Ulnar Collateral Ligament Reconstruction Versus Repair With Internal Bracing

Comparison of Cyclic Fatigue Mechanics

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Background: Ulnar collateral ligament (UCL) injuries have increased significantly in recent years, and reconstruction has become the preferred treatment for UCL injury over ligament repair. In a recent study, UCL repair with internal bracing demonstrated significantly greater resistance to gap formation in biomechanical tests, even at low cycles of valgus loading.

Purpose/Hypothesis: The purpose of this study was to compare the fatigue and failure mechanics of traditional UCL reconstruction with UCL repair and internal bracing. We hypothesized that repaired specimens would have less gap formation, closer return to native gap formation, and greater maximum torque to failure versus traditionally reconstructed specimens.

Study Design: Controlled laboratory study.

Methods: Ten matched pairs of cadaveric elbows were positioned at 90° of flexion and the native UCL subjected to 500 cycles of subfailure valgus loading. A simulated tear was created, and the 10 cycles were repeated. Each pair of specimens was next given repair with internal bracing on 1 side and a modified Jobe reconstruction on the contralateral side, followed by 100 manual cycles of flexion-extension, 500 cycles of valgus rotation, and, finally, rotation to failure.

Results: The specimens that received the repair unexpectedly experienced significantly less gapping in the torn state than did those in the reconstruction group. At the 10th cycle, repaired UCL injuries had significantly less gap formation than the reconstructed UCLs. At the 100th and 500th cycles, repaired UCL injuries continued to experience significantly less gap formation as compared with the reconstructed injuries.

Conclusion: When compared with the gold standard reconstruction technique, UCL repair with internal bracing is more resistant to gap formation under fatigue loading. However, the unexpected early difference between the torn states may have confounded this finding. Time-zero failure properties of this repair technique are on par with those of traditional reconstruction, even after 500 cycles of valgus loading.

Clinical Relevance: UCL reconstruction has become a common procedure among adolescent and elite-level throwers. Recent data suggest that UCL repair may be a viable option for younger athletes with acute proximal or distal UCL tears, allowing a faster return to play.

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

Over the past 15 years, ulnar collateral ligament (UCL) reconstruction has become a common procedure among adolescent and elite-level athletes.[4,11,16,21] Recent reports suggested that UCL injuries have increased significantly in recent years, particularly for young throwers (<19 years old).[4,11,12,15,16] Biomechanically, the anterior band of the UCL approaches its tensile strength in overhead throwing, as it is the primary restraint to valgus force at the elbow.[13,14] Since first reported by Jobe et al[18] in 1986, UCL reconstruction with a palmaris longus graft has become the preferred treatment for UCL injury among elite throwers desiring a return to throwing. Conversely, primary ligament repair had been largely abandoned, as historical

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attempts at UCL repair demonstrated poor results among professional pitchers, with 0% to 63% rates of return to the same or higher level of pitching.[1,3,7,18,20]

In the setting of acute proximal or distal UCL injury in a biomechanically stable joint, UCL repair may be a viable option. Recent data suggest renewed and successful interest in direct suture repair of the UCL for young athletes with acute proximal or distal tears.[2,22,24] Dugas et al[9] recently introduced a novel ligament repair technique intended to restore valgus stability, decrease soft tissue dissection, preserve bone, and allow a faster return to play. This construct consists of UCL repair, augmented with a spanning tape anchored at either end of the native insertion of the anterior band of the UCL (Internal Brace; Arthrex Inc). Compared with UCL reconstruction with a modified Jobe technique, biomechanical testing of this construct demonstrated significantly greater resistance to gap formation, even at low cycles of valgus loading.[9]

The purpose of this study was to compare the high-cycle fatigue and failure mechanics of this technique of augmented UCL repair with a typical modified Jobe UCL reconstruction technique. We hypothesized the following: (1) the repaired specimens would have less gap formation after 500 cycles and a higher maximum torque to failure when 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 native values.

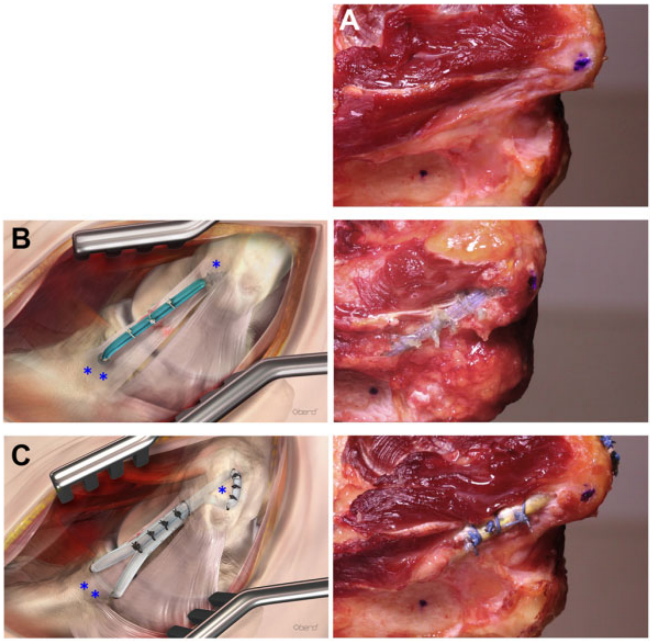

Figure 1. Artistic rendering (left) and cadaveric specimen (right): (A) intact native UCL, (B) UCL repair with internal brace, and (C) UCL reconstruction. Artistic rendering reprinted with permission from Dugas et al.[9] Anatomic landmarks: *proximal insertion onto the medial epicondyle; **distal insertion onto the sublime tubercle. UCL, ulnar collateral ligament.

METHODS

Specimen Preparation

Twenty fresh-frozen cadaveric upper extremities (10 matched pairs; 7 male, 3 female; mean age, 75 years; range, 46-91) were procured (Science Care) and stored at –20°C and thawed overnight at room temperature. If present, the palmaris longus was harvested and kept in saline for later use in reconstruction; if no palmaris was present, one from the repair limb of another specimen pair was utilized. Each specimen was dissected to expose the anterior band of the UCL. A medial incision was made just posterior to the medial epicondyle. The ulnar nerve was identified and transposed anteriorly. With a muscle-elevating approach,[3] the sublime tubercle was identified, and the flexor pronator muscle belly was dissected anteriorly off the tubercle to expose the anterior band of the UCL.

The flexor pronator origin and all ligamentous and capsular tissues were preserved. The humerus and forearm were then transected at the mid-diaphysis and potted in polymethyl methacrylate in acrylic pipe. On the dissected specimen, the humeral and ulnar insertions of the UCL were identified as previously described and marked with a fine-tipped surgical marker.[8] The positions of these markers were used for measurement of ligament displacement (Figure 1A).

Biomechanical Testing

Each specimen was mounted on an axial-torsional materials testing machine (MTS 858 MiniBionix II; MTS Systems) in a custom jig with the humerus positioned vertically and fixed in line with the test frame actuator. The elbow was positioned at 90° of flexion, and the forearm was mounted to the stationary base plate (Figure 2).[5,6,9,19,23] A 2-N·m valgus preload was applied to the native elbow, followed by a 60-second hold and then 500 cycles of valgus loading between 2 and 10 N·m.

A longitudinal split in the anterior band was then created to assess the ligament tissue quality and inspect the ligament for injury. The distal attachment of the UCL at the sublime tubercle was released with sharp dissection, simulating a distal avulsion tear of the UCL. Ten cycles were repeated in this torn state. Each pair of specimens was next randomly separated into either a repair group or a reconstruction group.

Ligament Repair

One limb from each pair was randomized with respect to side and underwent a repair technique published previously.[9] The distal anchor was placed first, at the apex of the sublime tubercle. A 2.7-mm drill bit was used to establish this hole, which was tapped with a 3.5-mm tap prior to placement of a 3.5-mm knotless SwiveLock (Arthrex Inc) suture anchor. This initial anchor was preloaded with a 2-mm collagen-coated FiberTape (Arthrex Inc) and a No. 0 nonabsorbable braided suture prior to final placement. The free ends of the No. 0 suture were passed through the ends of the detached UCL and tied down,

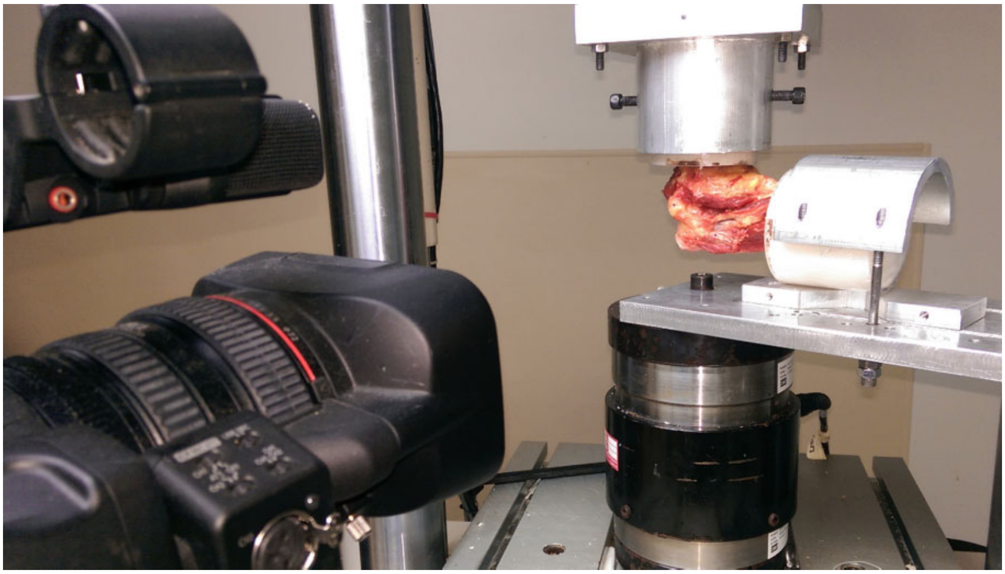

Figure 2. Biomechanical testing setup.

repairing the UCL to its native insertion site.[8] The native ligament was then repaired side to side with 3 simple No. 2-0 sutures. Next, the proximal anchor was placed after a 2.7-mm drill bit and 3.5-mm tap were inserted at the native insertion of the anterior band on the medial epicondyle. The free ends of the collagen-coated FiberTape were loaded into a 3.5-mm knotless SwiveLock. While the joint was reduced with a slight varus force at 20° of flexion, the SwiveLock was advanced such that the tension of the tape did not overtension the underlying native ligament. Three additional No. 0 absorbable sutures were passed around the native ligament and FiberTape to incorporate them (Figure 1B). The specimen was then mounted on the MTS machine for testing (Figure 2).

Ligament Reconstruction

On each contralateral limb, UCL reconstruction with a palmaris longus graft was performed. The previously harvested graft tendon ends were then whipstitched with No. 2 absorbable sutures. Two converging 3.5-mm tunnels were positioned 1 cm apart at the anterior and posterior aspects of the sublime tubercle, 5 mm from the joint line. Next, two 3.5-mm tunnels were placed in the medial epicondyle. One of these anchors was positioned at the native insertion of the anterior band and exited the humerus on the posterior side of the medial ridge. The second medial epicondyle tunnel was placed a minimum 1 cm from the exit point on the humerus of the first tunnel. Straight curettes were used to connect the 2 tunnels. The native ligament was repaired end to end in the same fashion as on the repair limb. Next, a Hewson suture passer was used to shuttle the graft through the ulnar tunnels. The limb that exited from the anterior ulnar tunnel was shuttled out through the distal medial epicondyle hole and pulled out the second tunnel. The posterior limb was shuttled into the distal entrance of the epicondylar tunnel and pulled out into the more proximal exiting hole (first tunnel). Similar to the repair limb, 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 five No. 2 mattress sutures were placed to secure the limbs over the medial epicondyle. Three additional No. 0 absorbable figure-of-8 sutures were placed through the graft and native ligament to incorporate them (Figure 1C).

Range-of-Motion Simulation and Specimen Testing

After the respective procedures were performed, each specimen was manually subjected to 100 cycles of flexion-extension range of motion to represent a simplified full range-of-motion protocol that might occur during postoperative rehabilitation. After being placed back into the test frame, the specimen was again loaded in valgus rotation for 500 cycles between 2 and 10 N·m,[9] followed by a ramp to failure at a rate of 1° per second of valgus rotation. Valgus torque, valgus rotation, and the method and location of failure were recorded. Failure was defined as mechanical failure of the system.

Additionally, gap formation measurements were taken for the 10th cycle of all conditions as well as for the 100th and 500th cycles of the intact and repair/reconstruction conditions. Gap formation was measured optically[9] as the change in distance of the 2 anatomic landmarks between the precycling hold and the peak of the cycle of interest (ie, 10th, 100th, or 500th).

Data Analysis

A 2-way analysis of variance (ANOVA) with repeated measures was employed to detect overall differences in gap

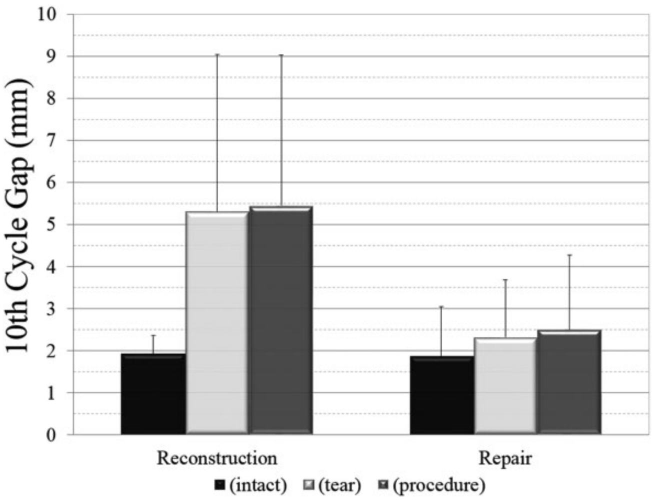

Figure 3. Gap formation after 10 cycles. After 10 cycles, ulnar collateral ligament repair demonstrated significantly less ($P = .008$) gap formation than reconstruction. Values are presented as mean ± SD.

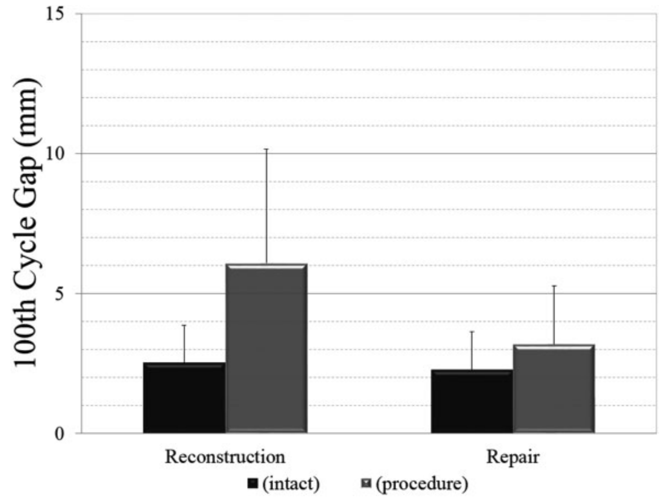

Figure 4. After 100 cycles, repaired ulnar collateral ligament injuries had significantly less ($P = .02$) gap formation than those with reconstruction. Values are presented as mean ± SD.

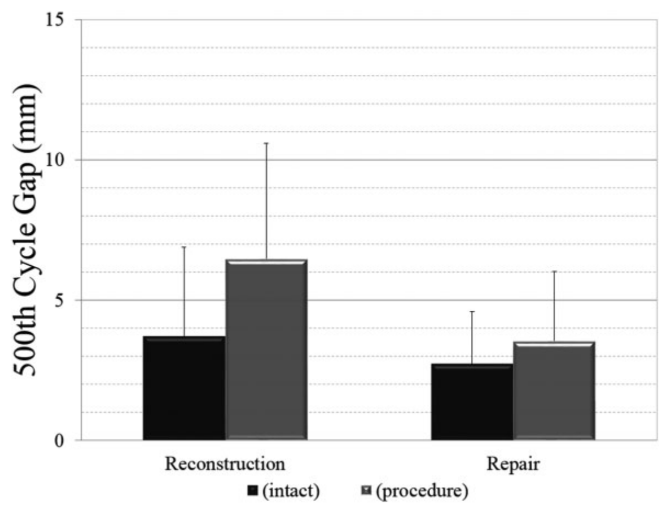

Figure 5. After 500 cycles, repaired ulnar collateral ligament injuries had significantly less ($P = .004$) gap formation than those with reconstruction. Values are presented as mean ± SD.

formation for the intact, torn, and surgical conditions. Post hoc comparisons were made between the procedures (post hoc Student *t* test) as well as among the 3 surgical conditions (Tukey honest significant difference). Significance was set at $P \leq .05$.

RESULTS

In the early stages (at the 10th cycle), there was a significant effect of the presence of injury ($P = .002$) as well as the type of corrective procedure ($P < .0001$) on gap formation. The interaction of these 2 effects was also significant ($P = .02$). Specifically, repaired UCL injuries had significantly less ($P = .008$) gap formation than the reconstructed group (mean ± SD 2.51 ± 1.77 vs 5.45 ± 3.58 mm, respectively), as shown in Figure 3. As compared with the reconstruction group, the specimens that received the repair also unexpectedly experienced significantly less ($P = .007$) gapping in the torn state. There was no difference ($P > .999$) in gap formation for the same specimens in their intact state (1.86 ± 1.19 for the repair group vs 1.92 ± 0.46 mm for the reconstruction group).

At the 100th cycle, there was a significant effect of the presence of injury ($P = .008$) as well as the type of corrective procedure ($P = .03$) on gap formation. The interaction of these 2 effects was not significant ($P = .06$). Specifically, repaired UCL injuries had significantly less ($P = .02$) gap formation than reconstructed UCLs (3.20 ± 2.08 vs 6.09 ± 4.06 mm, respectively), as shown in Figure 4. There was no difference ($P > .999$) in gap formation for the same specimens in their intact state (2.27 ± 1.36 for the repair group vs 2.51 ± 1.36 mm for the reconstruction group).

By the 500th cycle, there was a significant effect of the presence of injury ($P = .006$) as well as the type of corrective procedure ($P = .001$) on gap formation. The interaction of these 2 effects was not significant ($P = .08$). Specifically, repaired UCL injuries had significantly less ($P = .004$) gap formation than reconstructed UCLs (3.54 ± 2.48 vs 6.48 ± 4.11 mm, respectively), as shown in Figure 5. There was no significant difference ($P = .6$) in gap formation for the same specimens in their intact state (2.71 ± 1.88 for the repair group vs 3.70 ± 3.19 mm for the reconstructed group).

There were no statistically significant differences observed between reconstruction and repair with respect to gap formation at failure ($P = .265$), failure torque ($P = .403$), or torsional stiffness ($P = .162$). Modes of failure for the repaired elbows were ulnar screw pullout (6 of 10), ulnar bone tunnel failure (3 of 10), and humerus fracture (1 of 10). One of our repair samples underwent transligamentous failure during testing of the intact ligament, likely because of poor tissue quality, and was determined to be inadequate for repair. Modes of failure for the reconstructed elbows included ulnar tunnel fracture (7 of 10), humeral tunnel fracture (1 of 10), supracondylar distal humerus fracture (1 of 10), and graft failure at the humeral tunnel (1 of 10). One of our reconstruction samples failed during testing of the intact ligament and was determined to be inadequate for reconstruction.

DISCUSSION

As expected, on the basis of our first hypothesis, this cadaveric study showed that UCL repair with internal bracing was more resistant to gap formation under fatigue loading than the gold standard reconstruction technique; however, contrary to our second hypothesis, gap formation in the injured state at 10 cycles significantly increased for only the reconstruction group rather than both groups. The study also confirmed that the time-zero failure properties of this repair technique are on par with those of traditional reconstruction. In a previous study, this novel repair technique replicated the time-zero failure strength of traditional graft reconstruction and appeared to be more resistant to gapping at low cyclic loads[9]; however, the present study may more closely replicate the long-term stressors of return to play by analyzing fatigue loading properties. In addition, to our knowledge, the simulated rehabilitation protocol utilized in this study is the first attempt of its kind to establish the biomechanical properties for UCL reconstruction and repair at the time when the athlete would have returned to play.[26,27] As this is a cadaveric investigation, the simulated rehabilitation protocol did not include any biological processes (eg, inflammation, cellular responses) involved in actual injury healing and rehabilitation.

Early reports on UCL repair demonstrated poor results when compared with reconstructive methods, particularly for high-level baseball pitchers.[1,3,7] UCL repair was first reported in 1981 by Norwood et al,[20] in a study in which 2 of 4 patients had no residual instability at 2 years after surgical repair; however, none of the patients were high-level overhead athletes. Conway et al[7] reported on 14 repairs among overhead athletes, with 50% of patients able to return to their previous levels of activity. A deeper examination of their data set revealed that only 2 of 7 (29%) professional athletes returned, whereas 5 of 7 (71%) nonprofessional athletes returned. Azar et al[3] reported on 59 reconstructions and 8 repairs on male collegiate and professional baseball players; 81% of the reconstruction group returned to a previous level or higher, whereas only 63% of the repair group returned to a similar level of play.

Given historically high rates of failure for UCL repair, UCL reconstruction is still widely considered the gold standard surgical procedure for chronic symptomatic UCL instability for overhead athletes. Over a career of throwing, the elbow of a high-level player endures repetitive near-failure stresses that may cause UCL microtrauma, microinstability, and eventually complete failure of UCL attenuation.[7,27] Full reconstruction with graft augmentation to replace poor-quality ligament tissue is necessary in these cases, and we do not recommend UCL repair for these athletes.[7,18]

With the recent rise in acute UCL injuries documented for youth, adolescent, and high school throwing athletes, one may expect to see more acute UCL injuries without chronic ligament changes over a career of throwing. If the injury is isolated to the proximal or distal insertion area of the UCL, the ligament and remainder of the joint should be amenable to repair and rapid recovery. Additionally, the repair construct presented here and elsewhere[9] may allow for faster return to play, as it demonstrates superior resistance to gap formation, allowing the native ligament to heal without excessive stretch under valgus loads; however, this has yet to be determined with supporting clinical data.

Recent studies suggest renewed interest in UCL repair for younger athletes. Savoie et al[24] reported on the repair of proximal and distal UCL avulsion injuries in young throwing athletes (mean age, 17 years). These were repaired with suture through bone tunnels or to single-suture anchors, and the authors reported that 58 of 60 athletes returned to sport at the same level or higher within 6 months. Richard et al[22] reported on the direct repair of acute UCL ruptures from the humerus with bone tunnels or single-suture anchors at a mean of 20 days from injury. All of their patients also required suture repair of flexor-pronation mass avulsion at the time of surgery. Of the 11 patients, 9 returned to collegiate athletics by 6 months. Argo et al[2] reported their findings on female overhead athletes (mean age, 22 years), where all but 1 of 18 patients returned to sport at a mean 2.5 months. It appears that with proper evaluation and patient choice, direct UCL repair remains a viable option for young athletes with acute tear of the UCL. A biomechanically stable repair construct may make it possible to decrease rehabilitation time and allow for faster return to play compared with traditional UCL reconstruction, which carries a nearly 12-month period before return to play.

This study has several limitations that are inherent to cadaveric investigations, including our specimen age and sample size. Our mean specimen age is not representative of the athletes who typically undergo this procedure. This could have led to early failure attributed to bone quality, as shown with our most common modes of failure, which included humeral-sided fracture and ulnar bone tunnel failure. Inconsistent bone quality may have contributed some level of variability to our findings. Our attempt to replicate a true clinical distal-sided tear by elevating the UCL off the sublime tubercle to mimic a "T-sign"[25] 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. We chose to remove the ligament from its native distal insertion at the sublime tubercle as a means to replicate a distal UCL tear that would be amenable to repair. This also may have contributed to the unexpected finding of a difference between the torn states of the 2 groups.

The cyclic gapping data presented here confirm previously reported findings—that this UCL repair technique undergoes significantly less gap formation versus a traditional UCL reconstruction.[9] One potential confounding factor, however, is that a similar difference was noted in the torn condition at 10 cycles. This finding was unexpected and did not reflect a difference in the tear creation technique between groups. Measurements of the torn condition were made at 10 cycles only (ie, not at 100 or 500) to allow for comparison with previous work, which completed a maximum of 10 cycles prior to loading to failure. The difference in the torn condition at 10 cycles was not seen in the cited study.[9]

Perhaps the most important and clinically relevant finding of the present study is that resistance to gapping was maintained at higher loading cycles for this repair technique; that is, as compared with the gold standard reconstruction technique, the repair technique sustains its biomechanical properties to a superior extent under fatigue loading. One may extrapolate these findings clinically to their effect on postoperative rehabilitation protocols. Specifically, these results support the notion that an accelerated physical therapy protocol can be reasonably carried out after our repair procedure, allowing a significantly faster return to throwing without compromising the integrity of the repair.

Previous authors have demonstrated joint laxity and adaptive morphologic characteristics in the UCL of asymptomatic overhead athletes.[10,17] In these cases, however, such adaptive changes are likely secondary to chronic microinstability that occurs over a career of throwing; that is, they are not secondary to acute UCL injury. In the setting of acute UCL injury, the presence of gap formation may be more significant because it may lead to incomplete healing. Our biomechanical testing setup simulated early load-bearing conditions, similar to those in the early stages of a postoperative rehabilitation program.[27] In such early stages of the postoperative protocol, cyclic load is low as compared with the stressors that the UCL resists during the throwing motion, which occurs much later in the rehabilitation process.

Future clinical work with this repair technique may strengthen our findings. Because many of the patients for whom repair is indicated will go on to participate in their sports at similar or higher levels of competition, information related to outcomes would be useful, including return to sport, performance, symptoms, and failures. Currently, this procedure is used at our institution, and clinical outcome studies are underway. Should it become necessary, this technique lends itself to an easy revision procedure for several reasons. First, we use a biostable polyetheretherketone (PEEK) polymer anchor to minimize cyst formation, tunnel expansion, and/or osteolysis in bone while permitting anchor removal in a revision setting. Second, this anchor permits advanced imaging of the ligament at a later time without artifact. Third, the size of the anchor is 3.5 mm in diameter, similar to the size of a tunnel used 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 shows that UCL repair with internal bracing is more resistant to gap formation under fatigue loading than the gold standard UCL reconstruction technique; however, it is unknown to what degree the unexpected early difference seen between the torn states of the 2 groups might have affected this finding. It also confirms that the time-zero failure properties of this repair technique are on par with those of traditional reconstruction, even after high cycles of valgus loading. For some throwing athletes, particularly those who have high bone quality, this technique may provide a better outcome than standard UCL reconstruction.

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