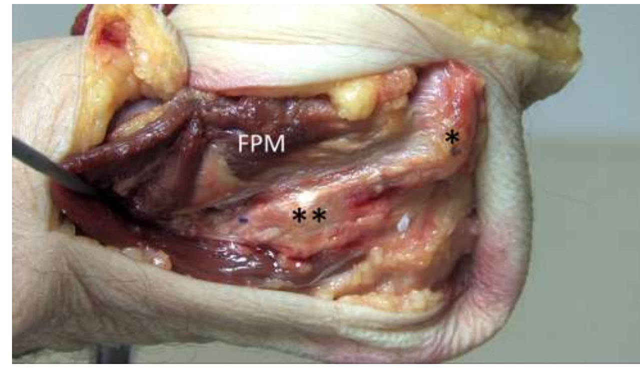

Figure 1. Intact cadaveric ulnar collateral ligament (UCL) with the flexor pronator mass elevated, the native ligament intact, and markers placed near the anatomic origin and insertion of the UCL. Anatomic landmarks are labeled as proximal UCL insertion onto the medial epicondyle (*), distal UCL insertion onto the sublime tubercle (**), and the retracted flexor pronator mass (FPM).

cement. During potting, the forearm was held in neutral rotation. The humeral and ulnar insertions of the UCL were identified by use of previously identified anatomic markers.[12] Briefly, the humeral origin was located along the anterior-inferior aspect of the medial epicondyle roughly 1.5 cm from the medial epicondyle and 2 cm from the joint line. The most prominent bony protuberance of the sublime tubercle was selected as the point of insertion on the ulna because it has been shown to sit directly in the center of the widest portion of the UCL footprint and is readily identifiable during surgery. After both points were identified, a fine-tipped surgical marker (Viscot Medical LLC) was used to mark each insertion point (Figure 1). The positions of these markers were later recorded with a Canon XH A1 HDV high-definition camera (Canon USA Inc) throughout the loading protocol to allow for subsequent calculation of ligament displacement.

Biomechanical Testing

Each specimen was mounted on an MTS 858 Mini Bionix II axial-torsional materials testing machine (MTS System Corp) in a custom jig with the elbow at 90° of flexion.[7,8,20,29] The humerus was positioned vertically and secured with its long axis in line with the MTS actuator while the forearm was mounted to the stationary base plate parallel to the ground. Once the specimen was secured with the elbow in its neutral position, a valgus rotational torque was applied to the humerus. A 2-N·m preload was applied followed immediately by 10 cycles of loading[8,20] between 2 and 5 N·m. After cycling, the distal UCL fibers were elevated sharply from the sublime tubercle of the ulna to simulate a distal tear (Figure 2). The 10 cycles were repeated. Then, each pair of specimens was randomly separated into a repair group or a reconstruction group. After the surgical procedures were performed, the specimens were again loaded for 10 cycles between 2 and 5 N·m, followed by

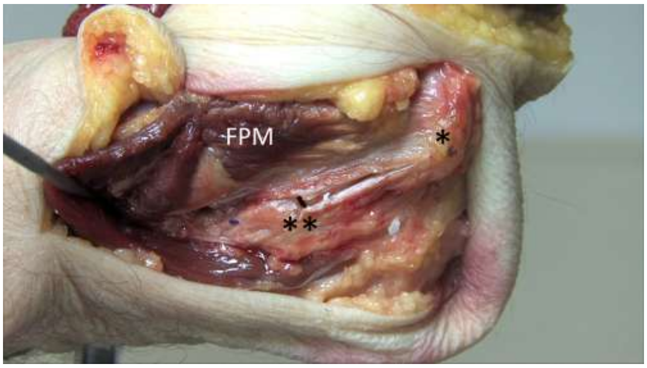

Figure 2. Cadaveric ulnar collateral ligament (UCL) in torn condition, with in-line ligament split and distal elevation off the sublime tubercle. Anatomic landmarks are labeled as proximal UCL insertion onto the medial epicondyle (*), distal UCL insertion onto the sublime tubercle (**), and the retracted flexor pronator mass (FPM).

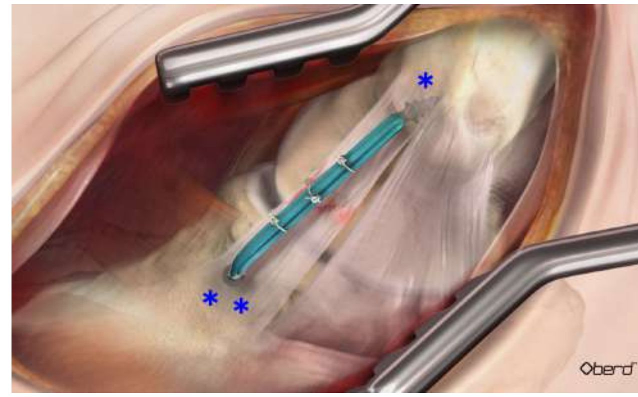

Figure 3. Artist's rendering of the cadaveric ulnar collateral ligament (UCL) after repair was performed. The augmentation integrated into the repair is visible. Anatomic landmarks are labeled as proximal UCL insertion onto the medial epicondyle (*) and distal UCL insertion onto the sublime tubercle (**).

a 60-second hold at 2 N·m. After holding, the 2 procedure groups were then loaded to failure at a rate of 1° per second. Failure was defined as mechanical failure of the system. Torque, rotation, and the method and location of failure were recorded. Additionally, gap formation measurements were taken immediately after the cycling phases of the intact, torn, and repair/reconstruction conditions. In the case of repair or reconstruction, the gap formation was measured during the 60-second hold between cycling and the ramp to failure.

Ligament Repair Technique

In one limb of each pair (randomized with respect to right or left), one 2.7-mm hole was drilled on the humerus and ulna. We centered the ulnar hole at the apex of the sublime tubercle and drilled on a vector approximately 60° radial to a line drawn down the center of the ulnar shaft. The humeral tunnel was drilled at the center of the native UCL footprint over the anterior-inferior aspect of the medial epicondyle and was drilled on a vector in line with the medial column and away from the articular surface of the ulna. Data from a previous publication were used as an anatomic reference in selecting these points to ensure that our implants would not compromise the largest or widest portion of the distal or proximal footprint of the native UCL insertion.[12] The first hole was then tapped with a 3.5-mm tap and a 3.5-mm knotless SwiveLock (Arthrex Inc) loaded with 2-mm FiberTape (Arthrex Inc), and a size 0 nonabsorbable suture was placed in the hole and advanced. The tape was anchored within the tunnel as close to the center of the native UCL attachments as possible. The screw from the SwiveLock was then advanced into the hole. The free ends of the size 0 suture were then passed through the ends of the created UCL detachment and the sutures were tied, repairing the native ligament to its insertion. Next, the longitudinal division in the ligament was closed with 3 simple size 2-0 stitches. After tapping of the second hole in the medial epicondyle, the free ends of the

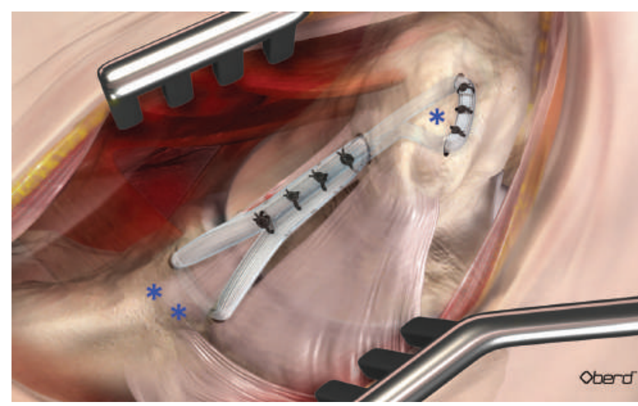

Figure 4. Artist's rendering of the cadaveric ulnar collateral ligament (UCL) after reconstruction was performed. The palmaris longus graft was used through bone tunnels. Anatomic landmarks are labeled as proximal UCL insertion onto the medial epicondyle (*) and distal UCL insertion onto the sublime tubercle (**).

FiberTape suture were loaded into a second 3.5-mm SwiveLock system. While the joint was reduced with slight varus pressure at 20° of elbow flexion, the SwiveLock was advanced such that the tension of the tape was not greater than that of the underlying ligament tissue. The screw from the second SwiveLock was advanced into the hole. Three additional size 0 absorbable figure-of-8 sutures were passed around the ligament and the FiberTape to incorporate them together (Figure 3). The specimen was then loaded onto the MTS machine for testing.

Ligament Reconstruction Technique

In each contralateral limb, two 3.5-mm drill tunnels were positioned approximately 1 cm apart at the anterior and posterior aspects of the sublime tubercle. These 2 tunnels were purposely converged to create a semicircular tunnel at the insertion of the native UCL. These tunnels were connected using a small curved curette. Next, two 3.5-mm drill tunnels were placed in the medial epicondyle. The first was positioned at the anatomic insertion site of the ligament off the anterior-inferior surface of the medial epicondyle. This hole was directed proximal-posterior, exiting the humerus on the posterior side of the medial ridge. The second medial epicondyle tunnel was started at the medial aspect of the epicondyle with at least a 1-cm bridge between the proximal exit site of the first tunnel and the entrance to the second tunnel. Straight curettes were used to connect the 2 tunnels. Next, the longitudinal division in the ligament was closed with 3 simple size 2-0 stitches. The previously harvested palmaris longus tendon ends were then whipstitched with a size 2 absorbable suture. With a suture passer and passing sutures, the tendon was first shuttled through the ulnar tunnel. Next, the limb that exited from the anterior aspect of the ulnar tunnel was shuttled through the distal medial epicondyle hole and pulled out of the second tunnel. The posterior limb was also shuttled into the distal entrance of the epicondylar tunnel and pulled out of the more proximal exiting hole (first tunnel). While the joint was reduced with slight varus pressure at 20° of elbow flexion, tension was placed on both limbs of the tendon graft. While tension was held, the graft limbs were crossed and five size 2 sutures were used to secure the limbs together over the epicondyle. Three additional size 0 absorbable figure-of-8 sutures were passed around the ligament and tendon reconstruction to incorporate them together (Figure 4).

Data Analysis

TestStar IIs software (MTS Systems Corp) was used to measure the torque-rotation characteristics of the elbow, allowing subsequent maximum torque and stiffness to be calculated as outcome measures, as in previous studies.[7,8,20,25] Additionally, gap formation[20] was used as a metric for evaluating the strain performance of the repairs and reconstructions. Cyclic and failure gap formation data for the intact, torn, repaired, and reconstructed states were obtained by analyzing the video footage with Image J 1.47v software (National Institutes of Health). A calibration image was generated with each test by use of a standard measurement device. This provided a conversion factor between pixel size and distance that could be used to measure gap changes between the markers. The resolution of this optical system was 15.4 ± 0.84 pixels/mm with accuracy within 6% and 17% when measuring known distances between 2.0 and 0.2 mm, respectively (gap measurements in this study were within this range). Gap in the cyclic testing was determined as the change in displacement between markers measured at the first 2 N·m of torque applied in the first cycle to the last 5 N·m of torque applied during the tenth cycle. Gap in the failure testing was taken at 10 N·m of torque. This represents the torque after which some specimens began to yield and fail. Torsional stiffness was calculated as the slope of the linear region of the torque-versus-rotation curve. Statistical analyses were performed with JMP 10.0.0 statistical software (SAS Institute). A 2-way analysis of variance (ANOVA) with repeated measures was used to detect overall differences in gap formation for the intact, torn, and surgical conditions. Post hoc comparisons were made between the 2 different procedures (post hoc Student t test) as well as between the 3 different surgical conditions (Tukey honestly significant difference). Significance for all tests was defined at $P \leq .05$.

TABLE 1
Results of Torque to Failure Test for Repair and Reconstruction Groups[a]

	Reconstruction Group	Repair Group	P Value
Gap at 10 N·m, mm	2.86 ± 2.14	2.02 ± 1.16	.2
Stiffness, N·m/deg	1.28 ± 0.49	1.32 ± 0.39	.4
Failure torque, N·m	20.9 ± 6.58	23.6 ± 10.8	.2

[a]Data are presented as mean ± SD. No statistical differences were found between the 2 groups. Paired t test P values are provided.

RESULTS

For the ramp-to-failure test, no significant differences were found among constructs in average ultimate torque, rotational stiffness, or gap formation at 10 N·m (Table 1). Modes of failure for the repaired elbows were ulnar screw pullout (4/9), epicondyle screw pullout (2/9), and humeral shaft/supracondylar fracture (3/9). There were no intrasubstance failures. Modes of failure for the reconstructed elbows were ulnar tunnel fracture (3/9), humeral shaft/supracondylar fracture (3/9), and intrasubstance tear (3/9). No medial epicondyle tunnel failures were seen.

The 2-way repeated-measures ANOVA showed an overall significant difference (P = .03) in gap formation for the repair group in the intact, torn, and repaired states, while no differences were found between intact, torn, and reconstructed states for the reconstruction group (P = .3). Post hoc tests for pairwise comparisons showed that the repair group displayed statistically greater resistance to gapping (Figure 5). Further, the Tukey post hoc test showed that compared with the intact state, valgus instability after release of the UCL distally was statistically significant in the repair group (P = .04). Compared with the torn state, restoration of valgus stability among repair specimens approached significance (P = .07), but this was not the case for the reconstructed group (P = .3).

DISCUSSION

In the current study, we present a new technique for the primary repair of UCL injuries of the elbow. Compared with specimens that underwent modified Jobe reconstructions, cadaveric specimens undergoing repair with internal

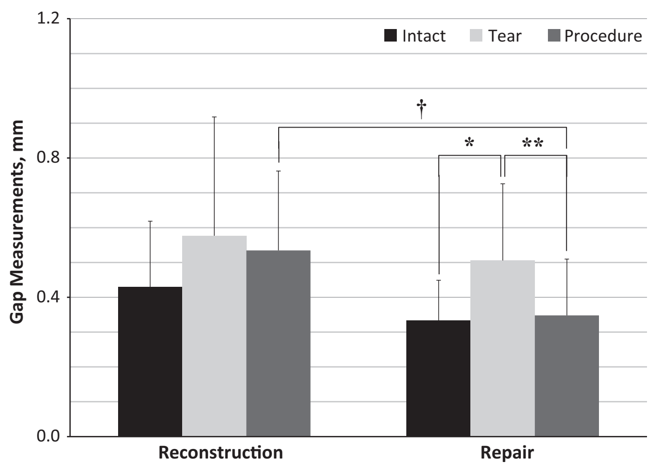

Figure 5. Graphic representation of the cyclic gap data for the repair and reconstruction groups. The repair group showed statistically less gap formation with small applied torque than did the reconstruction group (†*P* = .04). Within the repair group, the torn condition experienced significantly increased gap formation compared with the intact condition (**P* = .04) and a trend toward increased gap formation compared with the repaired condition (***P* = .07).

brace augmentation demonstrated similar biomechanics including ultimate failure strength, gap formation, and valgus stability.

Early reports on UCL repair are mixed but overall show dismal results when repair was performed on elite professional athletes and compared with reconstruction methods.[2,5,9] UCL repair was first reported by Norwood et al,[23] who successfully showed no residual instability at 2 years in 4 patients. One caveat to this is that none of the patients were high-level throwing athletes. In a follow-up study with Dr Jobe's patients, Conway et al[9] reported on 14 repairs in overhead athletes. The investigators showed that only 50% of subjects were able to return to their previous level of activity. When these results are subdivided for professional and nonprofessional, only 2 of 7 (29%) professional athletes returned, whereas 5 of 7 (71%) nonprofessional athletes returned. In 2000, Azar et al[5] reported their results on 59 reconstructions and 8 repairs on male college and professional baseball players. In the reconstruction group, 81% of patients were able to return to their previous level or higher, while only 63% of patients in the repair group were able to return to a similar level of play.

Secondary to the initial high rates of UCL repair failure in male elite overhead throwers, the current surgical treatment for most acute and chronic symptomatic UCL instability is graft reconstruction. During the career of male professional baseball players, the throwing elbow encounters repetitive near-failure stresses that may cause UCL microtrauma with eventual complete failure or gradual attenuation.[9,37] Full reconstruction with graft augmentation to replace poor-quality ligament is necessary in these patients.[9,19] Jobe et al[19] were the first to develop a reconstruction technique using free tendon graft weaved through bone tunnels in the medial epicondyle and sublime tubercle to recreate and retension a UCL. A majority of these patients were professional pitchers, and the investigators reported a 69% success rate in returning the players to their previous level of competition. Since that time, multiple modifications to this technique and other techniques have been developed, improving the clinical outcomes.[5,6,9-11,19,34] Overall rates of return to previous level of competition have been between 80% and 93%. In the most comprehensive study to date, Cain et al[6] evaluated the clinical outcome of 1281 patients from 1988 to 2006 who underwent a modified Jobe UCL reconstruction. The investigators found that 83% of athletes returned to their preinjury level of play or higher and that the average time to return to full competition was 11.6 months.

With the recent exponential increase in acute UCL injuries documented in youth, adolescent, and high school throwing athletes, one would expect to see more acute UCL injuries without chronic ligament changes. If the area of injury is isolated to only one insertion area, the ligament and remainder of the joint should be amenable to repair and rapid recovery, similar to other ligament injuries in the body. More recent studies have shown that primary UCL repair can be successful in younger athletes. Savoie et al[30] reported on the repair of proximal and distal UCL avulsion injuries in young throwing athletes (mean age, 17 years). These injuries were repaired with suture through bone tunnels or to single suture anchors. The investigators showed that 58 of 60 subjects returned to their sport at the same level or higher within 6 months. Richard et al[28] reported on the direct repair of acute UCL ruptures from the humerus by using bone tunnels or single suture anchors at a mean of 20 days from injury. All of the patients also required suture repair of flexor-pronation mass avulsion at the time of surgery, and 9 of the 11 patients returned to collegiate athletics by 6 months. Reporting on female overhead athletes with an average age of 22 years, Argo et al[3] showed that all but 1 of 18 patients returned to their sport at a mean of 2.5 months. It appears that with the proper evaluation and patient choice, direct UCL repair remains a viable option for young athletes with acute tear of the UCL. When one is treating a young, biomechanically stable elbow, using a repair technique with strong biomechanical properties may decrease rehabilitation time and return the athlete to play much sooner than is the case with typical UCL reconstruction, which carries a nearly 12-month return-to-play time.

Previous biomechanical studies of throwing have estimated tremendous acceleration rates and valgus torques between 52 and 120 N·m.[15,16,37] Fleisig et al[15,16] estimated a 35-N·m demand on the UCL to resist valgus torque during a pitch. The ultimate failure load of intact cadaver UCL was determined to be 22.7 N·m in one study[17] and 34 N·m in another study[1] using younger (mean age, 43 years) male cadavers. In the literature, multiple reconstruction methods have been biomechanically tested to failure; estimates have ranged from 13.6 to 30.5 N·m.[1,4,17,19] We did not test the intact condition to failure, but when the repair technique is compared with reconstruction, our results fall within this range (23.62 vs 20.52 N·m). Differences in testing method, cadaver age, and bone quality may have contributed to the observed variation in the results across studies. The repair technique also appeared to be more resistant to gap formation than the reconstruction technique under small cyclic loading conditions (0.35 vs 0.53 mm, respectively). This statistically significant difference ($P < .03$) was low in magnitude compared with displacements of 1 to 2 mm that have been shown to be important for medial elbow stability[14]; however, when one considers the early load-bearing conditions as would be seen in the early stages of a postoperative rehabilitation program, these changes could be important. We believe a more stable technique is more protective of the repair, allowing for early motion and small stresses of advanced rehabilitation protocols and, potentially, more rapid incorporation of the repair and subsequent earlier return to throwing. This technique may also be used with less invasive muscle- and bone-sparing approaches, which have been shown to decrease morbidity and improve outcomes.[32,34] Overall, the goal of this technique is to return players to competition as safely and quickly as possible.

Possible limitations to this study are specimen age and sample size, which are somewhat inherent to cadaveric studies. The age of the specimens was not representative of the athletes who typically undergo this procedure. This could have led to early failure related to bone quality, as was shown with our high rate of humeral-side fracture and ulnar bone tunnel failure. A limited specimen quantity and/or inconsistent specimen quality due to age may have increased variability and may have contributed to the lack of statistical significance between the intact and torn conditions in the reconstruction group. Our attempt to replicate a true clinical distal-sided tear by elevating the UCL off the sublime tubercle to mimic a "T-sign"[35] may have decreased the displacement of the tear state. If a true transection of the ligament had been performed, then greater instability of the tear state and statistical significance for the reconstruction group may have been seen. The cyclic gapping data presented here are perhaps the most important and the most promising. Under conditions of low cyclic demand, the augmented repair demonstrated less gap formation and a closer return to normal gap formation compared with the reconstructed specimens. These results support the notion that an accelerated physical therapy protocol may achieve a significantly faster return to play without compromising the early integrity of the repair. While previous authors have demonstrated dominant throwing arm joint laxity and adaptive morphologic characteristics in the UCL among asymptomatic overhead athletes,[13,18] in these cases, changes in the morphologic characteristics of the UCL and subsequent joint laxity arose through adaptation and were not believed to be related to acute injury. In the case of UCL repair after acute or chronic symptomatic injury, the clinical relevance of early gap formation may be much more significant because it may affect ultimate outcomes by way of incomplete or failed healing. Our load application is meant to simulate the early load-bearing conditions as would be seen in the early stages of a postoperative rehabilitation program. During this time period, the cyclic load is low compared with the stressors that the UCL undergoes during pitching, which would occur much later in the recovery process.

Future work could strengthen the biomechanical argument for this construct while addressing some of the clinically important questions that cannot be answered with a cadaveric model. A second cadaveric study that more robustly tests the cyclic behavior of these 2 techniques using a high-cycle fatigue biomechanical protocol at various degrees of flexion from 30° to 90° would be useful, as it would more closely replicate the long-term stressors of return to play. Clinically, because many of the patients in whom repair is indicated would potentially go on to participate in their sport at the same or higher level of competition, information related to outcomes including performance, symptoms, and failures would be useful. Currently, this procedure is used at our institution. However, we have yet to finish collecting data and publish our long-term results on outcomes. We believed that our technique lends itself to successful revision, should that become necessary, for several reasons. First, we use a biostable polyetheretherketone (PEEK) polymer anchor to minimize the potentially adverse outcomes of cyst formation, tunnel expansion, or osteolysis while also permitting anchor removal in the revision setting.[33] Second, the use of this anchor permits imaging of the ligament at a later time without artifact. Third, the size of anchor we have selected creates a 3.5-mm diameter tunnel in the bone, which is the same size created in many of the reconstruction techniques including docking, modified Jobe, and suspensory fixation. Should a reconstruction become necessary, the bone tunnels can be incorporated without sacrificing the strength of the final construct and without concern for significantly lytic or weakened surrounding bone.

CONCLUSION

The presented study shows that UCL repair augmented with an internal brace replicates the failure strength of traditional graft reconstruction but requires less soft tissue dissection and is bone preserving. The technique also appears to be more resistant to gapping at low cyclic loads. Overall, the biomechanical data are encouraging, and clinical data are needed to test the effectiveness of this type of repair.

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REFERENCES

1. Ahmad CS, Lee TQ, ElAttrache NS. Biomechanical evaluation of a new ulnar collateral ligament reconstruction technique with interference screw fixation. *Am J Sports Med*. 2003;31(3):332-337.
2. Andrews JR, Timmerman LA. Outcome of elbow surgery in professional baseball players. *Am J Sports Med*. 1995;23(4):407-413.

3. Argo D, Trenhaile SW, Savoie FH, Field LD. Operative treatment of ulnar collateral ligament insufficiency of the elbow in female athletes. *Am J Sports Med*. 2006;34(3):431-437.
4. Armstrong AD, Dunning CE, Ferreira LM, Faber KJ, Johnson JA, King GJ. A biomechanical comparison of four reconstruction techniques for the medial collateral ligament-deficient elbow. *J Shoulder Elbow Surg*. 2005;14(2):207-215.
5. Azar FM, Andrews JR, Wilk KE, Groh D. Operative treatment of ulnar collateral ligament injuries of the elbow in athletes. *Am J Sports Med*. 2000;28(1):16-23.
6. Cain EL, Andrews JR, Dugas JR, et al. Outcome of ulnar collateral ligament reconstruction of the elbow in 1281 athletes: results in 743 athletes with minimum 2-year follow-up. *Am J Sports Med*. 2010;38(12):2426-2434.
7. Chronister JE, Morris RP, Andersen CR, Buford WL, Bennett JM, Mehlhoff TL. A biomechanical comparison of 2 hybrid techniques for elbow ulnar collateral ligament reconstruction. *J Hand Surg Am*. 2014;39(10):2033-2040.
8. Cohen SB, Woods DP, Siegler S, Dodson CC, Namani R, Ciccotti MG. Biomechanical comparison of graft fixation at 30° and 90° of elbow flexion for ulnar collateral ligament reconstruction by the docking technique. *J Shoulder Elbow Surg*. 2015;24(2):265-272.
9. Conway JE, Jobe FW, Glousman RE, Pink M. Medial instability of the elbow in throwing athletes: treatment by repair or reconstruction of the ulnar collateral ligament. *J Bone Joint Surg Am*. 1992;74(1):67-83.
10. Dines JS, ElAttrache NS, Conway JE, Smith W, Ahmad CS. Clinical outcomes of the DANE TJ technique to treat ulnar collateral ligament insufficiency of the elbow. *Am J Sports Med*. 2007;35(7):2039-2044.
11. Dodson CC, Thomas A, Dines JS, Nho SJ, Williams RJ, Altchek DW. Medial ulnar collateral ligament reconstruction of the elbow in throwing athletes. *Am J Sports Med*. 2006;34(12):1926-1932.
12. Dugas JR, Ostrander RV, Cain EL, Kingsley D, Andrews JR. Anatomy of the anterior bundle of the ulnar collateral ligament. *J Shoulder Elbow Surg*. 2007;16(5):657-660.
13. Ellenbecker TS, Mattalino AJ, Elam EA, Caplinger RA. Medial elbow joint laxity in professional baseball pitchers: a bilateral comparison using stress radiography. *Am J Sports Med*. 1998;26(3):420-424.
14. Field LD, Altchek DW. Evaluation of the arthroscopic valgus instability test of the elbow. *Am J Sports Med*. 1996;24(2):177-181.
15. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med*. 1995;23(2):233-239.
16. Fleisig GS, Kingsley DS, Loftice JW, et al. Kinetic comparison among the fastball, curveball, change-up, and slider in collegiate baseball pitchers. *Am J Sports Med*. 2006;34(3):423-430.
17. Hechtman KS, Tjin-A-Tsoi EW, Zvijac JE, Uribe JW, Latta LL. Biomechanics of a less invasive procedure for reconstruction of the ulnar collateral ligament of the elbow. *Am J Sports Med*. 1998;26(5):620-624.
18. Hurd WJ, Eby S, Kaufman KR, Murthy NS. Magnetic resonance imaging of the throwing elbow in the uninjured, high school-aged baseball pitcher. *Am J Sports Med*. 2011;39(4):722-728.
19. Jobe FW, Stark H, Lombardo SJ. Reconstruction of the ulnar collateral ligament in athletes. *J Bone Joint Surg Am*. 1986;68(8):1158-1163.
20. Lynch JL, Pifer MA, Maerz T, et al. The GraftLink ulnar collateral ligament reconstruction: biomechanical comparison with the docking technique in both kinematics and failure tests. *Am J Sports Med.* 2013;41(10):2278-2287.
21. Miller CD, Savoie FH. Valgus extension injuries of the elbow in the throwing athlete. *J Am Acad Orthop Surg*. 1994;2(5):261-269.
22. Morrey BF, An KN. Articular and ligamentous contributions to the stability of the elbow joint. *Am J Sports Med*. 1983;11(5):315-319.
23. Norwood LA, Shook JA, Andrews JR. Acute medial elbow ruptures. *Am J Sports Med*. 1981;9(1):16-19.
24. Olsen SJ, Fleisig GS, Dun S, Loftice J, Andrews JR. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *Am J Sports Med*. 2006;34(6):905-912.
25. Paletta GA, Klepps SJ, Difelice GS, et al. Biomechanical evaluation of 2 techniques for ulnar collateral ligament reconstruction of the elbow. *Am J Sports Med*. 2006;34(10):1599-1603.
26. Petty DH, Andrews JR, Fleisig GS, Cain EL. Ulnar collateral ligament reconstruction in high school baseball players: clinical results and injury risk factors. *Am J Sports Med*. 2003;32(5):1158-1164.
27. Regan WD, Korinek SL, Morrey BF, An KN. Biomechanical study of ligaments around the elbow joint. *Clin Orthop Relat Res*. 1991; 271:170-179.
28. Richard MJ, Aldridge JM, Wiesler ER, Ruch DS. Traumatic valgus instability of the elbow: pathoanatomy and results of direct repair. *J Bone Joint Surg*. 2008;90(11):2416-2422.
29. Ruland RT, Hogan CJ, Randall CJ, Richards A, Belkoff SM. Biomechanical comparison of ulnar collateral ligament reconstruction techniques. *Am J Sports Med*. 2008;36(8):1565-1570.
30. Savoie FH, Trenhaile SW, Roberts J, Field LD, Ramsey JR. Primary repair of ulnar collateral ligament injuries of the elbow in young athletes: a case series of injuries to the proximal and distal ends of the ligament. *Am J Sports Med*. 2008;36(6):1066-1072.
31. Slocum DB. Classification of elbow injuries from baseball pitching. *Tex Med*. 1968;64(3):48-53.
32. Smith GR, Altchek DW, Pagnani MJ, Keeley JR. A muscle-splitting approach to the ulnar collateral ligament of the elbow: neuroanatomy and operative technique. *Am J Sports Med*. 1996;24(5):575-580.
33. Suchenski M, McCarthy MB, Chowaniec D, et al. Material properties and composition of soft-tissue fixation. *Arthroscopy*. 2010;26(6):821-831.
34. Thompson WH, Jobe FW, Yocum LA, Pink MM. Ulnar collateral ligament reconstruction in athletes: muscle-splitting approach without transposition of the ulnar nerve. *J Shoulder Elbow Surg*. 2001; 10(2):152-157.
35. Timmerman LA, Schwartz ML, Andrews JR. Preoperative evaluation of the ulnar collateral ligament by magnetic resonance imaging and computed tomography arthrography: evaluation in 25 baseball players with surgical confirmation. *Am J Sports Med*. 1994;22(1):26-31.
36. Tullos HS, Erwin WD, Woods GW, Wukasch DC, Cooley DA, King JW. Unusual lesions of the pitching arm. *Clin Orthop Relat Res*. 1972;88:169-182.
37. Wilson FD, Andrews JR, Blackburn TA, McCluskey G. Valgus extension overload in the pitching elbow. *Am J Sports Med*. 1983;11(2):83-88.