# The Effect of Ulnar Collateral Ligament Repair With Internal Brace Augmentation on Articular Contact Mechanics

## A Cadaveric Study

Travis S. Roth,* MD, David P. Beason,*† MS, T. Bradley Clay,* MD, E. Lyle Cain Jr,*‡ MD, and Jeffrey R. Dugas,*‡ MD

*Investigation performed at the American Sports Medicine Institute in Birmingham, Alabama, USA*

**Background:** There has been renewed interest in ulnar collateral ligament (UCL) repair in throwing athletes because of a greater understanding of UCL injuries, improvement in ligament repair technology, and potentially expedited rehabilitation time and return to play relative to UCL reconstruction.

**Purpose:** To evaluate elbow articular contact and overall joint torque after UCL reconstruction and repair augmented with a collagen-coated fiber tape, InternalBrace.

**Study Design:** Controlled laboratory study.

**Methods:** Ten matched pairs of cadaveric arms (mean age, 41 ± 11 years) were dissected to expose the UCL. Each specimen was secured into a custom test fixture at 90°, and 1 specimen from each pair underwent either a modified Jobe UCL reconstruction or UCL repair with InternalBrace. Each specimen underwent 10 cycles of elbow valgus angular displacement between 0° and 5° at a rate of 1 deg/s in the intact state, after UCL avulsion, and then after UCL reconstruction or repair. Articular contact mechanics and overall joint torque and stiffness were recorded.

**Results:** Contact mechanics of reconstructed and repaired specimens were not significantly different. Both reconstruction and repair procedures returned the overall resistance of the joint to valgus torsion to near-intact levels. UCL repair tended to restore joint torque more closely to the intact state than did reconstruction, given that reconstruction showed a nonsignificant trend toward lower torque than the intact state ($P = .07$).

**Conclusion:** Neither UCL reconstruction nor UCL repair with InternalBrace overconstrained the elbow joint, as both groups had similar contact pressures compared with the native joint. Both procedures also restored elbow joint torque and stiffness to levels not statistically different from the intact state.

**Clinical Relevance:** Given the sound biomechanical properties of UCL repair with InternalBrace, it may have a significant role as treatment for UCL injuries.

**Keywords:** ulnar collateral ligament; repair; reconstruction; InternalBrace; augmentation; biomechanical

Ulnar collateral ligament (UCL) injuries have significantly increased over the past few decades, especially in young throwing athletes.[15-17,19] Therefore, UCL reconstruction has become a common procedure to address UCL insufficiency in adolescent, collegiate, and professional throwers.[6,15,19,20,24,29] First described by Frank Jobe in 1986, the procedure has undergone significant evolution in terms of refinement of technique, surgical approaches, variations in tunnel drilling, graft choice, and fixation methods.[1,7,8,18,21] Return to play at the same or higher level has also been reported at rates between 83% and 95%.[6,10,11,23,28]

In contrast, repair, rather than reconstruction, of the UCL had historically poorer return-to-sport outcomes, ranging between 29% and 63%.[4,9] Accordingly, for years, UCL repair fell out of favor. More recent data, however, have suggested that UCL repair may be a viable treatment option, with favorable outcomes achieved in performing UCL repair in young athletes with acute proximal or distal tears.[3,30,31] Notably, Savoie et al[31] reported a series of 58 of 60 athletes able to return to sport at the same or higher level of play, within 6 months of UCL repair surgery. Therefore,

The Orthopaedic Journal of Sports Medicine, 9(4), 23259671211001069
DOI: 10.1177/23259671211001069

renewed interest in UCL repair, combined with the advent of enhanced suture and anchor technology, led to the development of a novel technique for UCL repair. This repair technique, augmented with a collagen-coated fiber tape, InternalBrace (Arthrex), was designed as a backstop to valgus stress and a biologic augment to ligament healing.

This form of augmented UCL repair has since demonstrated excellent biomechanical and clinical outcomes. From a biomechanical standpoint, cadaveric study comparison of augmented UCL repair to modified Jobe UCL reconstruction demonstrated significantly greater resistance to gap formation, even at low cycles of valgus loading.[14] In a follow-up study, the authors demonstrated time-zero failure properties of the repair technique on par with those of traditional reconstruction, even after 500 cycles of valgus loading.[22] This was then translated to favorable clinical results as Dugas et al[12] reported a return to play of 92% (102/111 athletes) at a mean of 6.7 months, with high Kerlan-Jobe Orthopaedic Clinic (KJOC) scores at 2 years.

The implementation of suture tape augmentation to joint repair introduces the possibility of overconstraining any joint spanned by the construct due to the fact that the suture tape material is stiffer than any soft tissue graft. This could apply to any joint utilizing this augmentation (eg, the tibiofemoral joint in medial collateral ligament or anterolateral ligament repair, the metacarpophalangeal joint involved in thumb UCL repair), but in the current study was specifically applied to the ulnohumeral joint as it pertains to augmented elbow UCL repair. While the literature has not yet addressed this potential overconstraint of any joint, surgeons commonly question this issue.

As clinical experience with UCL repair is ongoing, we sought to investigate a related biomechanical question in how this UCL repair technology affects articular contact mechanics across the elbow joint. The purpose of this study was to evaluate elbow articular contact and overall joint torque and stiffness in response to an applied angular displacement after UCL reconstruction and augmented UCL repair. We hypothesized that neither reconstructed nor repaired specimens would overconstrain the elbow joint, in that both groups would have similar contact pressures compared with the native joint.

## METHODS

### Specimen Preparation

Twenty upper extremities from 10 fresh-frozen cadavers (5 female, 5 male) with a mean age of 41 ± 11 years (range, 19-49 years) and a mean body mass index of 22.3 ± 2.7 kg/m$^2$ were provided in kind by Arthrex. Each of the 10 pairs was designated to have 1 elbow receive a modified Jobe UCL reconstruction, while the contralateral elbow would receive a UCL repair augmented with InternalBrace. To minimize any potential arm-dominance bias, limbs were distributed among the 2 procedure groups (reconstruction and repair) such that each group contained an equal number of right and left elbows.

Specimens were allowed to thaw to room temperature for approximately 24 hours before testing. If present, the palmaris longus tendon was harvested and kept in saline for later use in UCL reconstruction. If no palmaris longus tendon was present, the unused tendon from the repair limb of a different specimen was utilized. The humerus and forearm were transected at the mid-diaphysis. The forearm was placed in full supination as the radius and ulna were drilled and fixated with a quadricortical screw to maintain forearm rotation. This supinated orientation was chosen as the orientation that best stabilizes the UCL. The humerus and forearm were then potted in acrylic pipe using polymethylmethacrylate.

For all specimens, a medial incision was created just posterior to the medial epicondyle. The cubital tunnel was then exposed. The sublime tubercle and medial epicondyle were identified. For UCL exposure, a muscle-elevating approach was utilized to dissect and elevate the flexor-pronator musculature off of the anterior band of the UCL.[1,4] Subcutaneous tissue and flexor-pronator muscle mass were also dissected to expose the anterior elbow joint capsule overlying the ulnohumeral joint. A small, 2-cm capsulotomy was sharply created over the ulnohumeral joint space for subsequent pressure sensor placement. The lateral elbow was not dissected so as to not disrupt the lateral elbow ligamentous complex.

### Biomechanical Testing

Once initial dissections were completed, each specimen was secured into a custom test fixture (Figure 1) and mounted into a servohydraulic mechanical test frame (MTS Systems) with axial and torsional capabilities. The elbow joint was distracted using the test frame crosshead just enough to allow a single branch of a K-Scan 6900 pressure sensor (Tekscan) to be inserted into the ulnohumeral joint space (Figure 2). Once the sensor was in place, the distraction was removed, thereby tightly fixing the sensor in place within the joint space. A 2-point calibration was used for each sensor before testing using the test frame to apply 2

†Address correspondence to David P. Beason, MS, American Sports Medicine Institute, 833 St. Vincent's Drive, Suite 205, Birmingham, AL 35205, USA (email: davidb@asmi.org).
*American Sports Medicine Institute, Birmingham, Alabama, USA.
‡Andrews Sport Medicine and Orthopaedic Center, Birmingham, Alabama, USA.
Final revision submitted November 11, 2020; accepted December 16, 2020.
One or more of the authors has declared the following potential conflicts of interest or source of funding: This study was sponsored by Arthrex in the form of direct funding as well as in-kind donation of cadaveric specimens and surgical products used in study completion. T.S.R. has received education payments from Smith & Nephew. T.B.C. has received educational support from Smith & Nephew. J.R.D. has received consulting fees from Arthrex and DJO, nonconsulting fees from Arthrex and Smith & Nephew, 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.

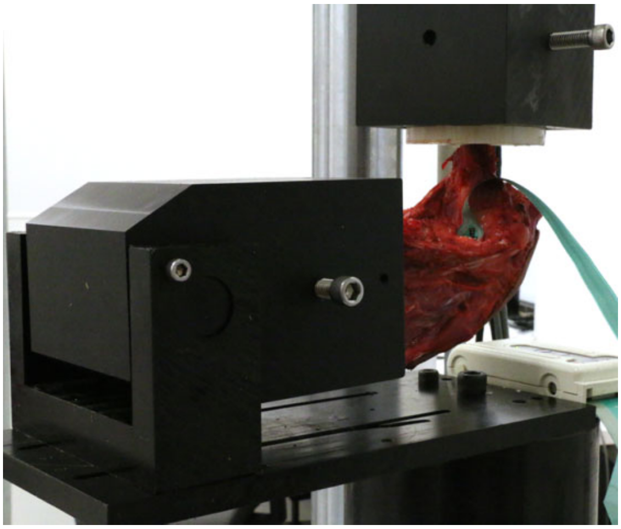

**Figure 1.** Overall test setup showing elbow in 90° of flexion, with the forearm fixed horizontally and the humerus vertically held by the test frame actuator.

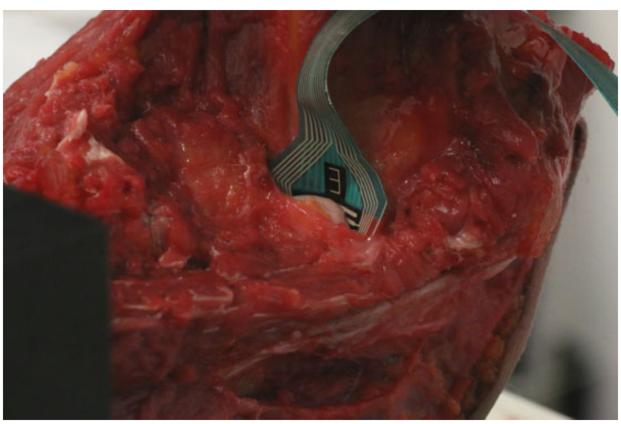

**Figure 2.** Pressure sensor inserted into ulnohumeral joint of a right elbow specimen.

compressive loads spanning the expected range of the intra-articular contact. After loading the pressure sensor, the specimen was positioned at 90° of elbow flexion,[14,22] where it would remain throughout the test. Biomechanical testing in the intact condition was conducted using the test frame actuator to internally rotate the humerus while holding the forearm stationary, creating a valgus torque on the medial elbow. Ten cycles of valgus angular displacement between 0° and 5° at a rate of 1 deg/s were performed before returning to zero. This range was chosen from preliminary tests to fall within the physiologic, subfailure range of the joint. Data were reported for only the 10th cycle.

After testing in the intact condition, a longitudinal split was then sharply created in line with the fibers of the anterior band of the UCL to expose the ulnohumeral joint line (Figure 3) as well as to assess ligamentous quality and inspect for injury. The distal insertion of the anterior band

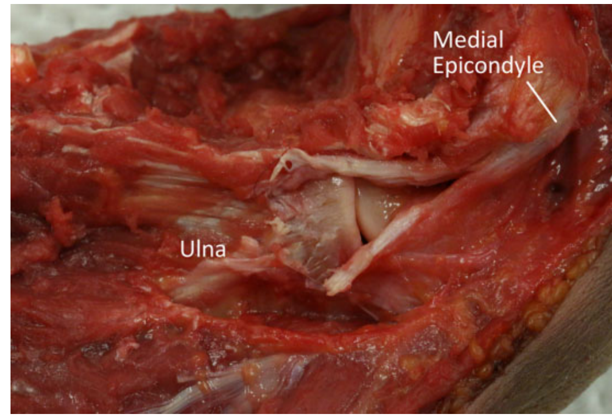


**Figure 3.** Longitudinal split created in the anterior band of the ulnar collateral ligament, exposing the ulnohumeral joint of a right elbow specimen.

of the UCL was then sharply released from the sublime tubercle, simulating a distal avulsion of the ligament. Ten cycles were repeated in this torn state.

## Ligament Repair

One limb from each pair underwent a repair technique as previously published.[12,14,22,26] Two 3.5-mm knotless SwiveLock (Arthrex) suture anchors were used in the augmented UCL repair procedure. The first (ie, distal) anchor was placed at the apex of the sublime tubercle. A 2.7-mm drill bit was used to drill this hole, which was then tapped with a 3.5-mm tap, before placement of the anchor. This first anchor was preloaded with a 2-mm collagen-coated suture tape (FiberTape; Arthrex) and a No. 0 nonabsorbable braided suture (FiberWire; Arthrex) before final placement. The free ends of the No. 0 suture were passed through the ends of the detached UCL. While the joint was reduced with a slight varus force at 20° of flexion, the sutures were tied down, repairing the UCL to its native insertion site.[13] The previous ligament split was then repaired side-to-side with 3 simple No. 0 sutures. Next, a second (ie, proximal) anchor was placed after a 2.7-mm drill bit and 3.5-mm tap were inserted at the native origin of the anterior band on the medial epicondyle. This proximal anchor was preloaded with the free ends of the same collagen-coated suture tape and then advanced such that the tension of the suture tape did not overtension the underlying native ligament and full range of motion was maintained. Three additional No. 0 nonabsorbable sutures were passed around the native ligament and suture tape to incorporate them (Figure 4). The specimen was then mounted on the test frame for a final round of testing as described above.

## Ligament Reconstruction

On each contralateral limb, UCL reconstruction with a palmaris longus autograft was performed utilizing a modified Jobe technique, as is standard at our institution.[1] The previously harvested graft tendon ends were whipstitched

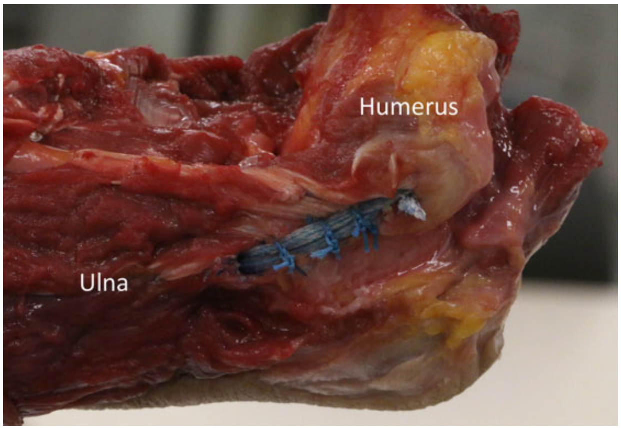


**Figure 4.** Completed ulnar collateral ligament repair with InternalBrace on a right elbow specimen.

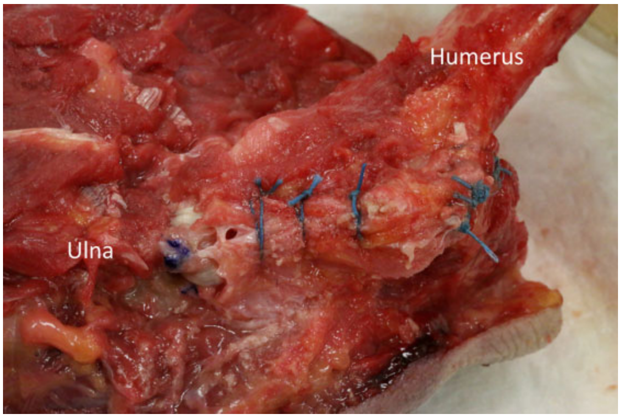


**Figure 5.** Completed ulnar collateral ligament reconstruction on a right elbow specimen.

with No. 0 sutures. Two converging 3.5-mm tunnels were drilled on the anterior and posterior aspects of the sublime tubercle, 1 cm from the joint line. Next, 2 tunnels of 3.5 mm were drilled in the medial epicondyle. One of these tunnels was positioned at the native origin of the anterior band and exited the humerus on the posterior side of the medial ridge. The second medial epicondyle tunnel was placed 1 cm from the exit point on the humerus of the first tunnel, converging with the first tunnel, to create overall Y-shaped humeral tunnels. Curettes were used to connect the tunnels and remove debris. Next, a Hewson suture passer was used to shuttle the graft through the ulnar tunnels, followed by the humeral tunnels. The posterior limb from the ulnar tunnel was shuttled into the distal entrance of the epicondylar tunnel and pulled out into the more proximal exiting hole (first tunnel). The limb that exited from the anterior ulnar tunnel was shuttled out through the distal medial epicondyle tunnel and pulled out the second tunnel. Similar to the repair procedure, the joint was reduced with a slight varus force at 20° of elbow flexion. With tension held on both limbs of the graft, the graft limbs were crossed, and 5 figure-of-8 sutures with No. 0 nonabsorbable sutures were placed to secure the graft limbs to themselves and to the underlying periosteum of the medial epicondyle. Three additional No. 0 nonabsorbable figure-of-8 sutures were placed through the graft and native ligament to incorporate them (Figure 5). The specimen was then mounted on the test frame for a final round of testing as described above.

### Data and Statistical Analysis

The pressure sensor was used to measure contact area, contact pressure, contact force, peak pressure, and peak force, while the test frame captured overall joint torque as a measure of the overall resistance provided by the joint for each test condition. Torsional stiffness was calculated as the slope of the linear region of the loading portion of the torque-angle curve. All measurements were reported at the 10th cycle. A 2-way analysis of variance (ANOVA) with repeated measures was performed for each test parameter using JMP Version 10.0.0 (SAS Institute). Where applicable, the Tukey honest significant difference tests were conducted to examine pairwise comparisons. Significance was set as $P \leq .05$.

## RESULTS

Only 10% (1/10) of reconstruction specimens were found to be without a palmaris longus tendon. For this single occurrence, the palmaris longus tendon from a specimen within 1 year of age was substituted. All specimens were able to complete all 10 test cycles with no failures.

The contact mechanics (Table 1) of reconstructed and repaired specimens were shown to be largely similar, with no overall differences shown for contact area ($P = .5$), contact pressure ($P = .7$), contact force ($P = .9$), peak pressure ($P = .9$), or peak force ($P = .9$). Joint torque was significantly affected by the type of procedure (reconstruction or repair; $P = .003$). The simulated tear and subsequent reconstruction/repair were shown to have a significant overall effect on contact area ($P = .0003$), contact force ($P = .0003$), peak pressure ($P = .04$), and peak force ($P = .04$); however, contact pressure was not affected ($P = .4$).

Measurements of joint torque demonstrated that both the reconstruction and repair procedures returned the overall resistance of the joint to valgus angular displacement to near-intact levels (Figure 6). Two-way ANOVA revealed a significant overall effect of both injury condition ($P < .0001$) and reconstruction/repair procedure ($P = .003$). Pairwise comparisons showed a significant decrease in torque for both groups as a result of the simulated tear ($P < .0001$), followed by a significant recovery from the torn condition to the reconstructed ($P = .04$) and repaired ($P = .01$) conditions. The reconstruction group, however, was still trending ($P = .07$) lower than the intact condition.

Likewise, both the reconstruction and repair procedures returned torsional stiffness to levels not significantly different from the intact state. Two-way ANOVA revealed a significant overall effect of injury condition ($P < .0001$) but not reconstruction/repair procedure ($P = .1$). Pairwise comparisons showed a significant decrease in stiffness for both

TABLE 1
Results of the Ulnar Collateral Ligament Valgus Torsion Tests For the Intact, Torn, and Procedure Conditions in Each Group[a]

| | Reconstruction Group | | | Repair Group | | | |
|---|---|---|---|---|---|---|---|
| | Intact | Torn | Procedure | Intact | Torn | Procedure | *P* |
| Torque, N·m | 6.23 ± 1.30 | 1.90 ± 0.54 | 4.18 ± 0.87 | 7.11 ± 3.15 | 3.31 ± 1.82 | 5.91 ± 2.53 | **.003** |
| Torsional stiffness, N·m/deg | 2.29 ± 0.57 | 0.91 ± 0.34 | 1.83 ± 0.45 | 2.16 ± 0.88 | 1.24 ± 0.65 | 2.21 ± 0.95 | .1 |
| Contact area, $mm^2$ | 68 ± 38 | 39 ± 21 | 46 ± 33 | 68 ± 29 | 34 ± 16 | 41 ± 21 | .5 |
| Contact pressure, MPa | 0.75 ± 0.41 | 0.62 ± 0.36 | 0.64 ± 0.45 | 0.68 ± 0.38 | 0.59 ± 0.38 | 0.66 ± 0.33 | .7 |
| Peak pressure, MPa | 1.59 ± 1.11 | 0.98 ± 0.72 | 1.11 ± 1.02 | 1.54 ± 1.07 | 1.07 ± 0.84 | 1.14 ± 0.62 | .9 |

[a]Data are presented as mean ± SD. Bolded *P* value indicates statistically significant difference between groups ($P < .05$; 2-way analysis of variance).

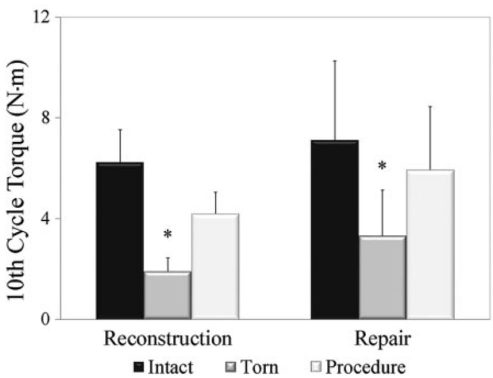


**Figure 6.** Mean elbow torque was significantly lower (*) in the torn condition when compared with intact and procedure conditions for both reconstructed and repaired specimens.

groups as a result of the simulated tear ($P < .004$), followed by a significant recovery from the torn condition to the reconstructed ($P = .003$) and repaired ($P = .002$) conditions.

## DISCUSSION

The results of this cadaveric study were consistent with the hypothesis in that neither UCL reconstruction nor augmented UCL repair overconstrained the elbow joint, as both groups had similar contact pressures compared with the native joint. Our data also demonstrated that both procedures restored elbow joint torque and stiffness to levels not statistically different from the intact state. UCL repair tended to restore joint torque more closely to the intact state than reconstruction, given that reconstruction showed a nonsignificant trend toward lower torque than the intact state ($P = .07$). In addition, to our knowledge, this is the first biomechanical study to demonstrate the absence of joint overconstraint when utilizing this technology for UCL repair.

Previous biomechanical evaluations of augmented UCL repair have also shown laboratory similarities between the procedure when compared with UCL reconstruction. Dugas et al[14] evaluated time-zero mechanics and load to failure in matched pairs of elbows after performing repair or reconstruction of the UCL. Greater resistance to time-zero gap formation of the elbow joint was demonstrated in the repair group as compared with the reconstruction group. Also, no significant difference was found in ultimate failure load between the groups. Similarly, Jones et al[22] evaluated UCL repair versus reconstruction in the setting of fatigue loading conditions. The authors reported greater resistance to gap formation in UCL repair specimens under repair conditions as well as no difference in time-zero failure properties between UCL repair and UCL reconstruction; however, differences in gap formation were also seen in the torn state. These 2 previous biomechanical studies used a torque-control loading protocol, whereas the current study used torsional angle control. This deviation in test methodology was made due to inherent differences in measured outcomes. The previous studies measured gap formation by applying a prescribed cyclic torque and measuring the resulting angle and joint gap. The current study was focused on determining torque and joint contact rather than applying them and hence applied a torsional angle, while measuring the resulting joint torque and contact values.

UCL repair has historically demonstrated poor outcomes, particularly in elite baseball pitchers.[2,4,9] Norwood et al[27] was the first to report outcomes of UCL repair in 1981, with 2 of 4 patients having no residual instability after 2 years; however, these patients were not elite overhead athletes. Later, Conway reported on a series of 14 UCL repairs in overhead athletes, in which only 50% were able to return to previous levels of activity. Specifically, 71% of the nonprofessional athletes and only 29% of the professional athletes were able to return to play.[9] Azar et al[4] reported 59 UCL reconstructions and 8 UCL repairs in male collegiate and professional baseball players. In this cohort, 81% of the reconstruction group returned to a previous level or higher level, whereas only 63% of the repair group returned to a similar level of play.

Accordingly, UCL reconstruction has been widely considered the gold standard for UCL injuries, especially in chronic, symptomatic UCL insufficiency seen in overhead throwers. In this setting, repetitive microtrauma to the ligament occurs as a high-level thrower endures near-failure levels of stress across the elbow joint, which attenuates the UCL in both quality and function.[9,32] UCL reconstruction is the treatment of choice for these patients and has demonstrated excellent results with high rates of return to play.[6,10,11,23,28]

However, more recent outcomes of UCL injuries in athletes with end-avulsions of the ligament or of higher UCL tissue quality may be amenable to UCL repair. Savoie et al,[31] in 2008, reported a repair technique for UCL avulsions performed in proximal or distal UCL avulsion injuries in young throwing athletes (mean age, 17 years). In this series, the authors reported 58 of 60 athletes returned to sport at the same level or higher within 6 months. Richard et al[30] also reported outcomes of direct repair of acute, humeral-sided UCL repaired with bone tunnels or suture anchors at a mean of 20 days from injury. Of the 11 patients, 9 reportedly returned to collegiate athletics by 6 months. Argo et al[3] similarly reported outcomes of female overhead athletes (mean age, 22 years), in which 17 of 18 patients returned to sport at a mean 2.5 months.

Most recently, our institution reported a rate of return to play at 92% (102/111 athletes) at a mean of 6.7 months performing the UCL repair protocol previously described and utilized in the present biomechanical study.[23-26] KJOC scores were also a mean of 88.2 at 2 years. In this series, patients were excluded if tissue quality was deemed unsuitable for repair, such as having UCL intrasubstance degeneration or insufficiency.[12] In that regard, it seems that with proper patient selection and favorable UCL quality, direct UCL repair remains a viable option for young athletes with acute tear of the UCL.

Given the recent rise in acute UCL injuries in youth, adolescent, and high school throwing athletes, we may begin to see more acute UCL injuries, as opposed to the typical, chronic ligament changes, sustained over a career of throwing. If the ligament injury is an end avulsion of the UCL, or the ligament lacks degenerative qualities, it may be amenable to repair and, therefore, a more rapid recovery.

Further, the repair construct described in this study may allow for faster return to play, as it demonstrates superior resistance to gap formation at time-zero and under fatigue conditions from a biomechanical standpoint.[23,24] This, in turn, may allow the native ligament to heal without excessive stretch under valgus loads. While this has not been proven clinically, Dugas et al[12] reported a substantially shorter time to return to play (mean, 6.7 months) compared with typical UCL reconstruction, which can be 12 months or greater.[6,25]

The current study has several limitations. First, the amount of tension placed on the graft (during either procedure) can be dependent on the technique and consistency of the surgeon. For this reason, we designed our study such that a single surgeon (T.S.R.) conducted all repairs and reconstructions, with care being taken to rigorously follow the same firmly established procedure,[12,14,22,26] which provides repeatability measures for InternalBrace tensioning. Second, our testing focused on a single flexion angle rather than an arc of angles throughout the normal range of motion. An elbow flexion angle of 90° was chosen to maintain consistency with previous studies[14,22] as well as to mimic as closely as possible the angle most similar to that of overhead throwers during arm cocking and early arm acceleration. A flexion angle of 90° is also the angle at which the repair is held during the earliest stages of postoperative recovery and is the central degree around which the therapy arc is restricted during initial physical therapy. Further, the use of cadaveric, rather than live, tissue eliminates potential biologically important factors in UCL surgery such as graft tissue healing to bone or graft incorporation with native tissue. It may be worth noting, however, that the collagen-coated nature of the InternalBrace construct may help augment incorporation into the native tissue in a true biologic (ie, noncadaveric) setting. Also, performing these procedures in cadaveric specimens in a laboratory, rather than operating room setting, may have limitations that are difficult to account for in the study. Finally, recovery from UCL surgery, repair or reconstruction, is a lengthy rehabilitation process that cannot be replicated in a laboratory setting.

Conversely, this cadaveric study had several strengths. Specimens utilized in this study were of a mean age of 41 ± 11 years (range, 19-49 years) and paired specimens, which ensured the quality of the tissue being studied. The authors had no failures of specimens due to poor tissue or bone quality nor any technical complications such as anchor pull-out. While this is not the first study to evaluate elbow contact pressure, it is the first we are aware of to evaluate ulnohumeral joint pressure before and after UCL repair and reconstruction, particularly with the use of Tekscan sensor technology. Bellato et al[5] previously demonstrated a reduction of the contact area and increased contact pressure between the coronoid and trochlea of the elbow after posteromedial rotatory instability injury of the elbow, a similar utilization of Tekscan technology.

Cadaveric studies have demonstrated similarities in biomechanical performance between UCL reconstruction and repair, as well as comparable and sound biomechanical strength[14,22,26]; however, future clinical outcomes will likely address questions not answered in these studies, such as procedure durability, need for revision, and complications. As this is a relatively new procedure, current outcomes in the literature are limited but have demonstrated the ability to undergo early rehabilitation, accelerated return to play compared with UCL reconstruction, and favorable rates of return to play.[12,33] In our experience, revision procedures have not posed a major challenge. This may be because we use a polyetheretherketone polymer anchor to minimize cyst formation, tunnel expansion, or osteolysis, while permitting anchor removal in a revision setting. Also, this anchor permits advanced imaging of the ligament at a later time without artifact. Last, the anchors are 3.5 mm in diameter, which is similar to the size of the tunnels drilled in UCL reconstruction. Thus, bone tunnels in a revision setting can be incorporated without sacrificing strength of the construct and without the concern for lytic or weakened bone around the tunnels.

## CONCLUSION

This study demonstrated that UCL repair with InternalBrace augmentation did not overconstrain the ulnohumeral joint, as both UCL repair and UCL reconstruction led to similar elbow articular contact pressures as compared with the native joint. Both UCL repair and reconstruction also restored elbow joint torque and stiffness to levels not statistically different from the intact state. Augmented UCL repair, however, tended to restore joint torque more closely to the intact state than did reconstruction.

## REFERENCES


1. Andrews JR, Jost PW, Cain EL. The ulnar collateral ligament procedure revisited: the procedure we use. *Sports Health*. 2012;4(5):438-441.
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. 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.
5. Bellato E, Fitzsimmons JS, Kim Y, et al. Articular contact area and pressure in posteromedial rotatory instability of the elbow. *J Bone Joint Surg Am*. 2018;100(6):e34.
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. Camp CL, Bernard C, Benavitz B, et al. Reconstruction of the medial ulnar collateral ligament of the elbow: biomechanical comparison of a novel anatomic technique to the docking technique. *Orthop J Sports Med*. 2019;7(7):2325967119857592.
8. Chang ES, Dodson CC, Ciccotti MG. Comparison of surgical techniques for ulnar collateral ligament reconstruction in overhead athletes. *J Am Acad Orthop Surg*. 2016;24(3):135-149.
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(12):2039-2044.
11. Dodson CC, Thomas A, Dines JS, et al. Medial ulnar collateral ligament reconstruction of the elbow in throwing athletes. *Am J Sports Med*. 2006;34(12):1926-1932.
12. Dugas JR, Looze CA, Capogna B, et al. Ulnar collateral ligament repair with collagen-dipped FiberTape augmentation in overhead-throwing athletes. *Am J Sports Med*. 2019;47(5):1096-1102.
13. 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.
14. Dugas JR, Walters BL, Beason DP, Fleisig GS, Chronister JE. Biomechanical comparison of ulnar collateral ligament repair with internal bracing versus modified Jobe reconstruction. *Am J Sports Med*. 2016;44(3):735-741.
15. Erickson BJ, Nwachukwu BU, Rosas S, et al. Trends in medial ulnar collateral ligament reconstruction in the United States: a retrospective review of a large private-payer database from 2007 to 2011. *Am J Sports Med*. 2015;43(7):1770-1774.
16. Fleisig GS, Andrews JR. Prevention of elbow injuries in youth baseball pitchers. *Sports Health*. 2012;4(5):419-424.
17. Fortenbaugh D, Fleisig GS, Andrews JR. Baseball pitching biomechanics in relation to injury risk and performance. *Sports Health*. 2009;1(4):314-320.
18. Griffith TB, Ahmad CS, Gorroochurn P, et al. Comparison of outcomes based on graft type and tunnel configuration for primary ulnar collateral ligament reconstruction in professional baseball pitchers. *Am J Sports Med*. 2019;47(5):1103-1110.
19. Hodgins JL, Vitale M, Arons RR, Ahmad CS. Epidemiology of medial ulnar collateral ligament reconstruction: a 10-year study in New York state. *Am J Sports Med*. 2016;44(3):729-734.
20. Hurwit DJ, Garcia GH, Liu J, et al. Management of ulnar collateral ligament injury in throwing athletes: a survey of the American Shoulder and Elbow Surgeons. *J Shoulder Elbow Surg*. 2017;26(11): 2023-2028.
21. Jobe FW, Stark H, Lombardo SJ. Reconstruction of the ulnar collateral ligament in athletes. *J Bone Joint Surg Am*. 1986;68(8): 1158-1163.
22. Jones CM, Beason DP, Dugas JR. Ulnar collateral ligament reconstruction versus repair with internal bracing: comparison of cyclic fatigue mechanics. *Orthop J Sports Med*. 2018;6(2): 2325967118755991.
23. Koh JL, Schafer MF, Keuter G, Hsu JE. Ulnar collateral ligament reconstruction in elite throwing athletes. *Arthroscopy*. 2006;22(11): 1187-1191.
24. Leland DP, Conte S, Flynn N, et al. Prevalence of medial ulnar collateral ligament surgery in 6135 current professional baseball players: a 2018 update. *Orthop J Sports Med*. 2019;7(9):2325967119871442.
25. Makhni EC, Lee RW, Morrow ZS, et al. Performance, return to competition, and reinjury after Tommy John surgery in Major League Baseball pitchers: a review of 147 cases. *Am J Sports Med*. 2014; 42(6):1323-1332.
26. Moore AR, Fleisig GS, Dugas JR. Ulnar collateral ligament repair. *Orthop Clin North Am*. 2019;50(3):383-389.
27. Norwood LA, Shook JA, Andrews JR. Acute medial elbow ruptures. *Am J Sports Med*. 1981;9(1):16-19.
28. Paletta GA, Wright RW. The modified docking procedure for elbow ulnar collateral ligament reconstruction: 2-year follow-up in elite throwers. *Am J Sports Med*. 2006;34(10):1594-1598.
29. 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*. 2004;32(5):1158-1164.
30. Richard MJ, Aldridge JM, Wiesler ER, Ruch DS. Traumatic valgus instability of the elbow: pathoanatomy and results of direct repair. *J Bone Joint Surg Am*. 2008;90(11):2416-2422.
31. 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.
32. Wilson FD, Andrews JR, Blackburn TA, McCluskey G. Valgus extension overload in the pitching elbow. *Am J Sports Med*. 1983;11(2): 83-88.
33. Wilson WT, Hopper GP, Byrne PA, MacKay GM. Repair of the ulnar collateral ligament of the elbow with internal brace augmentation: a 5-year follow-up. *BMJ Case Rep*. 2018;11(1):e227113.