Differences in Shoulder Internal Rotation Strength Between Baseball Players With Ulnar Collateral Ligament Reconstruction and Healthy Controls

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Background: Studies have indicated decreased shoulder internal rotation (IR) and external rotation (ER) strength in the throwing limb of baseball players after ulnar collateral ligament injury. There is limited evidence on the recovery of shoulder rotation strength after primary ulnar collateral ligament reconstruction (UCLR).

Hypothesis: At the time of return to throwing, baseball players who underwent UCLR would demonstrate decreased IR and ER shoulder strength in the throwing arm as compared with healthy baseball players.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Male competitive high school and collegiate baseball athletes participated in this study. Athletes who underwent UCLR were compared with healthy controls who were matched by age, height, weight, and position. Bilateral isometric shoulder ER and IR strength was measured using a handheld dynamometer for all participants at the time of initial evaluation (UCLR group) and throughout the course of a season (healthy group). Independent *t* tests were run to calculate mean differences in ER and IR shoulder strength between the groups, with significance set at $P < .05$.

Results: A total of 86 baseball athletes participated in this study (43 UCLR group, 43 healthy group). At the time of return to throwing (mean ± SD, 194 ± 30 days postoperatively), the 2 groups demonstrated no significant differences in nonthrowing arm ER or IR strength ($P = .143$ and .994, respectively). No significant difference was found between groups for throwing arm ER strength ($P = .921$); however, the UCLR group demonstrated significantly less throwing arm IR strength than the healthy group (144.2 ± 27.8 vs 157.6 ± 27.1 N; $P = .023$).

Conclusion: The results of this study demonstrate that throwing arm rotator cuff strength may not fully recover before the initiation of a return-to-throwing program after UCLR. These data provide a potential framework for clinicians to assist in the management and exercise prescription of the baseball athlete after UCLR and before medical release and the initiation of a return-to-throwing program.

Keywords: baseball; UCL; elbow; rotator cuff

The ulnar collateral ligament (UCL) is the primary restraint to valgus force at the elbow during the baseball throwing motion.[14] Throughout the last 3 decades, there has been a documented and steep rise in primary and revision UCL reconstruction (UCLR).[7,9,25,45] Up to 25% of major league pitchers and 15% of minor league pitchers have reported a history of primary UCLR.[9] Revision rates of 15% to 37% for baseball pitchers[25,45] and 3.4% to 8.2% for position players[7] have been reported after primary UCLR in professional baseball. While revision rates may vary among positions in baseball, it is well-established that decreased performance and career longevity are significantly diminished after surgery, making the focus of clinical outcomes after primary UCLR of paramount impact.[3,26]

A number of risk factors for excessive UCL stress and potential UCL injury or reinjury have been identified in the literature: glenohumeral range of motion measures,[16,40] measures of throwing volume,[1,34] kinetic chain deficits,[15,18] and parameters of pitching performance.[2,4,13,29,31,39] Decreases in rotator cuff strength have also been linked

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to risk for elbow injury.[6,17,38] Tyler et al[38] noted a relationship between decreased supraspinatus strength and increased relative internal rotation (IR) strength and its association to elbow pain during overhand throwing. Preseason external rotation (ER) weakness has been associated with throwing-related, time loss injuries that required surgery in a cohort of professional baseball pitchers.[6] More specific to a UCL-injured cohort, baseball players with confirmed UCL injury have demonstrated decreased rotator cuff strength at the time of injury.[17] These studies identified a potential association between rotator cuff strength and elbow injury risk but did not address the relationship of rotator cuff strength after UCL injury and its relationship to secondary injury or return to prior level of competition.

The rotator cuff is one component of the kinetic chain that transfers the forces necessary to obtain high-velocity throws while controlling the stresses placed across the medial elbow, especially in the late cocking and acceleration phases.[8] Therefore, baseball players looking to return to preinjury throwing performance after UCLR must demonstrate adequate muscular force before the initiation of a return-to-throwing program. However, to date, no studies have examined rotator cuff strength at the time of return to throwing after UCLR.

The purpose of this study was to compare isometric IR and ER strength of the throwing and nonthrowing shoulders in male baseball players diagnosed with UCL tears with that of healthy age-matched baseball players at the time of return to throwing. It was hypothesized that baseball players who underwent UCLR would demonstrate significant decreases in IR and ER strength in the throwing arm as compared with that of healthy players.

METHODS

Participants

This was a cohort study with institutional review board approval. Competitive high school and collegiate baseball players from across the United States were recruited to participate in this study. Male athletes who underwent UCLR were compared with healthy controls without a UCL tear matched by age, height, weight, and position. Assent and/or consent was collected before enrollment in the study.

Participants were considered for the study if they were a baseball athlete between the ages of 15 and 25 years. Inclusion criteria for the UCLR group were (1) an inability to throw as the result of an injury, (2) an inability to continue pitching or throwing in baseball at the level before the UCL injury, (3) clinical examination results positive for a UCL tear, (4) confirmation of a UCL tear via magnetic resonance imaging, and (5) intent to return to prior level of competition after UCLR and subsequent postoperative rehabilitation. Exclusion criteria were revision of primary UCLR, any full-thickness chondral defects >1 cm^2, and previous shoulder surgery for labral or rotator cuff pathology. Participants in the healthy group were included in this study if the baseball athlete (1) was between 15 and 25 years old, (2) had no history of UCLR or UCL repair, (3) had no history of shoulder surgery for labral or rotator cuff pathology in the past year, and (4) had no complaints of elbow or shoulder pain that limited or restricted recent participation. An investigator within our outpatient sports medicine clinic screened eligible participants and subsequently enrolled each individual who met the study criteria.

A total of 86 male competitive high school and collegiate baseball athletes participated in this study: 43 in the UCLR group and 43 in the healthy group. Figure 1 shows the recruitment process.

Surgical Procedure and Rehabilitation

The diagnosis of an elbow UCL tear was made by a fellowship-trained, board-certified orthopaedic surgeon (J.E.C.) and confirmed via magnetic resonance imaging. Participants who sustained a UCL tear were recruited during the initial evaluation by the participating physician (J.E.C.) and physical therapist (J.C.G.). All athletes in the UCLR group had surgery performed by the participating physician (J.E.C.) using the contralateral palmaris longus tendon graft; if the palmaris longus was absent in the contralateral extremity, the gracilis tendon graft was used.[23] If the athlete's contralateral palmaris longus tendon was available for a graft choice, a modified docked figure-of-8 procedure was performed[30]; if absent, the ipsilateral gracilis tendon graft was used via a docking method.[33]

Athletes in the UCLR group attended formal physical therapy with a standardized rehabilitation protocol (see Appendix Table A1) at the outpatient sports medicine clinic if they lived within a commutable distance. Those in the

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Ethical approval for this study was obtained from Texas Health Resources (STU-2019-1190).

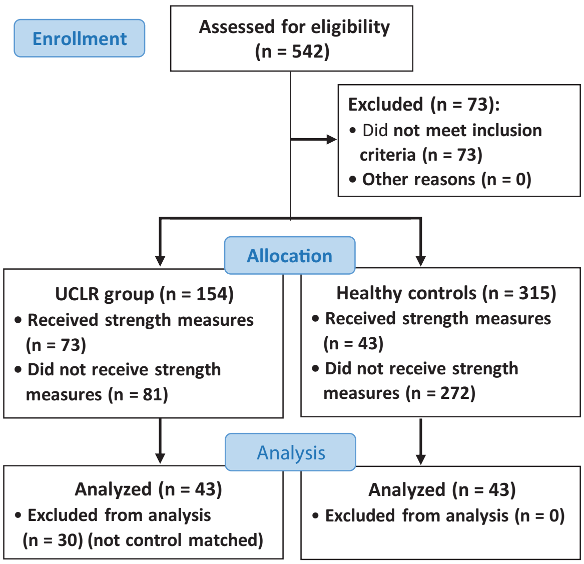

Figure 1. Flowchart of study enrollment process. UCL, ulnar collateral ligament.

UCLR group who were unable to be seen at the outpatient sports medicine clinic participated in formal physical therapy in closer proximity to their homes with the same standardized rehabilitation protocol. Each patient attending formal physical therapy outside of the sports medicine clinic was evaluated by a board-certified, residency-trained sports physical therapist at each physician follow-up (every 4-6 weeks). During the follow-up visit, the participants were provided with written recommendations to improve their standardization of care based on input from the treating surgeon and objective clinical data as measured by the sports physical therapist. The participants of the healthy group were recruited from local high schools and colleges, and all were healthy at the time of data collection.

Rotator Cuff Strength Testing

Rotator cuff strength testing was performed in the outpatient sports medicine center for the UCLR group and at various high schools and universities for the healthy group. Strength testing was performed as previously described.[17]

Using a handheld dynamometer (HHD; MicroFET 2 [Hoggan Scientific]), the primary examiner (J.C.G.) tested bilateral IR and ER isometric rotator cuff strength via a "make test" methodology.[37] An HHD was used in place of an isokinetic testing device because it is readily available and time-efficient. Isometric rotator cuff strength testing using an HHD has been shown to be a reliable method to measure rotator cuff strength.[20,32] To minimize variability with isometric rotator cuff strength testing, measurements were taken by the primary investigator (J.C.G.) to ensure consistency. Intrarater reliability standards were established in pilot testing for isometric rotator cuff strength and found to be good: ER, intraclass correlation coefficient (2,1) = 0.94 (SEM = 1.3); IR, intraclass correlation coefficient (2,1) = 0.93 (SEM = 2.1). Stabilization was not used, per previous literature[5,32] citing high inter- and intraexaminer reliability with manual stabilization.

Figure 2. Measurement for isometric rotator cuff (A) internal and (B) external rotation strength testing. The tester is pictured to the side of the participant to allow for visualization of dynamometer placement. The participant was instructed to rotate his arm inward (internal rotation) or outward (external rotation) with maximum effort while the investigator used minimal tactile cueing at the participant's elbow to decrease frontal plane compensation.

For isometric testing, the participant sat upright facing the examiner at the end of a treatment table with the arm positioned at the side in 0° of abduction, 90° of elbow flexion, and neutral rotation of the shoulder. A seated position with neutral abduction and rotation was chosen because of the previously reported inter- and intraexaminer reliability for this position.[32] The primary examiner then placed the HHD on the dorsal or volar side of the distal radioulnar joint to assess isometric ER or IR strength, respectively. The participant was verbally cued to sit tall with scapular retraction. The primary examiner instructed the participant to rotate his arm outward (ER) or inward (IR) with maximum effort for up to 5 seconds while maintaining the testing arm at the side with the same amount of elbow flexion. Minimal tactile cueing was applied to the lateral aspect of the participant's' elbow to maintain 0° of shoulder abduction during the test, to avoid compensation in the frontal plane (Figure 2). The primary investigator utilized a 10-point visual analog scale to monitor reports of pain during testing; any participant's reported pain >2 points resulted in the exclusion of his results. The mean measurement of 2 bilateral trials was documented for IR and ER. If there was wide discrepancy in measurement during one of the trials (>3.0 N), an additional trial was recorded for consistency.

For the UCLR group, medical release for return to throwing was based on clinical examination by the participating physician (J.E.C.) and a series of objective measures and patient-reported outcomes: humeral torsion, passive glenohumeral range of motion, and rotator cuff strength, as well as the Lower Quarter Y-Balance Test and the Kerlan-Jobe Orthopaedic Clinic Questionnaire. Rotator cuff strength

TABLE 1
Participant Demographics[a]

	UCLR Group (n = 43)	Healthy Group (n = 43)	*P*
Age, y	18.1 ± 1.8	19.7 ± 1.6	.70
Height, cm	186.3 ± 6.1	186.0 ± 6.9	.50
Weight, kg	87.3 ± 9.4	87.0 ± 10.4	.69
Dominant limb			.09
Right	38	32	
Left	5	11	
Playing experience, y	13.5 ± 1.9	14.9 ± 1.9	.89
Position			.11
Pitcher	36	28	
Catcher	1	1	
Infielder	1	8	
Outfielder	5	5	
Utility	0	1	

[a]Values are reported as mean ± SD or No. of participants. UCLR, ulnar collateral ligament reconstruction.

TABLE 2
Rotator Cuff Strength at the Time of Return to Throwing After UCLR vs Healthy Controls[a]

	Rotator Cuff Strength, N		
	UCLR Group (n = 43)	Healthy Group (n = 43)	*P*
Nonthrowing arm			
ER	116.8 ± 20.2	110.1 ± 18.1	.143
IR	149.9 ± 24.2	149.9 ± 26.4	.994
Throwing arm			
ER	117.9 ± 25.8	116.5 ± 19.0	.921
IR	144.2 ± 27.8	157.6 ± 27.1	**.023**

[a]Values are reported as mean ± SD. Bold *P* value indicates statistically significant difference between groups ($P < .05$). ER, external rotation; IR, internal rotation; UCLR, ulnar collateral ligament reconstruction.

testing was assessed at time of return to throwing (mean ± SD, 194 ± 30 days) by the primary investigator (J.C.G.) at the outpatient sports medicine center. All participants in the healthy group underwent strength testing before their fall or spring baseball season using the same methods as the UCLR group.

Statistical Analysis

The mean IR and ER strength of the throwing and non-throwing shoulders was compared between the UCLR and healthy groups. Independent *t* tests and chi-square analysis, when appropriate, were used to calculate mean differences between groups for all demographic data and for shoulder ER and IR strength. The significance level was set at $P < .05$.

Post hoc power analysis was performed using G*Power 3.1, with power set at 0.80 ($1 - \beta$) and $\alpha = .05$ (2-tailed) and with a calculated effect size of 0.49 for differences in throwing arm IR between groups. This revealed a power of 0.61 for our sample size.

RESULTS

Of the 43 participants in the UCLR group, 23 were seen at our sports medicine clinic, while 20 were seen at formal physical therapy clinics in closer proximity to the participants' hometowns. Of the 43 participants in the healthy group, 29 were measured preseason, 11 postseason, and 3 midseason. No participant had to withdraw from the study because of pain during testing. Descriptive characteristics are presented in Table 1. There were no significant differences in age, height, limb dominance, or weight between the UCLR and healthy groups.

The mean values for IR and ER rotator cuff strength of the throwing and nonthrowing arms are presented in Table 2. There was no significant difference between groups with regard to nonthrowing arm shoulder ER and IR strength. There was also no significant difference between groups for throwing arm shoulder ER strength. However, the UCLR group demonstrated significantly less throwing arm shoulder IR strength as compared with the healthy group (144.2 ± 27.8 vs 157.6 ± 27.1 N; $P = .023$, $d = 0.49$).

DISCUSSION

In the present study, no differences were found for nonthrowing arm isometric ER or IR strength or for throwing arm isometric ER strength. Baseball players who underwent UCLR demonstrated decreased isometric IR strength in the throwing arm when compared with healthy controls matched by age, height, weight, and position. The results support our hypothesis regarding differences in IR strength of the throwing arm, although no differences in ER strength of the throwing arm were found.

Several studies have investigated normative and baseline data in regard to rotator cuff strength in Little League,[19] high school,[22,38] and professional baseball athletes.[6] Conflicting evidence exists regarding rotator cuff strength in these populations.[6,19,22,38] In a study of 165 uninjured high school students, Hurd et al[22] found that shoulder ER strength on the throwing limb was less than that of the nonthrowing limb, whereas IR strength was higher on the throwing limb when compared with the nonthrowing limb. Similarly, when comparing isokinetic values for concentric and eccentric rotator cuff strength in high school baseball athletes, Mulligan et al[28] found that eccentric and concentric IR strength was higher on the throwing limb than the nonthrowing limb and that eccentric and concentric ER strength was lower on the throwing limb when compared with the nonthrowing limb. One study[36] cited greater shoulder ER and IR strength on the throwing limb versus the nonthrowing limb at the end of a competitive season, suggesting that time of year may play a role in the interpretation of strength results for healthy baseball athletes. When we consider other factors that may influence strength measurements, more recent evidence suggests that there is no difference in rotator cuff strength of the throwing limb by influence of position (pitcher vs position player).[11]

Previous work[17] on rotator cuff strength in baseball players diagnosed with a UCL injury revealed significant decreases in throwing arm shoulder IR and ER strength at the time of injury when compared with healthy controls matched by age, height, and weight. These findings, in combination with the results of the current study, suggest that athletes who sustain a UCL injury may recover ER strength throughout a course of recovery and rehabilitation but may not fully recover IR strength as compared with healthy controls. Interestingly, the healthy group in our study had weaker IR strength (157.6 ± 27.1 N) than the healthy group in the Garrison et al[17] study (174.9 ± 20.7 N), despite utilizing the same methodology and measuring device and including participants who were similar in age, height, and weight. These factors suggest that the deficit in IR strength after UCLR may be larger than that in the present data set. The authors from the previous study investigating rotator cuff strength in a UCL-injured cohort[17] did note that pain may have had an influence on the deficits at the time of injury; however, a visual analog scale was used to monitor for pain during rotator cuff strength testing, and they did not report any withdrawal attributed to pain during testing.

Several studies[21,24,32] have examined normative HHD isometric rotator cuff strength data, including ER:IR strength ratios. The use of an ER:IR strength ratio may prove beneficial to quantify normal strength while correcting for differences in the chosen units of strength measured. Two studies[21,24] analyzed ER:IR strength ratios utilizing a fixed HHD.

In a study examining rotator cuff strength in a group of 20- to 29-year-old men (n = 24), Hughes et al[21] found the ER:IR strength ratio to be 0.66 per a stabilized HHD. However, the testing positions in this study for ER and IR strength differed from those in the current study. In another study of rotator cuff strength using a stabilized HHD, Kolber et al[24] reported ER:IR ratios ranging from 0.76 to 0.78; yet, their results should be used with caution when applied to the current data, as their study comprised healthy male and female participants. More recently, Riemann et al[32] analyzed the rotator cuff strength and ratios of 90 healthy men (mean age, 23.3 years) with current or past upper extremity sport participation. They utilized 3 testing procedures, including a seated-at-neutral measure of IR and ER strength similar to the procedure used in the present study. In the seated-at-neutral position, the previous authors found an ER:IR strength ratio of 0.87 on the dominant limb. In the present study, the ER:IR ratio of the dominant limb was 0.81 on average, indicating that the overall strength of the rotator cuff in our UCLR group may be decreased at the time of return to throwing as compared with a healthy population.

It is important to note that although IR strength may continue to improve after medical release and return to throwing, a structured return-to-throwing program alone may not improve shoulder IR strength. In a study[44] of 9 NCAA Division II collegiate baseball pitchers (National Collegiate Athletic Association), isokinetic IR peak torque did not change over the course of a competitive baseball season. Furthermore, IR strength was observed to decrease over the course of a season in a cohort of high school pitchers.[27] As such, it can be hypothesized from these data that neither baseball pitching nor a return to throwing progression alone will improve IR strength. This observation could be attributed to the fact that IR eccentric workload was shown to decrease after a pitching load of 60 pitches.[10] The internal rotators of the shoulder are highly active during throwing; however, the amount of muscle endurance, the type of muscle contraction required, and the overall load of the internal rotators to complete a competitive season (or a return-to-throwing program) may not be enough stimuli to see clinically and statistically meaningful strength changes. While these studies[10,27,44] may help inform how IR strength changes with throwing, they included healthy collegiate and high school baseball athletes; it is unclear how these data would translate if the same testing protocols were applied to younger postoperative UCLR athletes. Future studies are warranted to investigate changes in IR strength throughout the course of a return-to-throwing program and/or a competitive season after UCLR. Additional research is needed to identify the long-term implications of deficits in throwing arm IR strength.

The combination of previous rotator cuff strength literature in relation to elbow injury in baseball players and findings from the current study suggests that the implementation of an isolated IR strengthening exercise program throughout rehabilitation after UCLR may be beneficial. Current rehabilitation protocols typically recommend strengthening of the rotator cuff for the internal and external rotators, either directly or through co-contraction, but with an observed emphasis on posterior rotator cuff strengthening (ER strengthening).[12,43] The strength of the posterior rotator cuff and external rotators is crucial for controlling the shoulder during baseball throwing and pitching and, in turn, mitigating forces across the medial elbow.[13,35] Decreased throwing arm shoulder ER strength has also been associated with throwing-related pain in adolescent pitchers,[36] emphasizing the importance of ER strength. The data in the present study suggest that continued isolated strengthening of the internal rotators should be implemented and encouraged throughout a rehabilitation protocol to properly restore IR strength before return to throwing. With isolated rotator cuff strengthening, clinicians should continue to follow the most current recommendations for rehabilitation after UCLR that address the entire kinetic chain.[41,42]

Limitations

This study is not without limitations. The participants in the UCLR group were measured at the time of return to throwing. We do not know if IR strength would have resolved after a return-to-throwing program at the time of full, unrestricted return to play or return to performance. Additionally, these athletes were not measured before UCLR. It is possible that athletes in the UCLR group were weaker at baseline versus the healthy controls, and the potential strength deficit may have played a contributing role in the development of UCL-related pain. Future studies should consider examining longitudinal strength to determine if decreasing shoulder strength is a risk factor for the development of UCL injury.

Although a majority of the UCLR group was seen at the outpatient sports medicine center, some of the participants were unable to be seen at the same clinic. The sports physical therapists at our outpatient sports medicine center made efforts to standardize the care of these athletes via written and verbal communication with the physical therapists overseeing the postoperative rehabilitation of the injured athletes at other locations; however, the lack of ability to directly oversee and provide postoperative rehabilitation for every participant may have influenced these results.

The participants in the healthy group were recruited from local high schools and universities, with measurements performed before the fall or spring baseball season. There is currently limited evidence available to say how time of year or season may affect rotator cuff strength, but this could have influenced the results of the strength measures for the healthy group. In the present study, ER and IR strength were evaluated isometrically with the participant in a seated position and the testing arm held to the side with the elbow flexed.

Although this does not represent a functional throwing position, it does allow for better standardization and reliability among measures. Additionally, the interpretation of rotator cuff strength tested in this position should be used with caution. Given the clinical nature of this study, rotator cuff strength assessments are subject to the involvement of secondary stabilizing muscles. Specifically, the deficits observed in IR strength may be attributed to rotator cuff weakness and potential contribution from the pectoralis major and latissimus dorsi muscles. To reduce the influence of these factors, patient cuing and training of the assessors were performed, as demonstrated by the acceptable level of measurement reliability.

Finally, post hoc analysis for the current study revealed 0.61 power with the current sample size. To reach appropriate statistical power (0.80), we would have needed to recruit 48 more participants (24 per group). This could change the results of significance testing with the addition of more participants.

CONCLUSION

Baseball players who underwent UCLR demonstrated decreased shoulder IR rotator cuff strength at the time of return to throwing when compared with healthy controls. These data provide a potential framework for clinicians in the treatment of baseball athletes after UCLR to ensure that rotator cuff strength has been adequately restored. Knowledge of these strength deficits may assist the clinician in the management and exercise prescription of the baseball athlete after UCLR and before medical release and the initiation of a return-to-throwing program.

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REFERENCES

1. Agresta CE, Krieg K, Freehill MT. Risk factors for baseball-related arm injuries: a systematic review. *Orthop J Sports Med*. 2019;7(2): 2325967119825557.
2. Aguinaldo AL, Chambers H. Correlation of throwing mechanics with elbow valgus load in adult baseball pitchers. *Am J Sports Med*. 2009; 37(10):2043-2048.
3. Andrews JR, Venkateswaran V, Christensen KD, et al. Outcomes after ulnar collateral ligament revision reconstruction in baseball players. *Am J Sports Med*. Published online October 21, 2020. doi:10.1177/0363546520951529
4. Anz AW, Bushnell BD, Griffin LP, Noonan TJ, Torry MR, Hawkins RJ. Correlation of torque and elbow injury in professional baseball pitchers. *Am J Sports Med*. 2010;38(7):1368-1374.
5. Beshay N, Lam PH, Murrell GA. Assessing the reliability of shoulder strength measurement: hand-held versus fixed dynamometry. *Shoulder Elbow*. 2011;3(4):244-251.
6. Byram IR, Bushnell BD, Dugger K, Charron K, Harrell FE Jr, Noonan TJ. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. *Am J Sports Med*. 2010;38(7):1375-1382.
7. Camp CL, Conte S, D'Angelo J, Fealy SA. Following ulnar collateral ligament reconstruction, professional baseball position players return to play faster than pitchers, but catchers return less frequently. *J Shoulder Elbow Surg*. 2018;27(6):1078-1085.
8. Chu SK, Jayabalan P, Kibler WB, Press J. The kinetic chain revisited: new concepts on throwing mechanics and injury. *PM R*. 2016;8: S69-S77.
9. Conte 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.
10. Dale RB, Kovaleski JE, Ogletree T, Heitman RJ, Norrell PM. The effects of repetitive overhead throwing on shoulder rotator isokinetic work-fatigue. *N Am J Sports Phys Ther*. 2007;2(2):74.
11. Dodds FT, Knotts S-LS, Penrod MI, Scoggins WA, Conners RT. Shoulder strength and range of motion between collegiate pitchers and position players in baseball. *Int J Exerc Sci*. 2020;13(6):123.
12. Ellenbecker TS, Wilk KE, Altchek DW, Andrews JR. Current concepts in rehabilitation following ulnar collateral ligament reconstruction. *Sports Health*. 2009;1(4):301-313.
13. 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.
14. Fleisig GS, Barrentine SW, Escamilla RF, Andrews JR. Biomechanics of overhand throwing with implications for injuries. *Sports Med*. 1996; 21(6):421-437.
15. Garrison JC, Arnold A, Macko MJ, Conway JE. Baseball players diagnosed with ulnar collateral ligament tears demonstrate decreased balance compared to healthy controls. *J Orthop Sports Phys Ther*. 2013;43(10):752-758.
16. Garrison JC, Cole MA, Conway JE, Macko MJ, Thigpen C, Shanley E. Shoulder range of motion deficits in baseball players with an ulnar collateral ligament tear. *Am J Sports Med*. 2012;40(11):2597-2603.
17. Garrison JC, Johnston C, Conway JE. Baseball players with ulnar collateral ligament tears demonstrate decreased rotator cuff strength compared to healthy controls. *Int J Sports Phys Ther*. 2015;10(4):476.
18. Hannon J, Garrison JC, Conway J. Lower extremity balance is improved at time of return to throwing in baseball players after an ulnar collateral ligament reconstruction when compared to preoperative measurements. *Int J Sports Phys Ther*. 2014;9(3):356.

19. Harada M, Takahara M, Mura N, Sasaki J, Ito T, Ogino T. Risk factors for elbow injuries among young baseball players. *J Shoulder Elbow Surg*. 2010;19(4):502-507.
20. Hayes K, Walton JR, Szomor ZL, Murrell GA. Reliability of 3 methods for assessing shoulder strength. *J Shoulder Elbow Surg*. 2002;11(1):33-39.
21. Hughes RE, Johnson ME, O'Driscoll SW, An K-N. Normative values of agonist-antagonist shoulder strength ratios of adults aged 20 to 78 years. *Arch Phys Med Rehabil*. 1999;80(10):1324-1326.
22. Hurd WJ, Kaplan KM, ElAttrache NS, Jobe FW, Morrey BF, Kaufman KR. A profile of glenohumeral internal and external rotation motion in the uninjured high school baseball pitcher, part II: strength. *J Athl Train*. 2011;46(3):289-295.
23. Ioannis D, Anastasios K, Konstantinos N, Lazaros K, Georgios N. Palmaris longus muscle's prevalence in different nations and interesting anatomical variations: review of the literature. *J Clin Med Res*. 2015;7(11):825.
24. Kolber MJ, Beekhuizen K, Cheng M-SS, Fiebert IM. The reliability of hand-held dynamometry in measuring isometric strength of the shoulder internal and external rotator musculature using a stabilization device. *Physiother Theory Pract*. 2007;23(2):119-124.
25. Liu JN, Garcia GH, Conte S, ElAttrache N, Altchek DW, Dines JS. Outcomes in revision Tommy John surgery in major league baseball pitchers. *J Shoulder Elbow Surg*. 2016;25(1):90-97.
26. Marshall NE, Keller RA, Lynch JR, Bey MJ, Moutzouros V. Pitching performance and longevity after revision ulnar collateral ligament reconstruction in Major League Baseball pitchers. *Am J Sports Med*. 2015;43(5):1051-1056.
27. McHugh MP, Tyler TF, Mullaney MJ, Mirabella MR, Nicholas SJ. The effect of a high pitch volume on musculoskeletal adaptations in high school baseball pitchers. *Am J Sports Med*. 2016;44(9):2246-2254.
28. Mulligan IJ, Biddington WB, Barnhart BD, Ellenbecker TS. Isokinetic profile of shoulder internal and external rotators of high school aged baseball pitchers. *J Strength Cond Res*. 2004;18(4):861-866.
29. Norton R, Honstad C, Joshi R, Silvis M, Chinchilli V, Dhawan A. Risk factors for elbow and shoulder injuries in adolescent baseball players: a systematic review. *Am J Sports Med*. 2019;47(4):982-990.
30. 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.
31. Portney DA, Buchler LT, Lazaroff JM, Gryzlo SM, Saltzman MD. Influence of pitching release location on ulnar collateral ligament reconstruction risk among Major League Baseball pitchers. *Orthop J Sports Med*. 2019;7(2):2325967119826540.
32. Riemann BL, Davies GJ, Ludwig L, Gardenhour H. Hand-held dynamometer testing of the internal and external rotator musculature based on selected positions to establish normative data and unilateral ratios. *J Shoulder Elbow Surg*. 2010;19(8):1175-1183.
33. Rohrbough JT, Altchek DW, Hyman J, Williams RJ, Botts JD. Medial collateral ligament reconstruction of the elbow using the docking technique. *Am J Sports Med*. 2002;30(4):541-548.
34. Salamh P, Jones E, Bashore M, Liu X, Hegedus EJ. Injuries and associated risk factors of the shoulder and elbow among adolescent baseball pitchers: a systematic review and meta-analysis. *Phys Ther Sport*. 2020;43:108-119.
35. Seroyer ST, Nho SJ, Bach BR, Bush-Joseph CA, Nicholson GP, Romeo AA. The kinetic chain in overhand pitching: its potential role for performance enhancement and injury prevention. *Sports Health*. 2010;2(2):135-146.
36. Trakis JE, McHugh MP, Caracciolo PA, Busciacco L, Mullaney M, Nicholas SJ. Muscle strength and range of motion in adolescent pitchers with throwing-related pain: implications for injury prevention. *Am J Sports Med*. 2008;36(11):2173-2178.
37. Turner N, Ferguson K, Mobley BW, Riemann B, Davies G. Establishing normative data on scapulothoracic musculature using handheld dynamometry. *J Sport Rehabil*. 2009;18(4):502-520.
38. Tyler TF, Mullaney MJ, Mirabella MR, Nicholas SJ, McHugh MP. Risk factors for shoulder and elbow injuries in high school baseball pitchers: the role of preseason strength and range of motion. *Am J Sports Med*. 2014;42(8):1993-1999.
39. Werner SL, Murray TA, Hawkins RJ, Gill TJ. Relationship between throwing mechanics and elbow valgus in professional baseball pitchers. *J Shoulder Elbow Surg*. 2002;11(2):151-155.
40. Whitt S, Garrison JC, Creed K, Giesler L, Conway JE. Baseball players diagnosed with ulnar collateral ligament tears demonstrate greater side to side differences in passive glenohumeral abduction range of motion compared to healthy controls. *Int J Sports Phys Ther*. 2019;14(3):353.
41. Wilk KE, Arrigo CA, Hooks TR, Andrews JR. Rehabilitation of the overhead throwing athlete: there is more to it than just external rotation/internal rotation strengthening. *PM R*. 2016;8:S78-S90.
42. Wilk KE, Hooks TR. Rehabilitation of the throwing athlete: where we are in 2014. *Clin Sports Med*. 2015;34(2):247-261.
43. Wilk KE, Yenchak A, Arrigo CA, Andrews JR. The advanced throwers ten exercise program: a new exercise series for enhanced dynamic shoulder control in the overhead throwing athlete. *Phys Sportsmed*. 2011;39(4):90-97.
44. Wilkin LD, Haddock BL. Isokinetic strength of collegiate baseball pitchers during a season. *J Strength Cond Res*. 2006;20(4):829.
45. Wilson AT, Pidgeon TS, Morrell NT, DaSilva MF. Trends in revision elbow ulnar collateral ligament reconstruction in professional baseball pitchers. *J Hand Surg Am*. 2015;40(11):2249-2254.

APPENDIX

TABLE A1
UCLR Rehabilitation Protocol[a]

General information
Texas Health Sports Medicine protocol assumes no detachment of flexor/pronator mass during surgery
Mean time to return to play: 11.6 mo (range, 9-13 mo)
Longer for professional pitchers and shorter for position players
No valgus stress for first 8 wk
Be aware of importance of kinetic chain, including lower extremities, trunk, and shoulder rehabilitation, for this protocol
Maintain cardiovascular fitness as appropriate
ROM must be recovered in a gentle, controlled manner
Return to sport
• Light tossing: ~4 mo
• Throwing off of mound: ~6-8 mo

(continued)

Table A1 (continued)

General information

Splint/sling care

- Splint to be worn for the first 10-14 d
- Keep splint dry and clean. Bag for shower
- Ultra sling to be worn for the first 3 wk

Milestones

Posterior split to be worn for first 10 d
Ultra sling: 0-3 wk
AROM: 0-3 wk
Strengthening: 6-12 wk
Integrated strengthening: 12-16 wk
Plyometrics: 12-16 wk
Throwing: 4 mo

Rehabilitation routine

Days 1-10

Soft ball or putty squeezes
Stationary bike

Days 11-21

Discontinue splint
Sling to be worn day and night for first 3 wk
AROM performed only for the first 3 wk unless patient presents with elbow stiffness

- Begin to recover elbow extension in neutral position: work elbow extension in all 3 positions (neutral, pronated, and supinated)
- Full AROM for pronation and supination as tolerated
- Full AROM wrist radial and ulnar deviation as tolerated
- Full AROM and AAROM of wrist flexion and extension
- Gentle stretching of wrist and fingers is permitted: should be performed at 90° of elbow flexion

Full AROM of shoulder
Shoulder: scapular positioning—emphasis on retraction and depression
Trunk: drawing in, bridge-ups, crunch, diagonal crunch
Lower extremity: body weight squat, calf raises, SLB

Weeks 4-8

Gradually achieve full elbow ROM
Full ROM should be achieved by week 6. Patient will need to perform extension loss program if full ROM not achieved by this time.

- Increase total end range time
- Beneficial for patients with a stiff elbow

Can add light resistance 1 mo postoperatively; can use resistance proximal to elbow joint

- Forearm, wrist, hand
- Scapular and rotator cuff muscle strengthening
- Trunk strengthening, stabilization
- Lower extremity strength and neuromuscular control exercises

Body weight leg strengthening and balance programs performed during rehabilitation off-days
Continue aerobic conditioning: stationary bike, elliptical, or swim exercise
Modalities as necessary
Neuromuscular reeducation

- Consider angular replication, end-range reproduction exercises

Home exercise program

- Continue to encourage ROM/flexibility
- When patient achieves full elbow extension, add combined finger, wrist, and elbow extension

2-3 mo

Program should be focused on full recovery of total body conditioning. Emphasis on trunk, scapular, and rotator cuff strengthening
Full ROM combined finger, wrist, elbow
Can begin light shoulder internal rotation
Full-range external rotation strengthening

- Excessive glenohumeral joint external rotation produces a valgus moment at elbow

Specific flexor capri ulnaris and flexor digitorum superficialis exercises

- May assist to resist valgus stress attributed to orientation

Begin eccentric biceps work between weeks 9 and 10

- Eccentric muscle control of the elbow prevents pathologic olecranon contact within the humeral fossa

(continued)

Table A1 (continued)

Rehabilitation routine
3-5 mo
This is the "preparation for return to throw" phase
• Integrated strengthening
• Body blade
• Manuals/PNF
• "Mirror" drills
• Plyometrics
Initiate plyometric drills (start with 2-handed drills, then progress to 1-handed drills)
Athlete should complete 4 wk of plyometric drills before progressing interval throwing program
Throwing program is initiated between the fourth or fifth months. Must have medical clearance.
Special considerations
Posture
Scapulary dyskinesis
GIRD/GERD
GH TROM
Humeral torsion
Hip ROM
Hip abduction weakness
Throwing mechanics

[a]AAROM, active assisted range of motion; AROM, active range of motion; GERD, glenohumeral external rotation deficit; GH, glenohumeral; GIRD, glenohumeral internal rotation deficit; PNF, proprioceptive neuromuscular facilitation; ROM, range of motion; SLB, single limb balance; TROM, total rotational range of motion; UCLR, ulnar collateral ligament reconstruction.