Medial Ulnar Collateral Ligament Repair With Augmentation

A Systematic Review and Meta-analysis of Preclinical Studies

Khalis Boksh,*† BSc(Hons), MBChB, MRCS, Pranav Mishra,† MBChB, MSc, MRCS, Nimra Akram,† BSc, MBBS, Sina Abdolrazaghi,† BSc, MBChB, and Harvinder Singh,† MBBS, MS, PhD

Investigation performed at the University Hospitals of Leicester NHS Trust, Leicester, UK

Background: Reconstruction is the gold standard treatment for medial ulnar collateral ligament (MUCL) injuries. However, recent studies show a successful and renewed interest in direct suture repair, particularly in young athletes. Repair augmentation with a suture tape may provide greater stability, enabling healing of the MUCL while protecting the repair at higher valgus loads.

Purpose: To perform a systematic review and meta-analysis on whether MUCL repair with augmentation provides a similar biomechanical profile to the traditional MUCL reconstruction.

Study Design: Systematic review.

Methods: The Cochrane Controlled Register of Trials, PubMed, Medline, and Embase were used to perform a systematic review and meta-analysis using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) criteria with the following search terms: ("ulnar collateral ligament" OR "medial ulnar collateral ligament") AND ("internal brace" OR "augmentation" OR "suture tape"). Data pertaining to certain biomechanical properties (gap formation, failure to torque [ultimate load to failure], stiffness, degree of valgus opening, and modes of failure) were extracted. The pooled outcome data were analyzed by random- and fixed-effects models. A total of 203 abstracts were identified through the aforementioned databases.

Results: After abstract and full-text screening, 6 biomechanical studies were included. All were on cadaveric elbows, with 53 repairs with augmentation and 53 reconstructions compared. There were no differences between the 2 in regard to ultimate load to failure (standard mean difference [SMD], –0.34 N·m; 95% CI, –1.36 to 0.68; $P = .51$) and rotational stiffness (SMD, 0.26; 95% CI, –1.14 to 1.66; $P = .72$). Despite a trend in resistance to gapping with augmented repair, this was not significant (SMD, –0.53; 95% CI, –1.08 to 0.01; $P = .06$). Augmented repairs were more likely to fail by pullout or at the suture-tendon/anchor-suture interface (odds ratio [OR], 12.19; 95% CI, 4.17 to 35.62; $P < .00001$), while failure by fracture was more common with reconstruction (OR, 5.75; 95% CI, 2.07 to 15.99; $P = .0008$).

Conclusion: MUCL augmented repair establishes the required time-zero structural properties without the need for a tendon graft. However, future clinical studies are necessary to determine its true effectiveness as well as its success at higher levels of professional sport.

Keywords: medial ulnar collateral ligament; suture tape; Jobe; docking reconstruction

The anterior bundle of the medial ulnar collateral ligament (MUCL) complex is the primary restraint to valgus stress at the elbow during overhead throwing.[32,36] Injury classically affects baseball pitchers, because of the high and repetitive stress on the ligament.[20] Primary repair was historically the treatment of choice. However, it was largely abandoned because of a combination of poor clinical outcomes, high rates of instability, and low return to sports (0%-63% return to previous or higher level of competition).[3,6,14,25]

Since the introduction and initial success of the Jobe technique,[25,26] with its superior results to direct repair,[2,3,14,34,37] ligament reconstruction has become the treatment of choice. Despite numerous construct modifications, the modified Jobe and docking techniques are the most accepted and frequently used procedures, with 68% to 95% of patients returning to play.[11,14,16,18,21,23]

However, in the past decade, epidemiological data have suggested a significant rise in MUCL injuries in

The Orthopaedic Journal of Sports Medicine, 11(5), 23259671231158373
DOI: 10.1177/23259671231158373

adolescents, likely due to early sports specialization and year-round throwing.[15,20] Young patients typically lack the chronic attritional damage and secondary pathological changes in the joint that are found in older athletes. Therefore, native tissue quality is likely to be preserved.[32,35] Furthermore, if the area of injury is isolated to only an insertional area (proximal or distal tear), the ligament should be amenable to repair and rapid recovery. This is underlined in recent studies, showing successful and renewed interest in suture repair of the MUCL for young athletes with acute proximal or distal tears, with a systematic review reporting an 87% return to play.[4,22,39,40]

More recently, MUCL repairs with augmentation such as suture tapes have been proposed in the literature.[17,42] It is thought that the collagen-coated tape provides added stability to the repaired ligament, allowing its healing while protecting it from stressors at higher valgus loads.[8] In contrast to reconstructive techniques, it can also preserve the patient's native anatomy and proprioception while limiting bone loss secondary to lack of tunneling.[42]

We therefore performed a systematic review and meta-analysis of the available literature to compare the biomechanical properties of MUCL repair with augmentation against the gold standard reconstructive techniques. We hypothesized that the biomechanical properties of augmented MUCL repairs would be similar to those of the traditional reconstructions.

METHODS

Literature Search

A systematic review and meta-analysis was carried out and reported according to the standards of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) criteria.[29] A search of the Cochrane Controlled Register of Trials, PubMed, Medline, and Embase was conducted from the inception of the databases to February 7, 2022. The search terms included ("ulnar collateral ligament" OR "medial ulnar collateral ligament") AND ("internal brace" OR "augmentation" OR "suture tape"). No restrictions were made on language, and efforts were made to obtain translated versions of all included studies. Bibliographies of included studies were examined for missed and potentially relevant studies.

Eligibility Criteria

All biomechanical studies on cadaveric elbows that compared the footprint characteristics of MUCL repair with augmentation and reconstruction were included. Furthermore, studies that reported on the clinical outcomes of MUCL repair were included. Exclusion criteria for biomechanical studies included noncadaveric elbow specimens, hybrid fixation, and differences in the repair construct for MUCL repair with augmentation and MUCL reconstruction within the same study. Review articles, letters to the editor, commentaries, and technical tips and publications pertaining to surgical tips were also excluded.

Outcome Measures

Outcome measures included gap formation, failure to torque (ultimate load to failure), stiffness, degree of valgus opening, and modes of failure.

Study Selection and the Assessment of Quality

Two authors (K.B. and P.M.) independently reviewed the titles and abstracts, after which relevant papers were reviewed in full by each author independently. Those that met the eligibility criteria were chosen, with discrepancies highlighted and reviewed by a third author (H.S.). The same 2 authors independently assessed the methodological quality of the biomechanical studies to include specimen preparation, surgical and repair techniques, hardware use, tunnel/anchor placement, index tear placement and formation, and biomechanical testing parameters.

Data Synthesis and Statistical Analysis

Review Manager 5.4 by the Cochrane collaboration was used for data synthesis and analysis. Standard mean differences (SMDs) were assessed for continuous parameters (gap formation, failure to torque, stiffness, and degree of valgus opening), and odds ratios (ORs) for all dichotomous variables (rate of fracture and pullout). Statistical heterogeneity was assessed using the I^2 and chi-square tests. A P value $<.1$ and an I^2 value $>50\%$ were considered suggestive of statistical heterogeneity, prompting a random-effects modeling estimate, Otherwise, a fixed-effects model was used.

RESULTS

In total, 203 abstracts were identified from the initial search. After removal of duplicates and exclusion of papers upon abstract review, 8 studies were left for full-text review. Two full-text articles were excluded based on the eligibility criteria; they did not investigate the desired biomechanical outcomes. This left 6 studies for quantitative and qualitative analyses (Figure 1).

*Address correspondence to Khalis Boksh, BSc(Hons), MBChB, MRCS, Department of Trauma and Orthopaedics, University Hospitals of Leicester NHS Trust, Infirmary Square, Leicester, LE1 5WW, UK (email: khalis_boksh@hotmail.co.uk).

†Department of Trauma and Orthopaedics, University Hospitals of Leicester NHS Trust, Leicester, UK.

Final revision submitted January 3, 2023; accepted January 17, 2023.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution. 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.

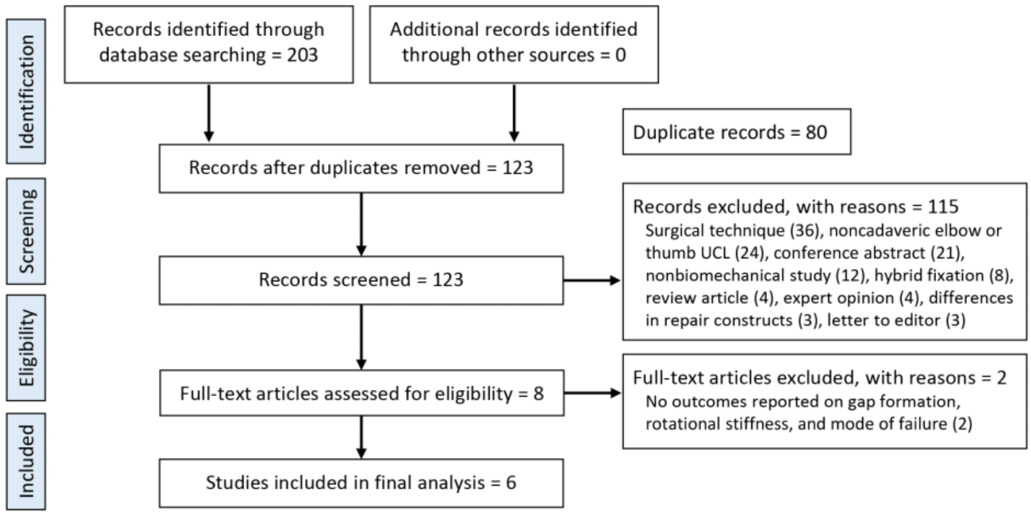

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart of study selection. UCL, ulnar collateral ligament.

Biomechanical Characteristics

Six biomechanical studies were identified from the literature.[7,9,19,27,31,43] In total, there were 106 cadaveric elbows, of which 53 were treated with ulnar collateral ligament (UCL) internal brace (IB) repair and 53 with UCL reconstruction. The mean age of the specimens was 63.7 years (range, 44.7-73.2 years), with 57.8% of the specimens being from men. The biomechanical characteristics, surgical techniques used, and testing details are described in Supplemental Tables S1, S2, and S3, respectively (Supplemental Material available separately).

There was inherent heterogeneity given the differences in repair techniques between the studies (Supplemental Table S2). Four studies had similar anchor and fixation placement for the FiberTape Internal Brace (Arthrex).[9,19,27,31] Of the remaining 2 studies, 1 had additional anchors incorporating SutureTape (Arthrex) in the sublime tubercle for posterior band augmentation.[43] The final study incorporated a novel suspensory fixation in the medial epicondyle for suture tape augmentation.[7]

Although reconstruction was the main comparator, 2 studies used the modified Jobe technique,[19,27] 2 the simple docking technique,[9,31] and 2 modified docking (Supplemental Table S2).[7,43]

Where described, specimen preparation was generally consistent among all studies, with either flexor-pronator mass splitting[9,31] or an elevation approach used for MUCL exposure.[19,27] Acute tears were either proximal or distal and were different among studies. Four studies split the mUCL in line with its fibers,[7,9,19,31] with 2 describing its proximal tear to include MUCL elevation at the medial epicondyle.[7,31] The final 2 studies created a longitudinal split in the anterior band with sharp release off the sublime tubercle, thus simulating a distal avulsion tear.[27,43]

Biomechanical testing techniques varied from elbow flexion of 70° to 90°, preload of 0.2 to 2 N·m, cyclical load of 2-5 to 2.5-10 N·m, and ultimate load to failure of 12 to 300 mm/min (Supplemental Table S3). All studies compared ultimate failure to torque, with 5 comparing rotational stiffness.[7,19,27,31,43] However, Jones et al[27] did not quantify the data for both tests. Four studies compared gap formation,[7,9,19,27] and all studies described modes of failure. However, neither outcome was quantified by Bachmaier et al.[7] Nevertheless, meta-analyses on these outcomes were performed.

Biomechanical Outcomes

Ultimate Failure to Torque. There were no differences between both groups on the ultimate failure to torque (SMD, –0.34 N·m; 95% CI, –1.36 to 0.68; $P = .51$) (Figure 2). There was a high level of heterogeneity among studies ($I^2 = 79\%$; $P = .0008$).

Rotation Stiffness. There were no differences between the groups on rotational stiffness (SMD, 0.26; 95% CI, –1.14 to 1.66; $P = .72$) (Figure 3). There was a high level of heterogeneity among studies ($I^2 = 85\%$; $P = .0002$).

Gap Formation. Despite a trend toward increased gap formation with the MUCL reconstruction, this was not significant (SMD, –0.53; 95% CI, –1.08 to 0.01; $P = .06$) (Figure 4). There was a low level of heterogeneity among studies ($I^2 = 0\%$; $P = .72$).

Mode of Failure: Fracture. Humerus-sided and ulnar tunnel fractures were more common in MUCL reconstruction groups compared with MUCL augmented repair (OR, 5.75; 95% CI, 2.07-15.99; $P = .0008$) (Figure 5). There was a moderate level of heterogeneity among studies ($I^2 = 48\%$; $P = .12$).

Mode of Failure: Anchor Pullout, Failure at Suture-Tendon or Anchor-Suture Interface. These were more common in MUCL augmented repair compared with MUCL reconstruction (OR, 12.19; 95% CI, 4.17-35.62; $P < .00001$) (Figure 6). There was a low level of heterogeneity among studies ($I^2 = 28\%$; $P = .24$)

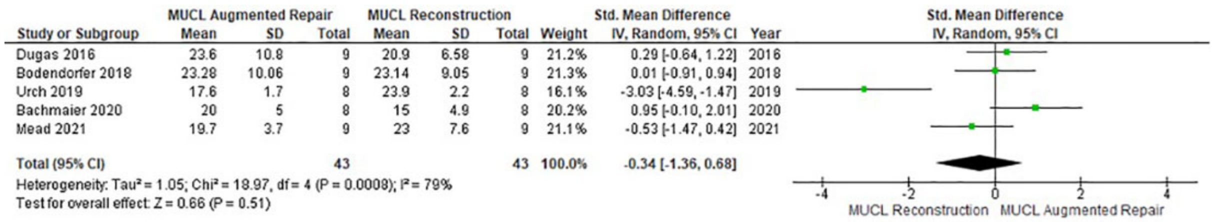

Figure 2. Forest plot of the comparison between groups for ultimate failure to torque (N·m). IV, inverse variance; MUCL, medial ulnar collateral ligament.

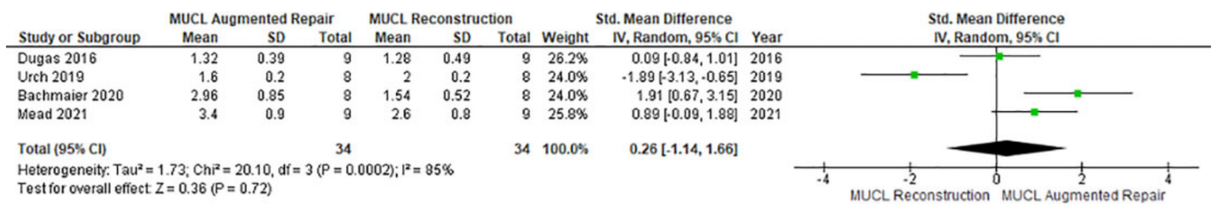

Figure 3. Forest plot of the comparison between groups for rotation stiffness (N·m/deg). IV, inverse variance; MUCL, medial ulnar collateral ligament.

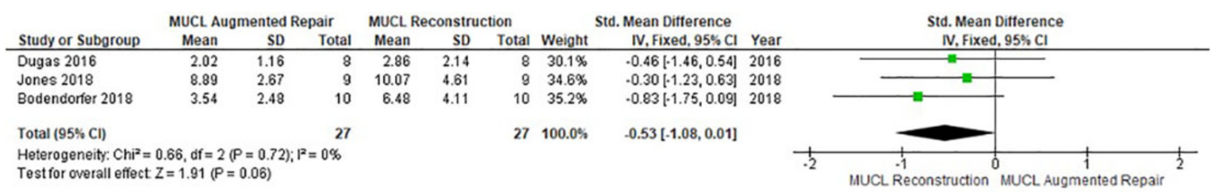

Figure 4. Forest plot of the comparison between groups for gap formation (mm). IV, inverse variance; MUCL, medial ulnar collateral ligament.

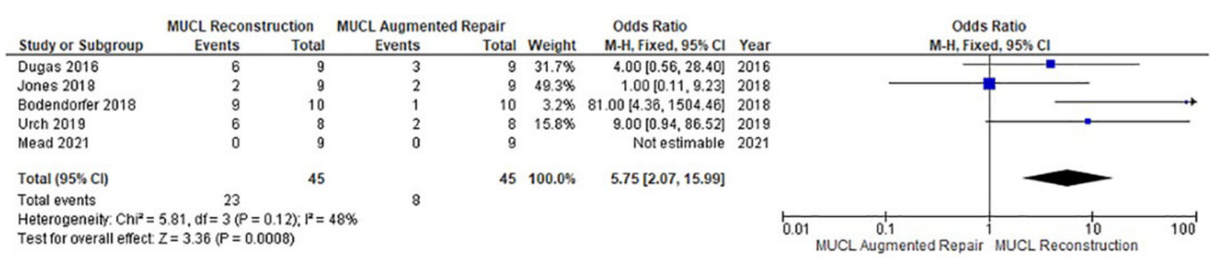

Figure 5. Forest plot of the comparison between groups for fracture. M-H, Mantel-Haenszel; MUCL, medial ulnar collateral ligament.

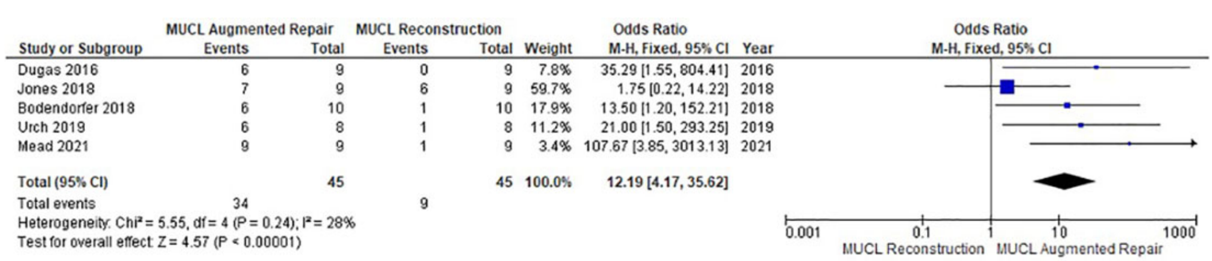

Figure 6. Forest plot of the comparison between groups for rate of pullout or suture-tendon or anchor-suture interface failure. M-H, Mantel-Haenszel; MUCL, medial ulnar collateral ligament.

Pairwise Comparisons for Intact, Torn, and Repaired or Reconstructed States

Five studies performed post hoc tests for pairwise comparison (Table 1). Despite nonsignificance, the MUCL augmented repair group generally experienced restored resistance to gapping and torsional stiffness more closely to the native ligament than the reconstruction group.[7,9,19,27]

Only 1 study compared ultimate load to failure and found that neither intervention restored the failure load to that of the native ligament.[7] With regard to kinematics, MUCL augmented repair restored valgus laxity and ulnar rotation to those of the native ligament in 0° to 120° of elbow flexion.[43]

Three studies analyzed valgus stability in the torn state. One study showed an improvement in valgus stability after repair or reconstruction,[7] and another, similar stability.[19] The remaining study showed better stability in the torn state.[27]

DISCUSSION

We performed a systematic review and meta-analysis on the biomechanical properties between direct repair with augmentation (the intervention) and the gold standard reconstruction techniques (the comparator) on MUCL injuries. Our analysis suggests that there was no difference between the 2 in regard to ultimate load to failure (SMD, –0.34 N·m; 95% CI, –1.36 to 0.68; $P = .51$) and rotational stiffness (SMD, 0.26; 95% CI, –1.14 to 1.66; $P = .72$). Despite a trend in resistance to gapping with augmented repair, this was not significant (SMD, –0.53; 95% CI, –1.08 to 0.01; $P = .06$). Augmented repairs were more likely to fail by pullout or at the suture-tendon/anchor-suture interface (OR, 12.19; 95% CI, 4.17 to 35.62; $P < .00001$), while failure by fracture was more common with reconstruction (OR, 5.75; 95% CI, 2.07 to 15.99; $P = .0008$).

The ultimate theoretical goal of the augmented repair with tape is to protect the repaired ligament as it heals. Its stress-shielding effects enable load transfer as soon as the

TABLE 1
Subgroup Analysis of Intact, Torn, and Repair or Reconstruction States[a]

	Augmented Repair		Reconstruction	
Study	Versus Native Ligament	Versus Torn Ligament	Versus Native Ligament	Versus Torn Ligament
Dugas (2016)[19]	**Gap formation:** 0.35 ± 0.16 vs 0.33 mm ($P > .05$)	**Gap formation:** 0.35 ± 0.16 vs 0.5 mm ($P = .07$)	**Gap formation:** 0.53 ± 0.23 vs 0.42 mm ($P = .3$)	**Gap formation:** 0.53 ± 0.23 vs 0.58 mm ($P = .3$)
Bodendorfer (2018)[9]	Gap formation: ■ At 100th: 10.38 ± 3.18 vs 8.96 ± 2.74 mm ($P = .387$ ■ At 1000th: 13.38 ± 4.76 vs 11.57 ± 4.36 mm ($P = .339$)	NR	Gap formation: ■ At 100th: 13.03 ± 6.65 vs 11.38 ± 6.39 mm ($P = .387$) ■ At 1000th: 16.64 ± 7.20 vs 14.17 ± 6.61 mm ($P = .339$)	NR
Jones (2018)[27]	Gap formation: ■ At 100th: 3.2 ± 2.08 vs 2.27 ± 1.36 mm ($P > .05$) ■ At 500th: 3.54 ± 2.48 vs 2.71 ± 1.88 mm ($P > .05$)	**Gap formation:** at 10th: repair > torn; 2.51 ± 1.77 mm vs NR ($P = .007$)	Gap formation: ■ At 100th: 6.09 ± 4.06 vs 2.51 ± 1.36 mm ($P > .05$) ■ At 500th: 6.48 ± 4.11 vs 3.7 ± 3.19 mm ($P > .05$)	**Gap formation:** reconstruction > torn ($P < .05$)
Urch (2019)[43]	Valgus laxity and ulnar rotation Restoration to native ligament at all elbow flexion angles	**Valgus laxity:** significant improvement after repair in all flexion angles ($P < .05$) **Ulnar rotation:** restored rotation to intact state at 0° and 30° of flexion	**Valgus laxity:** restoration to native ligament at 60° of flexion; failure to restore at 0° and 30° of flexion**;** **o**verconstrained **at** 90° and 120° **Ulnar rotation:** underrotated ulna at 30° and overrotated at 90°	**Valgus laxity:** significant improvement after reconstruction at all flexion angles except 0° ($P < .05$) **Ulnar rotation:** restored rotation to intact state at only 0°
Bachmaier (2020)[7]	**Torsional stiffness:** 2.96 ± 0.85 vs 2.60 ± 0.90 N·m/deg ($P > .05$) **Failure to load:** 20.0 ± 5.0 vs 32.2 ± 12.5 N ($P < .001$)	**Torsional stiffness:** 2.96 ± 0.85 vs 0.91 ± 0.34 N·m/deg ($P < .001$) **Gap formation:** 0.45 ± 0.24 vs 0.97 ± 0.35 mm ($P < .05$)	**Torsional stiffness:** 1.54 ± 0.52 vs 2.60 ± 0.90 N·m/deg ($P > .05$) **Failure to load:** 15 ± 4.9 vs 32.2 ± 12.5 N ($P < 0.001$)	**Torsional stiffness:** 1.54 ± 0.52 vs 0.91± 0.34 N·m/deg ($P > .05$) **Gap formation:** 0.60 ± 0.44 vs 0.97 ± 0.35 mm ($P > .05$)

[a]NR, not reported.All values presented as either mm or degrees.

repair reaches its yield point. This can explain its respectable torque-to-failure values, with its range (17.6-23.6 N·m) falling within that seen in multiple MUCL reconstruction cadaveric studies (13.6-30.5 N·m).[1,5,25] Such a stress shielding effect of the tape is underlined further in the ACL literature, where suture tape constructs incorporated in hamstring grafts significantly decreased graft elongation by 56%.[34]

Although rotational stiffness was similar, 1 study did show superior outcomes with augmented repair compared with MUCL reconstruction.[7] One particular explanation includes the collagen coating on the brace stimulating adhesion proliferation, alkaline phosphate activity, and protein synthesis. This can increase the cellularity in the healing ligament, yielding improved linear and dynamic stiffness.[28,31] Therefore, even at its worst, the augmented repair remains a viable alternative to reconstruction.

The trend toward increased gap formation with MUCL reconstruction suggests that the augmented repair may potentially allow the native ligament to heal without excessive stretch under valgus loads.[7,19,27] Furthermore, pairwise comparisons generally revealed that augmented repair restored gapping closer to the native ligament compared with reconstruction methods.[19,27] There are supportive studies that have analyzed this under cyclical and fatigue loading properties that replicate the long-term stressors of return to play.[27,44,45] This may support the notion that an accelerated postoperative rehabilitation program can potentially be undertaken with the repair augmentation. Ultimately, this may allow a faster return to play without compromising the integrity of the repair.

Augmented repairs were more likely to fail through suture pullout at the epicondylar fixation point or at the anchor-suture-bone interface. However, they were less likely to fracture compared with the reconstruction group. This makes them advantageous, as it lends the pathway to revision fixation with preservation of the sublime tubercle architecture, and the incorporation of future bone tunnels without sacrificing the strength of the construct.

All biomechanical studies were performed on cadaveric elbows. This reduced variability between samples and enabled more similar structures, allowing a meta-analysis to be conducted.

The details of repair and reconstruction were not standardized across all studies. For example, 4 studies tested elbow biomechanics at 90° of flexion,[7,9,19,27] with 2 at 70°.[31,43] Although the literature shows greatest valgus instability at these flexion angles,[12,24,33,41] the greatest stress is generally observed at about 80° to 90° of arm flexion in the late cocking phase in overhead-throwing athletes.[13]

However, in time-zero biomechanics, the elbow is relatively stabilized by bony conformity at 90°. Therefore, it may be more appropriate to conduct testing dynamically between 30° and 120°, as the anterior bundle provides the most significant restraint to valgus in this range.[1,5,10,30,38] Only 1 study in the review addressed the posterior band.[49] Recent literature suggests that the posterior band experiences more strain than the anterior band at 70° of flexion, indicating its importance at higher flexion angles.[36]

Tear location and degree of transection were inconsistent among studies, with 1 involving the entire ulnar footprint,[43] 2 proximal tears,[7,31] and 2 distal tears.[19,27] If a true transection is performed, then greater instability of the tear will be observed, to which valgus stability should be restored after reconstruction or augmented repair. This is underlined in the study of Bachmaier et al,[7] in particular for augmented repairs, after post hoc tests for pairwise comparison. However, there were 2 studies in the systematic review in which resistance to gapping was either similar or better in the torn state compared with the repair/reconstructive state.[19,27] Both studies performed a longitudinal split within the ligament, enabling congruency of the remaining ligament with the surrounding capsular and ligamentous tissue. Therefore, in preserving the ligament's integrity, the treatment effects may have been underestimated. In summary, this emphasizes the importance of uniformity across studies with the performance of complete MUCL transection.

There were variations in the thickness of the tape constructs in the augmented repair. Four studies used 2-mm FiberTape,[7,9,19,27] 1 study 1.3-mm SutureTape,[43] and another 1.5-mm tape (product name not given).[31] Smaller, smoother tapes result in lower friction at the anchor-suture-bone interface,[45] an effect amplified further in weaker and older cadaveric bone. This can cause earlier failure upon loading, which may underline the poorer results seen with augmented repair in the study by Urch et al.[43]

Despite this, all studies chose a loading force within 10 N·m of valgus moment, in keeping within the toe and linear elastic region of the MUCL without plastic deformation. Although slight differences in anchor numbers and fixation were noted, they were overall appropriate in all studies with reference points selected to ensure implants would not compromise the largest or widest portion of the distal or proximal footprint for native UCL insertion.[19]

Of the 5 meta-analyses performed, 3 showed homogeneity: gap formation, fracture mode of failure, and pullout. However, optimal standardization is required to estimate the true pooled effect, and this should be stringently controlled for in future studies. Nevertheless, these results are highly promising in an era of renewed interest in MUCL repair as a potential way to reduce rehabilitation in young athletes without chronic attritional changes.

Recent studies have underlined the success of MUCL repair, with 81.9% to 96.7% of young athletes returning to play between 2.5 and 6 months,[4,39,40] a stark contrast to the 11.6 to 16.8 months seen in those with MUCL reconstruction.[11] Through the structural and biological support of the internal brace, the added durability at the repair site should further decrease rehabilitation time, allowing for a faster return to play for athletes. Attempts were made to incorporate clinical outcome papers within the systematic review to explore this, but the low number (n = 2) of such papers meant this could not be synthesized adequately.[20] This was in view of the low number of clinical studies (n = 2).[17,36] However the key results from both included a young cohort (mean age, 18.2 years) of high school athletes (63.6%) that predominantly played baseball (90.7%), all of whom had adequate tissue quality with no deficiency. The mean follow-up was 23.9 months, with ≥92% returning to play within 6.9 months. The mean Kerlan-Jobe Orthopaedic Clinic score was over 90, which is significant, as it approaches that of the study by Kraeutler et al,[28] who concluded that a healthy pitcher should score in the 90s. There was a relatively low number of complications (4.6%), of which over half were related to the ulnar nerve. These functional results, with the backdrop of promising biomechanical properties, lend to the UCL repair with tape augmentation as being a viable alternative to the traditional repair technique and gold standard reconstruction for amateur overhead-throwing athletes. However, as the primary focus was on young athletes, further studies are required to appreciate how it will hold up to the additional volume of throwing required in professional sports.

Limitations

There are several limitations in this study. These mainly stem from the heterogeneity among the included studies, to include specimen preparation, surgical techniques, hardware use, and tunnel/anchor placement. Nevertheless, the qualitative analysis of each individual study indicates that the 2 techniques provide similar results. The age of cadaveric specimens (mean, 63.7 years) was not representative of athletes who typically undergo this procedure. Additionally, the differences in age and bone quality may have contributed to the variability in study findings.

The majority of studies did not robustly test the cyclical behavior using a high-cycle fatigue biomechanical protocol at various degrees of flexion, from 30° to 120°. Such properties would have more closely replicated the long-term stressors of play. There were small sizes in all studies. However, because of the difficulty in procuring suitable cadaveric specimens, this problem is commonly encountered in biomechanical research. Nevertheless, the use of ≥16 specimens in all studies falls within the range of the previous literature.[1,5,13,30] Furthermore, with the cadaveric specimens, the biomechanical testing would not have included any of the biological processes (eg, inflammation and cellular responses) involved in actual healing and rehabilitation. Finally, some biomechanical studies did not provide precise means or metric values, prohibiting authors from adding these to the meta-analysis.

CONCLUSION

MUCL repair with tape augmentation has a similar biomechanical profile to the gold standard reconstruction techniques. Furthermore, it requires less soft tissue dissection and is bone preserving. Limiting its applicability to those patients with acute tears without chronic attritional changes ensures that the augmented repair is performed only in situations in which tissue is healthy and robust. However, future clinical studies are necessary to determine the true effectiveness of MUCL repair and its success at higher levels of professional sport.

SUPPLEMENTAL MATERIAL

Supplemental Material for this article is available at http://journals.sagepub.com/doi/suppl/full/10.1177/23259671231158373#supplementarymaterials

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. Alberta FG, ElAttrache NS. Diagnosis and treatment of distal biceps and anterior elbow pain in throwing athletes. *Sports Med Arthrosc*. 2008;16(3):118-123.
3. Andrews JR, Timmerman LA. Outcome of elbow surgery in professional baseball players. *Am J Sports Med*. 1995;23(4):407-413.
4. 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.
5. Armstrong AD, Dunning CE, Ferreira LM, Faber KJ, Johnson JA, King GJW. A biomechanical comparison of four reconstruction techniques for the medial collateral ligament - deficient elbow. *J Shoulder Elbow Surg*. 2005;14(4):206-215.
6. 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.
7. Bachmaier S, Wijdicks CA, Verma NN, Higgins LD, Gleiner S. Biomechanical functional elbow restoration of acute ulnar collateral ligament tears: the role of internal bracing on gap formation and repair stabilization. *Am J Sports Med*. 2020;48(8):1884-1892.
8. Bernholt DL, Lake SP, Castile RM, Papangelou C, Hauck O, Smith MV. Biomechanical comparison of docking ulnar collateral ligament reconstruction with and without an internal brace. *J Shoulder Elbow Surg*. 2019;28(11):2247-2252.
9. Bodendorfer BM, Looney AM, Lipkin SL, et al. Biomechanical comparison of ulnar collateral ligament reconstruction with the docking technique versus repair with internal bracing. *Am J Sports Med*. 2018; 46(14):3495-3501.
10. Bruce JR, Andrews JR. Ulnar collateral ligament injuries in the throwing athlete. *J Am Acad Orthop Surg*. 2014;22(5):315-325.
11. 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.
12. Callaway GH, Field LD, Deng XH, et al. Biomechanical evaluation of the medial collateral ligament of the elbow. *J Bone Joint Surg Am*. 1997;79(8):1223-1231.
13. Ciccotti MG, Siegler S, Kuri JA, Thinnes JH, Murphy DJ. Comparison of the biomechanical profile of the intact ulnar collateral ligament with the modified Jobe and the docking reconstructed elbow: an in vitro study. *Am J Sports Med*. 2009;37(5):974-981.
14. Contte SA, Fleisig GS, Dines JS, et al. Prevalence of ulnar collateral ligament surgery in professional baseball players. *Am J Sports Med*. 2015;43(7):1764-1769.
15. 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.
16. Dodson CC, Thomas A, Dines JS, Nho SJ, Williams R, Altchek DW. Medial ulnar collateral ligament reconstruction of the elbow in throwing athletes. *Am J Sports Med*. 2006;34(12):1926-1932.
17. Dugas JR, Looze CA, Capogna B, et al. Ulnar collateral ligament repair with collage-dipped FiberTape augmentation in overhead throwing athletes. *Am J Sports Med*. 2019;47(5):1096-1102.

18. 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.
19. Dugas JR, Walters BL, Beason DP, Fleisg 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.
20. Erickson BJ, Bach BR, Verma NN, Bush-Joseph CA, Romeo AA. Treatment of ulnar collateral ligament tears of the elbow: is repair a viable option? *Orthop J Sports Med*. 2017;5(1):2325967116682211.
21. 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.
22. 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.
23. Floris S, Olsen BS, Dalstra M, Sojbjerg JO, Sneppen O. The medial collateral ligament of the elbow joint: anatomy and kinematics. *J Shoulder Elbow Surg*. 1998;7(4):345-351.
24. 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.
25. Jackson T, Jarrell SE, Adamson GJ, Chung KC, Lee TQ. Biomechanical differences of the anterior and posterior bands of the ulnar collateral ligament of the elbow. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(7):2319-2323.
26. Jobe FW, Stark H, Lombardo SJ. Reconstruction of the ulnar collateral ligament in athletes. *J Bone Joint Surg Am*. 1986;68(8):1158-1163.
27. 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.
28. Kraeutler MJ, Ciccotti MG, Dodson CC, Frederick RW, Cammarota B, Cohen SB. Kerlan-Jobe Orthopaedic Clinic overhead athlete scores in asymptomatic professional baseball pitchers. *J Shoulder Elbow Surg*. 2013;22(3):329-332.
29. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *J Clin Epidemiol*. 2009;6(7):e1000100.
30. McAdams TR, Lee AT, Centeno J, Giori NJ, Lindsey DP. Two ulnar collateral ligament reconstruction methods: the docking technique versus bioabsorbable interference screw fixation—a biomechanical evaluation with cyclic loading. *J Shoulder Elbow Surg*. 2007;16(2):224-228.
31. Mead RN, Nelson TJ, Limpisvasti Orr, ElAttrache NS, Metzger MF. Biomechanical comparison of UCL repair using suspensory fixation versus UCL reconstruction. *Orthop J Sports Med*. 2021;9(9):23259671211038992.
32. Miller CD, Savoie FH. Valgus extension injuries of the elbow in the throwing athlete. *J Am Acad Orthop Surg*. 1994;2(5):261-269.
33. Mullen DJ, Goradia VP, Parks BG, Matthews LS. A biomechanical study of stability of the elbow to valgus stress before and after reconstruction of the medial collateral ligament. *J Shoulder Elbow Surg*. 2002;11(3):259-264.
34. Noonan BC, Bachmaier S, Wijdicks CA, Bedi A. Independent suture tape reinforcement of tripled smaller-diameter and quadrupled grafts for anterior cruciate ligament reconstruction with tibial screw fixation: a biomechanical full construct model. *Arthroscopy*. 2020;36(2):481-489.
35. Norwood LA, Shook JA, Andrews JR. Acute medial elbow ruptures. *Am J Sports Med*. 1981;9(1):16-19.
36. O'Connell R, Hoof M, Heffernan J, O'Brien M, Savoie F. Medial ulnar collateral ligament repair with internal brace augmentation: results in 40 consecutive patients. *Orthop J Sports Med*. 2021;9(7):23258671211014230.
37. Regan WD, Korinek SL, Morrey BF, An KN. Biomechanical study of ligaments around the elbow joint. *Clin Orthop Relat Res*. 1991;271:170-179.
38. Rettig AC, Sherrill C, Snead DS, Mendler JC, Mieling P. Nonoperative treatment of ulnar collateral ligament injuries in throwing athletes. *Am J Sports Med*. 2001;29(1):15-17.
39. 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.
40. 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.
41. Søjbjerg JO, Ovesen J, Nielsen S. Experimental elbow instability after transection of the medial collateral ligament. *Clin Orthop Relat Res*. 1987;218:186-190.
42. Trofa DP, Lombardi JM, Noticewala MS, Ahmad CS. Ulnar collateral ligament repair with suture augmentation. *Arthrosc Tech*. 2017;7(1):e53-e56.
43. Urch E, Limpisvasi O, ElAttrache NS, et al Biomechanical evaluation of a modified internal brace construct for the treatment of ulnar collateral ligament injuries. *Orthop J Sports Med*. 2019;7(10):2325967119874135.
44. Wilk KE, Macrina LC, Caoin EL, Dugas JR, Andrews JR. Rehabilitation of the overhead athlete's elbow. *Sports Health*. 2012;4(5):404-414.
45. Wilson FD, Andrews JR, Blackburn TA, McCluskey G. Valgus extension overload in the pitching elbow. *Am J Sports Med*. 1983;11(2):83-88.