Professional Pitchers Display Differences in UCL Morphology and Elbow Gapping During Moving Valgus Stress Testing After UCL Reconstruction

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Background: Ulnar collateral ligament (UCL) reconstruction (UCLR) of the elbow has received much attention given the rise in incidence among baseball pitchers. Stress ultrasonography has been demonstrated to be a critical evaluation tool of the UCL. No study has dynamically evaluated the ability of UCLR to restore normal kinematics.

Purpose/Hypothesis: The purpose of this study was to compare ulnohumeral gapping during a moving valgus stress test as well as UCL thickness between professional pitchers with and without UCLR. We hypothesized that the ulnohumeral joint will display greater gapping and the UCL graft will be thicker in pitchers after UCLR compared with uninjured pitchers.

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

Methods: Ultrasonography was used to measure the medial ulnohumeral joint distance and the UCL thickness of 70 asymptomatic professional baseball pitchers; 6 of the participants had a history of UCLR. Images were captured of the dominant (D) and nondominant (ND) elbows at the maximal cocking position under 2 loaded conditions within the moving valgus stress test arc: (1) gravity stress and (2) 2.5 kg (5.5 lb) of valgus force using a dynamometer. Intra- and interrater reliability of the measurements was established with intraclass correlation coefficients (ICCs). Separate mixed-model analyses of variance (D side $\times$ UCL) were used to compare the D and ND elbow variables between pitchers with and without a history of UCLR.

Results: All measurements displayed good reliability according to ICCs. Pitchers with a history of UCLR demonstrated less gapping (5.6 ± 2.9 vs 4.2 ± 1.2 mm; $P = .002$) and greater UCL graft thickness (0.17 ± 0.07 vs 0.11 ± 0.08 mm; $P = .03$) compared with the native ligament in pitchers without prior UCL injury.

Conclusion: Our data demonstrated that the UCLR results in a thicker, stiffer construct with less medial elbow gapping than the anatomical UCL. Using ultrasound to evaluate the UCL was a reliable, efficient, and clinically feasible method to assess UCL thickness and joint gapping in players with a history of UCLR. Future studies may consider this approach to evaluate surgical techniques and graft types for UCLR.

Keywords: ulnar collateral ligament; ultrasound; moving valgus stress test; baseball

Incidence of ulnar collateral ligament (UCL) injuries has been on the rise among pitchers from the high school level[19] to the professional level.[21] Many physical and performance factors contribute to this problem, which has garnered much attention nationally.[8,12,13,17,19] UCL injury leads to significant loss of velocity and inability to pitch. UCL reconstruction (UCLR) is considered the gold standard surgical procedure allowing pitchers to return to competitive play.

The mechanics of pitching contributing to UCL injury are well described, with valgus torque increasing across the elbow during the late cocking and early acceleration phases of throwing,[6,7,9,18] where the elbow ranges from approximately 70° to 120° of flexion.[16] The UCL, in particular the anterior bundle, is the main stabilizer of the elbow to valgus stress and is prone to injury with repetitive stress.[3]

UCL injuries are diagnosed through a combination of symptom history, physical examination, and imaging-stress radiographs, magnetic resonance imaging (MRI), or ultrasonography. O'Driscoll et al[16] characterized the moving valgus stress test to reproduce the provocative range

The Orthopaedic Journal of Sports Medicine, 9(11), 23259671211035734
DOI: 10.1177/23259671211035734

of the pitching arc as a dynamic means to assess UCL integrity. A positive "moving valgus stress test" on physical examination with medial-sided elbow pain may be indicative of an injury to the UCL.

Static imaging studies such as MRI are very useful for showing details of soft tissue injury, but they do not provide any functional or dynamic assessment of the UCL. Furthermore, abnormal UCL MRI findings may be misleading and they have been reported in 65% to 87% of asymptomatic baseball players.[10,11] Stress ultrasound (US) may improve diagnostic evaluation of the throwing elbow during a dynamic assessment by applying a valgus force, as experienced with throwing. Several studies using stress ultrasonography have revealed UCL thickening in the dominant (D) elbow as well as increased medial joint space gapping compared with the nondominant (ND) elbow in asymptomatic baseball players.[1,2,4,15] However, these studies were performed with an elbow flexion angle of 30° due to the constraints of the valgus stress testing apparatus (Telos device), which is ineffective at greater flexion angles.[4] Not only is this not representative of the elbow flexion position of maximal valgus force during throwing, it is also not easily reproducible in the office or training room setting, limiting its clinical application.

In the current study, we hypothesized that US evaluation during the moving valgus stress test arc in professional pitchers with a history of UCLR will display less ulnohumeral joint gapping and greater UCL graft thickness compared with the native ligament in pitchers without UCLR. No studies have reported on UCL characteristics using this stress ultrasonography method, and few studies have reported on the UCL graft after UCLR using stress ultrasonography.

METHODS

Ultrasonography was used to assess medial ulnohumeral joint distance and UCL thickness of 70 asymptomatic professional baseball pitchers during spring training. The sample contained a majority of right-handed pitchers (49 right; 21 left) and had an average age of 23 ± 3 years. All players were asymptomatic and participating fully in spring training activities at the time of assessment. Six of the 70 athletes had a history of UCLR on the D throwing elbow (9%).

A 5-MHz linear-array transducer (FUJIFILM Sonosite Inc., Bothell, WA, USA) using standard transducer gel was used to capture images of the D and ND throwing elbows under 2 valgus-loaded conditions statically at 90° of flexion and within the moving valgus stress test arc in a similar manner to the moving valgus stress examination.[16] The maximal joint distance was observed on the US image with (1) valgus gravity stress and (2) 2.5 kg (5.5 lb) of valgus load applied at the wrist using a handheld dynamometer with digital readout (microFET-2; Hoggan Scientific). Pitchers were imaged lying in the supine position with 90° of shoulder abduction with a towel roll between the upper arm and the examination table. The distal humerus was held as a fulcrum by the examiner placing a moving valgus stress, while another examiner with extensive formal US training controlled the US transducer. The handheld dynamometer was placed at the ulnar styloid on all participants (Figure 1). Two separate trials were recorded on each extremity within each testing participant.

A short series of sagittal US images were saved from the moving valgus stress US examination, and then the single image was selected of the maximal ulnohumeral gapping (Figure 2). Ulnohumeral joint distances and UCL thickness were measured in both stressed conditions and compared between the D and ND elbows. Ulnohumeral joint distance was measured by a straight line between the peaks of the medial humeral trochlea and sublime tubercle at the joint line (Figure 2A). UCL thickness was measured from the most superficial border of the UCL to the deepest portion of the UCL defined by the perpendicular line from the peak of the medial humeral trochlea. All measurements were performed by 2 sports medicine fellowship–trained physicians using the OsiriX platform (Pixmeo SARL) on identical computing devices.

The physicians performing the stress US examination and those selecting the images (M.J.K., J.C.) were blinded to arm dominance and UCL status as much as possible.

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Final revision submitted February 4, 2021; accepted February 25, 2021.

One or more of the authors has declared the following potential conflict of interest or source of funding: M.J.K. has received educational support from Arthrex and Peerless Surgical, consulting fees from Arthrex, speaking fees from Arthrex, and hospitality payments from Exactech. C.A.T. has received research support from Arthrex and Neurotech-Kneehab, consulting fees from Breg, speaking fees from Arthrex, and stock/stock options in Players Health and Trex. D.J.G. has received educational support from Arthrex and hospitality payments from Encore Medical, Mid-Atlantic Surgical, Smith & Nephew, and Stryker. M.L.S. has received educational support from Arthrex. D.J.W. has received research support from Zimmer Biomet; educational support from Peerless Surgical; consulting fees from Arthrex, Ceterix, and Zimmer Biomet; and speaking fees from Arthrex. R.J.H. has received grant support from Encore Medical, educational support from Arthrex, consulting fees from Arthrex and Pacira Pharmaceuticals, speaking fees from Arthrex, and royalties from Encore Medical. T.J.N. has received educational support from Gemini Mountain and consulting fees from Stryker. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from Greenville Health System (ID No. Pro00004915).

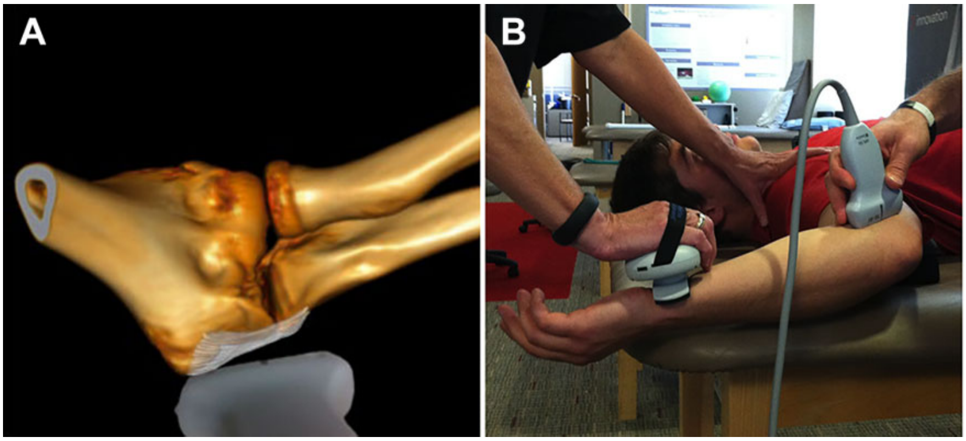

Figure 1. Medial ulnohumeral joint distance and UCL thickness imaging. (A) Graphic displaying the ultrasound placement to obtain the medial ulnohumeral joint distance and UCL thickness. (B) The shoulder is positioned within the coronal plane with a towel roll placed under the distal humerus, while the moving valgus stress is applied via a handheld dynamometer at a standard load of 2.5 kg (5.5 lb). UCL, ulnar collateral ligament. Image previously published in Mayer BK, Shanley E, Bailey LB, et al. Predictive risk of ulnar collateral ligament injury based on ligament morphology and dynamic abnormalities in professional baseball pitchers using stress ultrasonography. *Orthop J Sports Med*. 2015;3(7 suppl 2): 2325967115S00162.

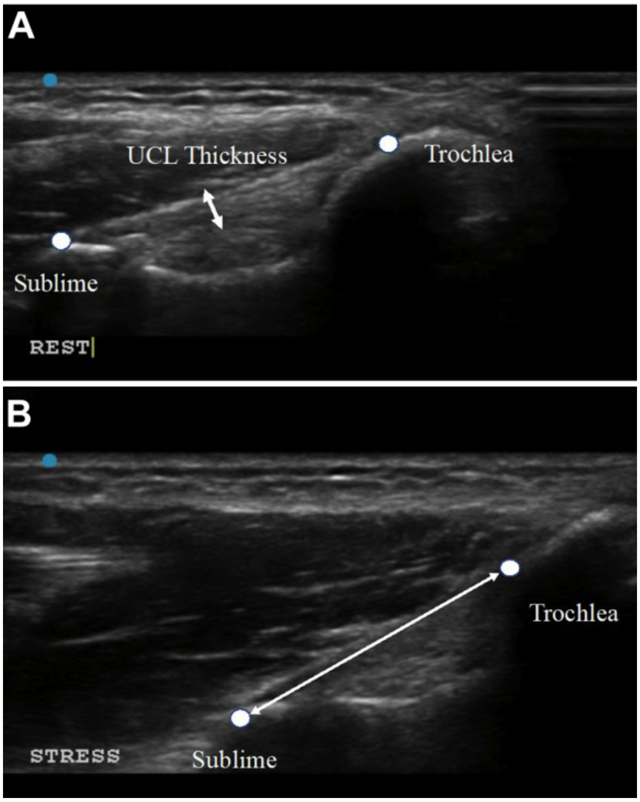

Figure 2. (A) Ulnar collateral ligament (UCL) thickness measured as the superficial to deep margins perpendicular to the line bisecting the joint. The arrows represent the thickness of the UCL. The white dots represent the insertion of the UCl on the trochlea and sublime tubercle. (B) Stress view of the medial elbow gapping was measured at rest between the sublime tubercle and the medial trochlea.

During physical examination, it was impossible not to see which arm was D due to adaptations or UCLR scars, and as the UCLR clearly appears different during image measurement, there was no way to blind this portion of the process.

Intra- and interrater reliability was established by calculating the intraclass correlation coefficient (ICC) and standard error of measurement (SEM) for each testing parameter. All variables were assessed for normality before analyses. A 1-way analysis of variance (ANOVA) using averaged rater values was used to establish the significance between D and ND elbow conditions. Separate mixed-model ANOVAs (arm dominance $\times$ UCL) were used to compare D and ND arm variables between pitchers with UCLR and those who never had a UCL injury ($\alpha = .05$). The minimal detectable change was calculated using the following formula: $1.96 \times \text{SEM} \times \sqrt{2}$.

RESULTS

All measures displayed good reliability, with ICCs ranging from $\text{ICC}_{(2,1)} = 0.94$ to 0.98 (SEM = 0.14-0.26 mm) for intrarater reliability and $\text{ICC}_{(2,\ k)} = 0.82$ to 0.87 (SEM = 0.38-0.65 mm) for interrater reliability (Table 1). The average ulnohumeral joint distance with valgus gravity stress was significantly greater in D elbows versus in ND elbows, respectively (4.1 ± 1.2 vs 3.6 ± 0.84 mm; $P = .001$). The D arm of uninjured pitchers demonstrated greater gapping compared with the ND arm (5.4 ± 1.2 vs 4.7 ± 0.86 mm; $P = .001$). However, pitchers with UCLR demonstrated less gapping compared with pitchers without UCLR (4.2 ± 1.2 vs 5.6 ± 2.9 mm; $P = .002$) (Figure 3). The average UCL thickness in UCLR was significantly greater in D elbows compared with ND elbows (1.1 ± 0.09 vs 1.65 ± 0.11 mm; $P <$ .03). Furthermore, the pitchers with UCLR demonstrated

TABLE 1
Reliability of Ultrasound Measurements[a]

	Dominant Elbow			Nondominant Elbow		
	ICC	SEM (mm)	MDC (mm)	ICC	SEM (mm)	MDC (mm)
Intrarater reliability						
Gravity valgus	0.98	0.14	0.39	0.98	0.17	0.47
Loaded valgus	0.99	0.02	0.07	0.97	0.11	0.30
UCL thickness	0.94	0.07	0.19	0.99	0.16	0.44
Interrater reliability						
Gravity valgus	0.87	0.38	1.1	0.82	0.43	1.2
Loaded valgus	0.84	0.43	1.2	0.84	0.65	1.8
UCL thickness	0.84	0.47	1.3	0.59	0.73	2.0

[a]ICC, intraclass correlation coefficient; MDC, minimal detectable change; SEM, standard error of measure; UCL, ulnar collateral ligament.

greater graft thickness (1.1 ± 0.08 mm vs 0.17 ± 0.07; $P = .03$) compared with the native UCL of D arms in pitchers without UCL injury (Figure 3).

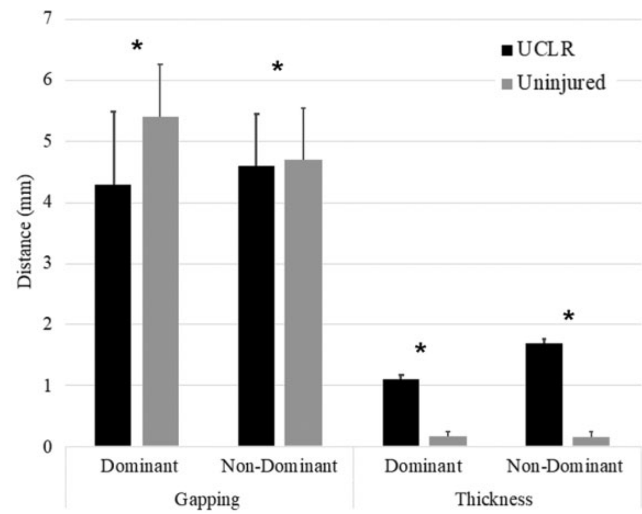

Figure 3. Pitchers with a history of UCLR demonstrated less gapping and thicker UCL graft compared with pitchers without a history of UCLR. *Statistically significant difference. UCL, ulnar collateral ligament; UCLR, ulnar collateral ligament reconstruction.

DISCUSSION

To our knowledge, this is the first study to utilize stress ultrasonography as a clinically applied tool to assess the provocative pitching arc of motion associated with the moving valgus stress test. Our results show that this approach is reproducible in pitchers' elbows after UCLR. Pitchers with UCLR demonstrated less gapping and a thicker UCL graft compared with pitchers without a history of UCLR. This suggests ultrasonography during the moving valgus stress test is applicable in the evaluation of the throwing elbow.

Our study also showed that greater pitching elbow UCL thickness (3.4 mm [D arm] vs 2.8 mm [ND arm]; $P < .001$) was consistent with previous studies. Nazarian et al[15] reported mean thickness of 6.3 mm in D arms versus 5.3 mm in ND arms and Ciccotti et al[4] reported measurements of 6.15 mm in D arms versus 4.82 mm in ND arms. Although our absolute measurements were smaller, Popovic et al[20] reported mean UCL thickness of 1.68 mm in D arms and 1.21 mm in ND arms, showing that some discrepancy can be explained by different measurement techniques,[15,24] although all studies reported a trend toward thicker UCLs in D arms.

The greater UCL thickness across all D elbows may represent adaptive change to repetitive stress or pathologic response to repetitive trauma and may be related to medial joint space opening in throwers. This was suggested by Ciccotti et al,[4] who reported a weak positive correlation between ligament thickness and joint space widening with stress. This is consistent with our prior results showing that pitchers who displayed greater gapping were more likely to sustain a UCL injury in the next season.[23] This suggests that extent of ligament thickness and joint space widening could indicate an "at risk" throwing elbow. In a separate subgroup analysis of players aged 17 to 21 years within the Ciccotti et al cohort, Atanda et al[2] reported that UCL thickness increased with increasing years of professional pitching experience and may represent the earliest UCL change that occurs with throwing. They subsequently further supported this assertion in a group of 102 youth pitchers (ages 12-18 years), finding a significant difference in UCL thickness between age groups (12-14 and 15-18 years) but no difference in change in joint space.[1] Tajika et al[26] reported a greater difference in UCL thickness on the throwing elbow in high school pitchers with a history of elbow pain with throwing compared with pitchers without a history of symptoms.[26] They also found a significant negative association between UCL thickness and a self-evaluation score for pitching performance.

In the current study, 6 professional pitchers underwent UCLR after sustaining an injury to the UCL. All were more than 18 months from surgery, asymptomatic, and back to competitive play. We observed that mean graft thickness was significantly greater in the 6 pitchers after UCLR compared with unoperated native UCLs as well as significantly decreased ulnohumeral gapping compared with their ND arm and the D arms in uninjured pitchers. This is in contrast to the study by Merolla et al[14] that showed intact grafts with slight medial laxity with the valgus stress maneuver. However, their cohort was very heterogeneous, only included 6 overhead athletes (out of 15) in addition to various injury mechanisms such as elbow dislocations/trauma, different graft selection (autograft/allograft), and different surgical techniques. They also failed to report any quantitative measurements of medial joint opening, elbow flexion angle used, or amount or method of stress applied. Although our UCLR numbers were small, it seems that surgery can reduce some of the medial gapping that occurs whether acute or chronically/progressively and stress ultrasonography could be a useful tool to assess the integrity of the reconstruction construct after UCLR or to evaluate for reinjury.

Additionally, the magnitude of medial elbow joint space opening was similar to prior reports using techniques that are not clinically applicable. This suggests that a functional stress to the throwing arm using US to image the UCL and gapping appears to provide a reliable and clinically relevant method to assess the throwing elbow. We believe that this approach allows for the bony and ligamentous variability between pitchers and isolates the anterior band of the UCL, as opposed to prior methods in an extended position.

While multiple stress ultrasonographic studies have reported similar trends in dynamic medial gapping of throwing elbows, differences exist in elbow flexion angle utilized, quantity of stress applied, and specific measurement techniques. Sasaki et al[22] published one of the first reports using stress US on college baseball players and showed an average side-to-side difference in the medial ulnohumeral joint space of 1.1 mm (2.7 mm in D arms vs 1.6 mm in ND arms) with gravity valgus stress at 90° of elbow flexion. Nazarian et al[15] reported a nonsignificant difference in joint space width at rest but a 1.2-mm difference (4.2 mm in D arms vs 3 mm in ND arms) with "maximal" stress applied at 30° of flexion in asymptomatic professional pitchers. Most recently, Ciccotti et al[4] reported a 0.84-mm difference (4.56 mm in D arms vs 3.72 mm in ND arms) in professional pitchers using 150 N (approximately 33.7 lb) of stress at 30° of elbow flexion.

Our results show similar trends in medial elbow gapping of professional pitchers with a 0.5-mm difference (4.1 mm in D arms vs 3.6 mm in ND arms) using gravity valgus stress and a 0.7-mm difference (5.4 mm in D arms vs 4.7 mm in ND arms) with 5.5 lb of valgus stress applied at the elbow flexion angle where maximal joint opening occurred. Although our reported stressed joint space difference (0.7 mm) is less than the findings of other studies, this could be attributed to many different variables, including stress applied (5.5 lb vs 150N/33.7 lb) and specific measurement techniques of US images.

Other studies using stress ultrasonography have sought to control certain factors within the examination, which may be ideal scientifically and biomechanically; however, these factors are cumbersome and impractical for clinical applicability. The Telos device used in the majority of studies involving UCL stress ultrasonography was intended to provide a standardized stress to the elbows during testing. However, the 30° flexion angle utilized in these studies was mainly a function of device limitations, as it reportedly will not allow flexion angles beyond 60°.[2] The biomechanical studies described by Callaway et al[3] showed that maximal medial elbow opening after anterior band UCL sectioning occurred at 90° of elbow flexion, compared with 30°, 60°, and 120° of elbow flexion. A prior sequential sectioning study by Søjbjerg et al[25] reported the greatest effect of an absent anterior bundle at 70° of elbow flexion.[25] Despite these differences, it seems clear that elbow flexion positioning of 30° does not represent the position of greatest anterior bundle UCL stress, nor does it reflect elbow position during the late cocking/early acceleration phases of throwing. Furthermore, the Telos device constraints, while sound in controlling for measurement error, lack the practical feasibility regarding time and resources required for obtaining this information within a clinical setting.

It has been well established that asymptomatic throwing elbows demonstrate increased medial joint space gapping with stress, and often even at rest, compared with the nondominant elbow. Ellenbecker et al[5] used stress radiography to evaluate medial ulnohumeral joint space opening in 40 asymptomatic professional pitchers showing significant differences between dominant and nondominant elbows with and without stress applied. Their study utilized radiography as opposed to ultrasonography, and while a calibration standard was used with the radiographs, there was no means to account for variability in cartilaginous architecture.

The strengths of our study include the ease of performing the examination, using an established reference range to assess the UCL in conjunction with a simple, handheld dynamometer by the examiner to control for valgus force. The examiner can feasibly hold the distal humerus with the other hand to limit shoulder external rotation and maintain the fulcrum of the extremity over a towel roll while applying stress. The second examiner can hold the US over the UCL to visualize along the long axis and record the image. Our data demonstrate that this method is reliable as determined by the intra- and interrater ICCs obtained, suggesting that isometric measurement at a specific elbow flexion angle is not required for measurement accuracy. This approach was kept as simple as possible to reflect clinical application, and shows side-to-side differences and UCLR, differences showing this method is accurate to assess UCL laxity and thickness can be used to assess UCL integrity. An additional strength of this study is that the reviewers were blinded to the US examination of the professional pitchers.

Our results should be viewed within the limitations of our study. Incorporating the method we have described allows for qualitative and quantitative assessment of the UCL during stress ultrasonography. Although we showed statistical significance, we only had 6 pitchers who had UCL injury and subsequent reconstruction. A larger number evaluated prospectively after UCLR with controls would be beneficial to fully understand the biomechanical effects on the elbow after UCLR. Our conclusions are also limited, as we do not have serial assessments of the players over consecutive seasons using this method. By comparing the nondominant control measurements serially along with the dominant measurements, this would add further validity that our method is reliable over independent testing conditions. Finally, the technical limitations of dynamic assessment led us to subjectively assess the maximal ulnohumeral joint distance between static points within the moving valgus stress test arc, and dynamic measurements were recorded from this arc position.

CONCLUSION

This is the first study to our knowledge evaluating stress ultrasonography of the UCL during the moving valgus stress test in professional pitchers. This study demonstrates a reliable method of screening an elite group of pitchers with regard to ulnohumeral joint distance and UCL morphology as applied to customary clinical examination techniques. Pitchers who had undergone UCLR displayed greater resting ulnohumeral opening, but less gapping when loaded. Additionally, UCLR pitchers displayed greater UCL thickness compared with those pitchers without UCLR. This suggests the UCLR graft construct provided more stiffness compared with the noninjured arms. There was also observed greater gapping between dominant and nondominant pitching arms, which are consistent with trends reported in other studies using other methods. These findings indicate that combining ultrasonography with a moving valgus stress test of the elbow is practical and can provide reliable information pertaining to the laxity and thickness of the UCL. Further studies may be able to utilize this combination of testing to evaluate between elbow morphology with other risk factors such as pitching load, shoulder range of motion, and humeral torsion to develop a more robust pitcher injury risk profile.

ACKNOWLEDGMENT

The authors acknowledge the contribution and cooperation of the Colorado Rockies Baseball Club, the director of medical operations, Thomas Probst, ATC, PT, and the athletic training staff of the Colorado Rockies Baseball Club for their assistance in this research project.

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