Biomechanical Comparison of Ulnar Collateral Ligament Reconstruction With the Docking Technique Versus Repair With Internal Bracing

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Background: The modified Jobe technique of ulnar collateral ligament (UCL) reconstruction has previously been biomechanically compared with primary repair augmented with internal bracing. However, the docking technique has not been compared with repair with internal bracing.

Hypothesis: Load to failure, gapping, and valgus opening angle are similar under valgus loading at 90° of flexion between repair with internal bracing and the docking technique for the UCL.

Study Design: Controlled laboratory study.

Methods: Nine matched pairs of fresh-frozen cadaveric elbows were potted with the forearm in neutral rotation. The palmaris longus tendon graft was harvested, and the bone was sectioned 14 cm proximal and distal to the elbow joint. First, native UCL testing was performed at 90° of flexion with 0.5 N·m preload, followed by a 5 N·m valgus moment to the elbow in cycles of 1, 10, 100, and 1000 at 1 Hz. The specimens were then loaded to failure at a rate of 0.2 mm/s. Next, the elbows were randomly divided into matched pairs to undergo either UCL reconstruction with docking technique or UCL repair augmented with internal bracing. Last, these specimens underwent testing as aforementioned.

Results: Load to failure, gapping, and valgus opening angle did not differ significantly between native ligaments that underwent reconstruction or repair with internal bracing, paired native ligaments and reconstructions, paired native ligaments and repairs augmented with internal bracing, or reconstructions and repairs augmented with internal bracing.

Conclusion: UCL reconstruction with docking technique and repair augmented with internal bracing provides valgus stability to the medial elbow comparable to the native ligament at 90°. No significant differences were noted between docking reconstruction and repair techniques for load to failure, gapping, or valgus opening angle during cyclic loading at time zero.

Clinical Relevance: Our results suggest that UCL repair with internal bracing has a similar biomechanical profile at the time of initial fixation compared with the docking technique of UCL reconstruction.

Keywords: baseball; elbow; biomechanics; pediatric; ulnar collateral ligament

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Increased attention has been paid to elbow ulnar collateral ligament (UCL) injuries in throwing athletes in the past 2 decades,[35] with one institution noting a 22-fold increase in incidence from 1994 to 2010.[14] The injury classically afflicts baseball pitchers, because the ligament plays a crucial role in stabilizing the elbow throughout the throwing motion.[8] The incidence is especially on the rise in adolescents, likely as a result of early sport specialization and year-round throwing.[6,12,13,17,26,28] Although nonoperative management is an option, faster return to play makes operative care of UCL ruptures desirable for both patients and parents.[1,15,20,34]

In 1986, Jobe et al[16] described the first successful UCL reconstruction, which was in a Major League Baseball pitcher. The success of the Jobe technique compared with poor results of nonoperative management[7,11,30] and direct primary repair[2,3,10,12,16,25,30] resulted in a strong preference for reconstruction. Nevertheless, multiple authors raised concerns regarding difficulty in achieving optimal graft tension, risk of medial epicondyle fracture, and flexor-pronator origin detachment.[4,9,20,24,30] This led to the evolution of reconstruction methods, including a muscle-splitting or elevating modification of the Jobe technique,[3,33] abandonment of obligatory ulnar nerve transposition,[33] docking technique,[11,31] and

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interference screw technique.[1] Whereas Conway et al[10] reported a 68% rate of return to play with the Jobe technique, Cain et al[6] observed an 83% return to play with the American Sports Medicine Institute (ASMI) modified Jobe technique and a 20% rate of complications (mostly resolving neuropraxias). Lower rates of complications have been observed in reconstruction with the docking, modified docking, and interference screw fixation techniques.[36]

The rising incidence of UCL injuries in younger athletes has led to a renewed interest in UCL repair. Young patients typically lack the chronic degeneration and attritional wear that are found in older athletes, such that acute tears in young patients are potentially amenable to repair.[12,22,25] Savoie et al[32] reported on 60 young athletes who underwent primary UCL repair, and 97% returned to play within 6 months. However, these results were not replicated, with other studies demonstrating between 29% and 69% rates of return to play after isolated UCL repair.[6,10]

In an effort to improve on primary repair of the UCL, augmentation techniques were developed and first described by Walters et al.[34] Dugas et al[12] conducted a biomechanical study comparing primary UCL repair reinforced with an internal brace and modified Jobe reconstruction and found no significant difference in ultimate torque or gapping. Walters et al reported excellent results in 22 young athletes, with 92% and 96% returning to play at 6 and 12 months, respectively. Given these encouraging results, we sought to compare the biomechanics of internal bracing as described by Dugas et al with the docking technique used by Dodson and Altchek.[11,12] Several biomechanical studies have compared the performance of the alternative reconstructions with the Jobe technique, suggesting equal[9] if not superior[4] performance with the former. When novel approach to surgical UCL treatment is considered, a comparison of its performance to traditional reconstruction techniques is warranted. We hypothesized that no significant difference in load to failure, gapping, or valgus opening between docking and UCL repair with internal bracing would be demonstrated.

METHODS

Specimen Preparation

Nine matched pairs of fresh-frozen cadaveric elbows (18 elbows with mean ± standard deviation [SD] age of 62.9 ± 1.4 years, body mass index 23.8 ± 3.4; 4 males and 5 females) were procured and stored at –20°C. Specimens were thawed for 12 hours before being dissected free of all soft tissue except for the capsule and the medial and lateral ligament complexes. The palmaris longus tendon graft was harvested, and the bone was sectioned 14 cm proximal and distal to the elbow joint. The palmaris longus tendon was present in all specimens. Both ends were potted with rigid fixation in acrylic pipe with polymethylmethacrylate cement, with 90° of elbow flexion and the forearm in neutral rotation.

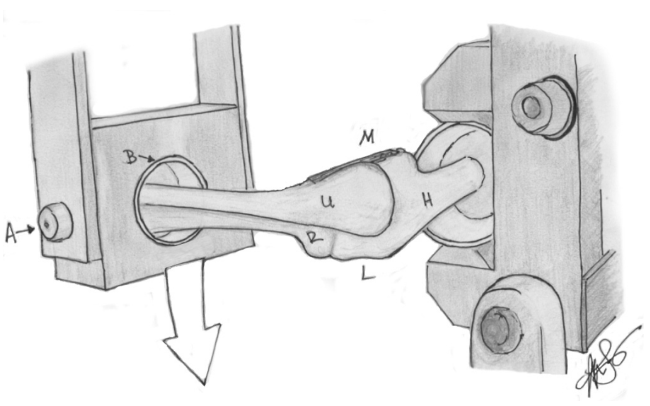

Figure 1. Materials testing system used in the study. The actuator applies a downward valgus load (arrow) to the potted radius (*R*) and ulna (*U*). The humerus (*H*) is also potted. The setup allows for rotation (*A*) and pistoning (*B*) to maintain a constant lever arm length. M, medial; L, lateral. Diagram courtesy of Austin M. Looney, MD.

Biomechanical Testing

Native UCL testing was performed with the same protocol used to test the reconstructions and repairs. Initial testing was performed at 90° of flexion and neutral rotation. The forearm was fixed on a materials testing system (MTS Bionix; MTS Systems), and the humerus was positioned parallel to the floor (Figure 1). A 0.5 N·m preload was applied, followed by a 5 N·m valgus moment to the elbow. This moment was applied in a cyclic fashion at 1 Hz for 1000 cycles. Actuator displacement and valgus angles at cycles 1, 10, 100, and 1000 were recorded. The specimens were then loaded to failure at a rate of 0.2 mm/s. Next, elbows were randomly divided with matched pairs to undergo either UCL reconstruction with docking technique or UCL repair augmented with internal bracing. The sutures and anchors described were donated by Arthrex Inc.

UCL Repair Technique

The repair procedure (Figure 2) was performed in the manner described by Dugas et al.[12] In brief, a 2.7-mm hole was

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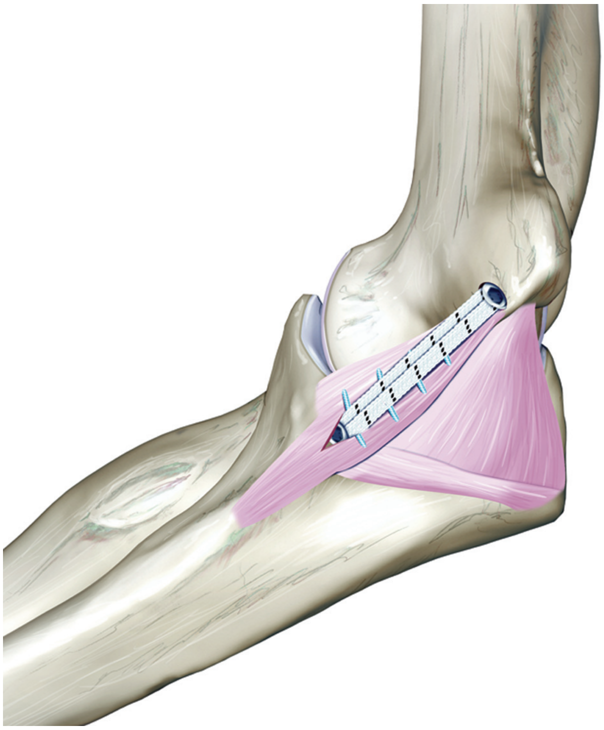

Figure 2. Ulnar collateral ligament repair with internal bracing. Figure reproduced and adapted with permission from Arthrex Inc.

drilled into the humerus and ulna: The humeral tunnel was centered at the native UCL footprint in a vector in line with the medial column and away from the articular surface of the ulna, and the ulnar tunnel was centered at the sublime tubercle apex in a vector approximately 60° radial to the ulnar shaft. The ulnar tunnel was tapped with a 3.5-mm tap, and then a 3.5-mm fully threaded, knotless suture anchor (SwiveLock; Arthrex Inc) loaded with a 2-mm suture tape (FiberTape; Arthrex Inc) and a No. 0 nonabsorbable suture was advanced into the hole. The tape was anchored within the tunnel at the center of the native UCL attachment, and the anchor was then advanced. The free ends of the No. 0 suture were passed through the ends of the UCL rupture, and the sutures were tied, repairing the native ligament to its insertion. The longitudinal division in the ligament was closed with three simple No. 2-0 sutures. After the humeral tunnel was tapped, the free ends of the suture tape were loaded into a second anchor. The joint was reduced with slight varus pressure at 20° of elbow flexion, and the anchor was advanced such that the tension of the tape was not greater than that of the underlying ligament. To prevent overtensioning of the construct, we inserted the anchor with the elbow in a slight varus stress as we would have for a reconstruction. We confirmed a tight fixation when the second anchor was placed but also made sure that the anchor placement did not cause the medial compartment to close anymore. Three additional No. 0 absorbable figure-of-8 sutures were passed around the ligament and the suture tape.

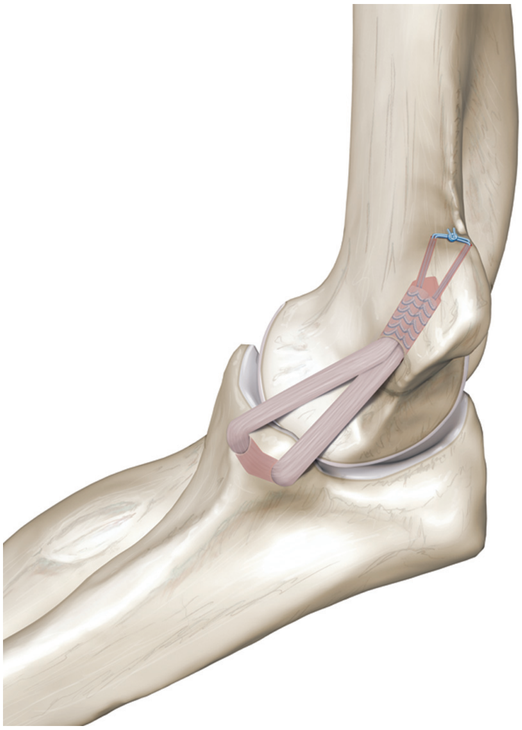

Figure 3. Docking technique for ulnar collateral ligament reconstruction. Figure reproduced and adapted with permission from Arthrex Inc.

UCL Docking Reconstruction Technique

Docking reconstruction was performed as initially described by Rohrbough et al[31] (Figure 3). In brief, a 3.0-mm drill was used to create holes on the anterior and posterior aspects of the sublime tubercle, connected by a 2-cm bone bridge. The holes were connected with a small curved curette. A 4.0-mm drill was used to create a tunnel of approximately 15 mm depth along the axis of the medial epicondyle. A 1.5-mm drill was then used to create 2 small holes on the anterior surface of the medial epicondyle at the end of the tunnel separated by a bone bridge of approximately 5 to 10 mm. One limb of the palmaris graft was whip-stitched with a No. 2 nonabsorbable suture (FiberWire; Arthrex Inc), and this end was passed through the ulnar tunnel and docked into the humeral tunnel with the suture ends exiting one of the two small 1.5-mm holes. With the elbow reduced and the forearm in maximum supination, graft tension was maintained while a gentle varus stress was applied and the elbow was ranged from flexion to extension repeatedly to reduce graft creep. Graft length was then determined by holding the free limb of the graft adjacent to the humeral tunnel with the elbow in roughly 30° of flexion and estimating the length needed to achieve appropriate graft tension without bottoming out in the tunnel. The free limb was marked and prepared with another No. 2 nonabsorbable suture, and excess tendon was removed. This limb was then docked in the humeral tunnel, and with the forearm maximally supinated and a gentle varus stress applied, the sutures were tied over the humeral bone bridge with

TABLE 1
Comparison of Gapping, Valgus Opening Angle, and Ultimate Load to Failure for NDR, NRIB, DR, and RIB[a]

	NDR	NRIB	DR	RIB	*P* Value	
					ANOVA	Welch
Gapping (mm)						
C1	1.74 ± 0.87 (1.08-2.41)	2.16 ± 0.82 (1.53-2.79)	2.30 ± 0.48 (1.93-2.67)	1.99 ± 0.91 (1.29-2.69)	.488	NS
C10	8.60 ± 3.76 (5.71-11.49)	7.93 ± 2.44 (6.06-9.81)	10.07 ± 4.61 (6.53-13.62)	8.89 ± 2.67 (6.83-10.94)	.625	.672
C100	11.38 ± 6.29 (6.54-16.21)	8.96 ± 2.74 (6.85-11.06)	13.03 ± 6.65 (7.92-18.14)	10.38 ± 3.18 (7.94-12.82)	.387	.356
C1000	14.17 ± 6.61 (9.08-19.25)	11.57 ± 4.36 (8.22-14.92)	16.64 ± 7.20 (11.11-22.18)	13.38 ± 4.76 (9.72-17.04)	.339	NS
Failure	50.94 ± 15.29 (39.19-39.29)	36.93 ± 16.65 (24.14-49.73)	47.87 ± 15.16 (36.21-59.52)	41.92 ± 11.50 (33.09-50.76)	.208	NS
Valgus Opening, deg						
C1	0.99 ± 0.51 (0.60-1.38)	1.29 ± 0.43 (0.96-1.62)	1.31 ± 0.28 (1.10-1.52)	1.14 ± 0.52 (0.74-1.54)	.397	NS
C10	4.90 ± 2.15 (3.25-6.55)	4.53 ± 1.37 (3.48-5.59)	5.76 ± 2.62 (3.74-7.77)	5.08 ± 1.52 (3.91-6.25)	.618	.664
C100	6.48 ± 3.53 (3.76-9.19)	5.09 ± 1.56 (3.89-6.29)	7.40 ± 3.72 (4.54-10.26)	5.92 ± 1.80 (4.54-7.31)	.380	.345
C1000	8.02 ± 3.67 (5.20-10.85)	6.61 ± 2.45 (4.73-8.50)	9.40 ± 3.99 (6.34-12.46)	7.61 ± 2.67 (5.55-9.66)	.351	NS
Failure	26.62 ± 7.05 (21.20-32.04)	19.87 ± 7.98 (13.73-26.00)	25.21 ± 6.92 (19.89-30.53)	22.55 ± 5.55 (18.29-26.82)	.193	NS
Load to Failure, N·m						
Failure	28.98 ± 10.02 (21.28-36.68)	29.54 ± 9.30 (22.40-36.69)	23.14 ± 9.05 (16.19-30.10)	23.28 ± 10.06 (15.55-31.01)	.328	NS

[a] Values are presented as mean ± standard deviation (95% confidence interval). The Levene test was significant for gapping and valgus opening for cycles 10 and 100. No significance was found with the Welch analysis of variance (ANOVA) for gapping or valgus opening for these cycles. C1, cycle 1; C10, cycle 10; C100, cycle 100; C1000, cycle 1000; DR, docking reconstructions; NDR, native docking reconstructions; NRIB, native repairs with internal bracing; NS, not significant; RIB, repairs with internal bracing.

the elbow in roughly 30°. Repaired and reconstructed specimens were potted and subjected to the same cycling and load to failure testing as performed with the native ligament specimens.

Statistical Analysis

Statistical data were analyzed with SPSS (SPSS Inc). Each variable was reported as the mean ± standard deviation. Values were compared by use of a 1-way analysis of variance (ANOVA). The Levene test was used to test for equality of variance. In the event of unequal variances, Welch ANOVA was used to compare samples. Last, in the event of significant differences among groups, a post hoc pairwise comparison was planned with the Fisher test of least significant difference (LSD). Significance was set at $p < .05$.

RESULTS

No significant differences were found among groups for gapping or valgus opening for any cycle. Additionally, no significant differences were noted among groups for ultimate load to failure. Since no significant differences were demonstrated, a post hoc LSD test was not performed. These findings are summarized in Table 1.

Four of the specimens repaired with internal bracing failed via pullout of the distal anchor. One specimen failed via proximal anchor pullout, and 2 specimens failed via suture pullout of the anchors (1 proximal, 1 distal). The remaining specimens failed via ulnar fracture at the distal anchor. In the docking group, there were 2 failures via fracture of the ulnar tunnel. There was 1 midsubstance tendon rupture. In the remaining specimens, failure occurred at the proximal suture-tendon interface.

DISCUSSION

We observed no significant differences in the performance of the UCL docking reconstruction and repair with internal bracing groups in terms of gapping, valgus angulation, or ultimate load to failure at the time of initial fixation. Previous biomechanical studies have evaluated performance of the Jobe technique at 30° to 120°[24] and graft fixation with interference screws at 70°[1] against the performance of intact ligaments. Additional studies have compared the docking technique with interference screw graft fixation at 70°,[20] the Jobe and docking techniques loaded from 30° to 110° and failure tested at 90°,[9] and the Jobe and docking techniques with interference screw and EndoButton graft fixation at 90°.[4] More recently, Dugas et al[12] examined the biomechanical performance of a repaired UCL augmented with internal bracing compared with a modified Jobe reconstruction. The investigators found no significant difference between constructs in average ultimate torque or gapping at 10 N·m. However, the repair group had significantly less gapping than the reconstruction group with small applied torque. We also found less gapping (and valgus opening angle) in the repair group, but these differences were not statistically significant. Based on these findings, UCL repair with internal bracing has been suggested as a potential alternative to reconstruction, particularly in younger athletes in whom UCL injuries typically do not have a chronic attritional component. Success has been reported with the technique in a small number of athletes.[34]

Because the docking technique is another commonly used method for UCL reconstruction,[1,4,9,11,20,24] we thought that comparison of the repair augmented with internal bracing versus the docking technique would contribute to the literature. Previous work found no difference in the biomechanical performance of Jobe and docking reconstructions[9]; therefore, we considered that examining UCL repair with internal bracing versus docking reconstruction offered a reasonable comparison to the Dugas et al[12] study. Notably, a comparison between the novel repair with internal bracing technique and the more commonly used docking reconstruction technique has not been performed, to our knowledge. Additionally, the repair with internal bracing technique was introduced by the same group that has reported data regarding the technique, and a secondary investigation would provide a means to corroborate their findings. In the Dugas et al study, the ligaments were sharply sectioned before repair or reconstruction, and the study was not designed to compare the performance of repair or reconstruction with the performance of native ligaments. We elected to subject the intact ligaments to the same tests as our repaired and reconstructed specimens, including loading to ligament failure. We thus were able to compare the performance of repaired and reconstructed specimens with the performance of the native ligaments on the same respective elbows. Here, too, we found no statistically significant difference in any of the measured parameters, although the native ligament had a higher ultimate load to failure.

The finding of no difference between repaired and reconstructed specimens and native ligaments has been reported in specimens reconstructed with palmaris autografts with the Jobe technique[24] and interference screw fixation.[1] In the study by Mullen et al,[24] both intact and reconstructed specimens were tested at 30°, 60°, 90°, and 120°. The only significant differences between intact and reconstructed specimens were observed at 120°. In that study, however, the UCL was sharply removed from all specimens before reconstruction, and load to failure parameters were not reported. In contrast, Ahmad et al[1] loaded 10 native specimens to failure, but the ligaments of reconstructed specimens were sharply removed. Presumably, this procedure eliminated the possibility that some remnant ligament would contribute to the strength of the reconstruction, thus isolating the construct for comparison with intact ligaments.

Other authors have reported inferior performance of reconstructed specimens relative to native UCLs.[4,9,20] McAdams et al[20] excised the native UCL after cycling elbows at 70° of flexion and did not load native ligaments to failure, but the investigators found significantly greater valgus angles in reconstructed specimens by the 1000th cycle compared with intact ligaments. Armstrong et al[4] sectioned the posterior UCL bundle and subsequently loaded the remnant anterior bundle to failure or 5-mm increased gapping at 90°. Although observing lower peak load to failure in all reconstructed specimens relative to intact ligaments, those investigators used the same specimens to examine subsequent reconstruction techniques and noted that this aspect of the study design may have interfered with the results. Ciccotti et al[9] loaded intact specimens at 30°, 60°, 90°, and 110° and then to failure at 90° and repeated this sequence for reconstructed specimens. Reconstructed specimens exhibited similar valgus laxity at 90° and 110° as intact specimens but not at lower flexion angles. Greater peak load to failure was observed in native ligaments.

The current study is not without limitations. One factor may be the small sample size. Due to the difficulty of procuring suitable cadaveric specimens, this problem is commonly encountered in biomechanical research. Previous UCL biomechanical studies have been carried out with 14 to 20 specimens.[1,4,9,12,20,24] While this study's power would have been enhanced by the inclusion of more specimens, the use of 18 specimens falls within the range of previous studies. A post hoc power analysis with an alpha set at .05 and 80% power indicated that this study would have required 40 samples for each group (for a total of 80 samples) to detect the difference between the mean ultimate load to failure (6.05 N·m with a common standard deviation of 9.6) for native and reconstructed or repaired samples in this study. This required sample size is much larger for detecting smaller differences between groups. Another inherent weakness of cadaveric biomechanical studies is the older age of the specimens relative to the patient population of interest; the mean age of our specimens was 62.9 ± 1.4 years. Finally, the concern exists with all biomechanical studies that study conditions do not accurately re-create the physiological reality that the studies portend to examine. Previous studies have tested the UCL at 30°,[21,27] 70°,[23] 90°,[12] and 15° to 90°.[18,19] At 90° and out of full supination, the elbow is relatively stabilized by bony conformity. To isolate the anterior bundle of the UCL, it may have been more appropriate to conduct testing between 30° and 40° of flexion in full supination or dynamically between 30° and 120° where the anterior bundle provides the most significant restraint to valgus.[1,4,5,7,12,20,29] However, 90° is the general position of the elbow in late cocking and early acceleration and allows testing of the entire UCL complex. We were fortunate to have multiple, well-described experimental models for UCL biomechanical testing available in the literature, and we carefully designed and carried out this study in accordance with these, albeit with the elbow at a fixed 90° of flexion. Unfortunately, a standard flexion angle for cyclic loading of the elbow UCL has not been established. Regardless, we agree with previous authors that these established biomechanical models for testing UCL valgus stability are fairly accurate depictions of the stresses placed on the ligament during throwing.

Strengths of our study include the use of the docking technique for comparison against repair augmented with internal bracing, as this technique is widely used in UCL reconstruction. Additionally, we decided to load native ligaments to failure instead of sectioning them, as has been performed in other related studies. We believe this method to be a more accurate representation of acute rupture with subsequent surgical treatment, and this provided us a baseline for force and torque for native UCL failure.

One final consideration and caution: These biomechanical results do not suggest any effect on a patient's clinical outcome. However, Walters et al[34] showed a 92% return to play at 6 months, which is a higher rate than most studies on UCL reconstruction. However, the long-term performance remains unknown. Because the intent of internal bracing is to provide stability throughout ligament healing and maturation, the question remains whether this construct may overprotect the ligament and thereby decrease the necessary load required for the ligament to remodel and mature; this could affect the long-term outcome. These questions cannot be answered within the confines of the current study.

In conclusion, our results suggest that UCL repair with internal bracing has a similar biomechanical profile at the time of initial fixation compared with the docking technique of UCL reconstruction. Further studies, including clinical studies, are necessary to determine whether this repair option can provide outcomes that are reliable and comparable to commonly used reconstruction techniques for UCL injuries.

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