J Shoulder Elbow Surg (2021) 30, 495–503

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Journal of Shoulder and Elbow Surgery

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The ulnar collateral ligament responds to stress in professional pitchers

Peter N. Chalmers, MD[a,*], Joy English, MD, RMSK[a], Daniel M. Cushman, MD[b], Chong Zhang, MS[c], Angela P. Presson, PhD[d], Steve Yoon, MD[d], Brian Schulz, MD[d], Bernard Li, DPT[e]

[a]*Department of Orthopaedic Surgery, University of Utah, Salt Lake City, UT, USA*
[b]*Division of Physical Medicine, University of Utah, Salt Lake City, UT, USA*
[c]*Division of Epidemiology, Department of Medicine, University of Utah, Salt Lake City, UT, USA*
[d]*Division of Sports Medicine, Kerlan-Jobe Orthopaedic Institute, Los Angeles, CA, USA*
[e]*Sports Science and Player Performance, Los Angeles Angels, Anaheim, CA, USA*

Background: Our purpose with this study was to determine the response of the ulnar collateral ligament (UCL) in professional pitchers after exposure to a season of pitching and to rest during an off-season.
Methods: In a prospective study supported by Major League Baseball, all pitchers within a single professional baseball club were enrolled. An ultrasound of the ligament was then performed by a single fellowship-trained ultrasonographer at the beginning of the season (T1), the end of the season (T2), and the beginning of the following season (T3). We measured the UCL thickness and ulnotrochlear joint opening at 30° of flexion with and without stress. Two ultrasound images were saved. Inter- and intra-rater reliability were determined. A multivariable analysis was conducted.
Results: A total of185 total pitchers were included: 94 pitchers at T1, 83 at T2, and 118 at T3. These pitchers had 12 [7, 15] (median [interquartile range]) years of pitching experience and had a peak velocity of 95 [93, 97] miles/hour. Intra- and inter-rater reliability were excellent. The baseline UCL thickness was associated with peak velocity ($P = .031$) and prior UCL reconstruction ($P = .024$). After accounting for pitching experience, peak velocity, and prior UCL reconstruction, thickness increased during the season ($P = .002$) and decreased during the off-season ($P = .001$). After accounting for these same variables, valgus laxity at 30° increased during the season ($P = .002$) and decreased during the off-season ($P = .029$).
Conclusion: The UCL responds to stress in professional pitchers by becoming thicker and more lax, and responds to rest by becoming thinner and less lax.
Level of evidence: Basic Science Study; Physiology

Keywords: Ulnar collateral ligament; baseball pitching; ligament biology; elbow instability

This study was performed under the University of Utah institutional review board as approved protocol #100272. Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was not required by our institutional review board.

*Reprint requests: Peter N. Chalmers, MD, Department of Orthopaedic Surgery, University of Utah, 590 Wakara Way, Salt Lake City, UT 84108, USA.

E-mail address: p.n.chalmers@gmail.com (P.N. Chalmers).

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https://doi.org/10.1016/j.jse.2020.06.027

Pitching-related injuries are highly prevalent, occurring in 30%-74% of pitchers.[7,37] The ulnar collateral ligament (UCL) is one of the most common sites of pathology, with 25% of Major League Baseball (MLB) pitchers having undergone reconstruction.[11] These injuries are increasing in frequency and are occurring in very young athletes.[7,37] This ligament has thus become a major focus of study within sports medicine.[6,12,14,16,18-23,26,29] Although the surgical treatment of these tears has received a great deal of attention, very little evidence exists regarding the natural history of the pathology and the nonoperative treatment of these injuries.[15,42,44]

In particular, the optimal treatment of partial thickness tears remains unclear. Several recent studies have suggested favorable outcomes with platelet-rich plasma injections.[13,15,42] However, no comparative natural history data are available. Asymptomatic, experienced pitchers within the MLB have significant damage within the ligament.[28,30] Given that (1) elbow pain is highly prevalent among pitchers[7,37] and (2) many asymptomatic, experienced pitchers within the MLB have significant damage within the ligament,[28,30] partial injuries may occur, be ignored by the player, and then resolve as the ligament may have some intrinsic capacity for healing or adaptation to stress.

Several studies have indirectly suggested that the ligament may have an intrinsic adaptive response. (1) Among high-level pitchers, the UCL is thicker in the dominant, as compared with the nondominant elbow.[2,3,10,40,49] (2) The UCL thickness correlates with pitching experience.[3] (3) The UCL thickness has also been demonstrated to increase in thickness during the course of a single season in high school players.[33] (4) The UCL thickness also correlates with a subjective self-satisfaction score among pitchers, suggesting that adaptation within the ligament may improve performance.[49] All of these findings suggest an adaptive response. However, these findings could all arise from selection bias as professional pitchers are a highly selected group. Furthermore, it remains unclear whether these adaptive changes alter ligament laxity and therefore joint opening to stress. No prior studies have prospectively, longitudinally followed asymptomatic professional pitchers to understand whether ligamentous adaptation occurs in response to the stress of pitching and the rest of the off-season.

Our purpose with this study was to determine the response of the UCL in professional pitchers after exposure to a season of pitching and to rest during an off-season. Our hypothesis was that the UCL would respond to stress by thickening and becoming less lax and would respond to rest by reversal of these changes.

Methods

This study was supported by a grant from the MLB. This is a prospective longitudinal study. We screened all professional pitchers within a single club (the Los Angeles Angels) for enrollment. We excluded pitchers who underwent a surgery, so recently they had not yet returned to throwing and pitchers not playing because of injury. We offered those patients who met criteria enrollment within the study. This study included all major and minor league pitchers within the Los Angeles Angels organization. Our study involved 3 time points: (1) initial screening for inclusion and data collection occurred during spring training physicals, (2) a second examination at the completion of the season, and (3) a third examination during spring training for the subsequent year.

Data collection

Players first completed a survey to collect age, hand dominance, number of years pitching, peak pitch velocity, current medial elbow pain, injury history on the dominant elbow, history of being on the disabled list for a shoulder or elbow injury during the prior season, and any treatments received for the shoulder or elbow during the prior season.

Almost all prior ultrasonographic studies of the UCL have been performed with the elbow at 30° of flexion.[2,3,10,40] However, this position for the elbow poorly approximates the 90°-100° of elbow flexion observed among highly skilled adult and professional pitchers when maximum valgus stress is applied to the elbow in late cocking/early acceleration.[17,24,25,51] Our testing protocol thus included both the traditionally tested 30° of flexion and 90° of flexion.

We evaluated participants in the supine position on the examination table. To rapidly position the elbow, we used 3D-printed templates to hold the arm at both 30° of flexion and 90° of flexion. We placed the shoulder in 90° of abduction and external rotation. In this position, we obtained images of the UCL using a 15-6 MHz linear array transducer (Model: Edge II; Sonosite, Bothell, WA, USA). We imaged the ligament at the midportion of the anterior bundle midway between the face of the medial epicondyle and the ulnar attachment of the ligament on the sublime tubercle. Static imaging included a measurement of the UCL thickness (mm) without weight applied and ulnotrochlear distance (mm) both with and without a weight applied. We selected a 2.3 kg load as higher loads were associated with discomfort and difficulty relaxing medial elbow musculature in pilot testing. This load is similar to a prior study that used 2.5 kg[4] and multiple other studies that have used gravity stress alone.[31,46] After applying the load, we measured ulnotrochlear distance ultrasonographically in mm. We changed the elbow flexion angle to 90°, and we measured the ulnotrochlear distance with the arm supported and with the same load. We performed all measurements on the dominant elbow with the subject in a relaxed state. We deidentified all electronic measurements and recorded them on a spreadsheet for data analysis, and we recorded images blindly for interpretation as documented below.

A physician with fellowship training in ultrasound and with extensive experience performing ultrasounds of the UCL performed the ultrasonographic examinations. This individual performed these measurements in a blinded fashion. Players and team physicians were blinded to the findings of the ultrasound. These ultrasound images were for research purposes only and were not documented within the electronic medical record. These measures were necessary to protect player confidentiality and to prevent ultrasound findings from influencing player or team behavior.

We determined both intra- and inter-rater reliability. Two experienced ultrasonographers separately evaluated a group of 30 randomly selected ultrasound images, blinded to each other's measurements. Both ultrasonographers also evaluated the same group twice separated by a period of a month while blinded to their prior measurements. From these we calculated intraclass correlation coefficients with the a priori level of acceptableness of 0.75.[8]

Statistical analysis

We summarized study variables descriptively. We summarized continuous variables as median (interquartile range) and range, and categorical variables as frequency and percentage. Study outcomes included the UCL thickness, valgus laxity at 30°, and valgus laxity at 90°, which were measured at 3 time points: preseason 1 (T1), postseason 1 (T2), and preseason 2 (T3). For each outcome, we analyzed the effect of player characteristics including years of pitching, peak velocity, and prior UCL reconstruction (UCLR) at the baseline time point using linear regression models. We also analyzed the effect of player characteristics over the 3 time periods using generalized estimating equations models. Correlation among outcome measures from the same player was accounted for assuming an exchangeable correlation structure. We constructed multivariable models for both the baseline and longitudinal models that included all player characteristics. Before multivariable analysis, we assessed collinearity using the variance inflation factor, and there were no issues (all variance inflation factor values were <2.5). We also created models with time interactions for peak velocity, years of pitching, and prior UCLR and reported type 3 P values for each interaction to assess whether the relationships between player characteristics and outcomes changed over time. We mean-centered years of pitching and standardized peak velocity to have mean 0 and a standard deviation of 1. We reported regression coefficients from all models with 95% confidence intervals (CIs) and P values. Within these models, we included the history of a UCLR as a variable to ensure that any changes in thickness or laxity over time were present after first accounting for the changes expected in these variables due to the prior UCLR. The decision was made to account for the history of the UCL as a variable instead of excluding patients who are post-UCLR as this approach allows us to analyze the effects of time after accounting for the effects of a history of UCLR. This approach also allows the analysis to draw inference regarding patients with a history of UCLR as well. Because a substantial number of elite pitchers are post-UCLR, these inferences are important for this patient population. As the number of pitchers post-UCLR within our cohort was too small to allow a multivariate model within this subpopulation, it was not possible to conduct 2 parallel analyses within each population.

We assessed inter-rater and intra-rater reliability for the measurement of the 3 radiographic outcomes (UCL thickness, valgus laxity at 30°, and valgus laxity at 90°) by the 2 independent raters as outlined above. We calculated the intraclass correlation coefficient (2-way mixed effects, single rater, absolute agreement) for each outcome for inter-rater and intra-rater reliability, and we reported 95% CIs.

We assessed statistical significance at the .05 level, and all tests were 2-tailed. We conducted all analyses using R v.3.5.1. Two biostatisticians with advanced degrees in biostatistics conducted all analyses.

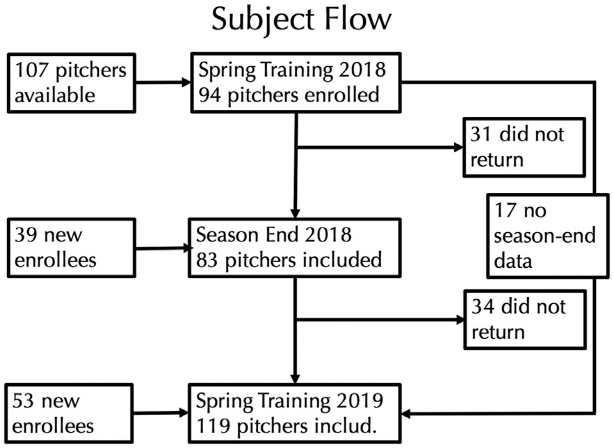

Figure 1 Flowchart demonstrating subject flow during the study, including number of subjects included at each time point, number of new enrollees at each time point, number of subjects who "did not return" due to injury, trades, or designation for assignment, and number of subjects included from time point to time point as a number and as a percent of those available for follow-up. *Includ*., included.

Results

Study cohort

We included a total of 185 total pitchers. Because of extensive player movement into and out of the system, not all players were available for follow-up at all time points (see Fig. 1). A total of 107 pitchers were within the Los Angeles Angels system during spring training of 2018. A total of 94 (88%) agreed to be enrolled within our study. During the season, 31 pitchers became unavailable during the season because of injury, trades, or designation for assignment, leaving 63 available for follow-up. During the season, 39 new pitchers joined the system. There is no point at the end of the season where all pitchers within the system are geographically colocalized. As the teams are separately geographically and have complex travel schedules, it was not possible for the study team to reach all teams within a 2-week window of time. A 2-week window was selected a priori, as this was $<10\%$ of the overall season length of 26 weeks. Thus, we evaluated only pitchers from 4 of the 6 teams within the system at time point 2. We evaluated only pitchers from 2 of the 6 teams (17 pitchers) at preseason time points. Pitchers evaluated at the season end included 46 pitchers evaluated at the beginning of the season and the 39 new enrollees, and thus we included 83 pitchers at the end of the season. During the off-season, 34 pitchers became unavailable because of injury, trades, or designation for assignment, and 53 new pitchers joined the system. Of these, we included 119 at the beginning of the 2019 season (Figs. 1 and 2).

These pitchers were 23 [21, 25] years old (median [interquartile range]), had 12 [7, 15] years pitching experience, had a peak velocity of 95 [93, 97] miles per hour,

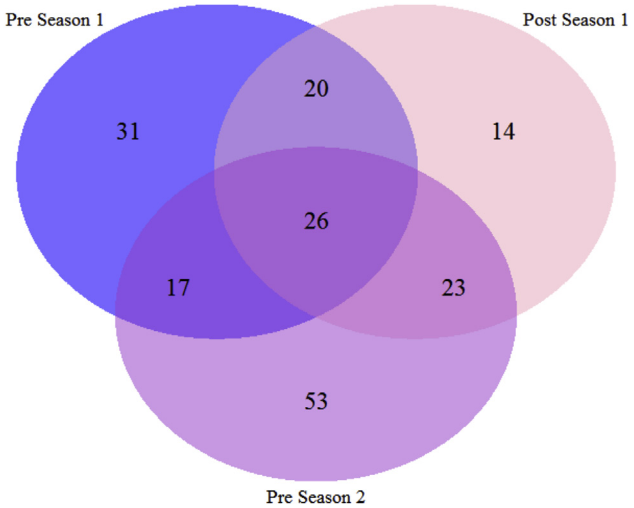

Figure 2 Venn diagram demonstrating player overlap between time points. Each number represents the number of pitchers who received an ultrasound examination at each time point.

were 74 [72, 76] inches tall, weighed 207 [190, 226] pounds, and included 36 (20%) left-hand dominant and 148 (80%) right-hand dominant pitchers. Our cohort included 24 pitchers (13%, 24 of 185) who underwent UCLR before time point 1, 10 pitchers (5%, 10 of 185) who underwent UCLR between time points 1 and 2, and 7 pitchers (4%, 7 of 185) who underwent UCLR between time points 2 and 3, for a total of 22% (41 of 185) pitchers who underwent UCLR either before or during the study.

Reliability

We performed a reliability assessment for our ultrasound measurement that demonstrated adequate inter- and intra-rater reliability for analysis of 30 ultrasound images (Table I).

UCL thickness

Examining the UCL thickness at baseline, adjusting for years of pitching and prior UCLR, peak velocity was positively associated with thickness ($P = .031$). Adjusting for peak velocity and number of years of pitching, prior UCLR was associated with 1.2 mm greater thickness at baseline (95% CI: 0.16, 2.21; $P = .024$, Table II). In a multivariable model including time, years of pitching experience, and prior UCLR, peak velocity was associated with thickness ($P = .03$), prior UCLR was associated with significantly greater thickness ($P < .001$), the UCL thickness increased during the season ($P = .002$), and the UCL thickness decreased during the off-season ($P = .001$) such that overall thickness changed significantly across time points (type 3 P value = .002, Fig. 3, Table III). Thus, the UCL thickness significantly increased during the season ($P = .002$) and decreased during the off-season ($P = .001$) even after accounting for changes in thickness due to a history of UCLR. In a multivariate model including all interactions between time and pitcher characteristics variables, none of the variables had significant interactions with time (Supplementary Table S1).

Valgus laxity at 30°

Examining valgus laxity at 30° at baseline, there were no associations in either univariable or multivariable analysis with peak velocity ($P = .15$), number of years of pitching experience ($P = .11$), or prior UCLR ($P = 1.00$, Table II). In a multivariable analysis, valgus laxity at 30° increased during the season ($P = .002$) and decreased during the off-season ($P = .029$), such that there was a significant overall change with time (type 3, $P = .008$, Table IV, Fig. 4). Thus, valgus laxity significantly increased during the season ($P = .002$) and decreased during the off-season ($P = .029$) even after accounting for changes in laxity due to a history of UCLR. In a multivariable model that included interactions between time and pitcher characteristics, there was a significant interaction between peak velocity and time (type 3, $P = .019$), which means that the relationship between peak velocity and valgus laxity at 30° changed significantly across time (Supplementary Table S2).

Valgus laxity at 90°

Examining valgus laxity at 90° at baseline, there were no associations with peak velocity ($P = .95$), number of years of pitching experience ($P = .98$), or prior UCLR ($P = .98$, Table II). Examining valgus laxity at 90° over time, in a multivariable analysis, valgus laxity at 90° did not change over time (Supplementary Table S3, type 3, $P = .18$). These results are unchanged in a multivariable analysis that included interactions (Supplementary Table S4).

Discussion

Our hypothesis was only partially confirmed, as within our study, the UCL responded to stress by becoming thicker and more lax at 30° of elbow flexion and responded to rest by becoming thinner and less lax at 30°. Thus, the UCL appears to be biologically active and adapts to stress. Within our study, rest nearly completely reversed the changes of the season, in a model accounting for peak velocity, number of years of pitching, and history of UCLR. Within our study, ultrasonographic evaluation at 30° better associates with the sequalae of pitching workload than ultrasonographic evaluation at 90°.

UCL thickness

Within our study, the UCL thickness was associated with baseline peak pitch velocity, significantly increased during

Table I The results of our inter-rater and intra-rater reliability analysis of ultrasound data with bracketed values representing 95% confidence intervals

ICCs	Inter-rater	Intra-rater 1	Intra-rater 2
UCL thickness	0.851 [0.684-0.930]	0.957 [0.911-0.980]	0.936 [0.868-0.969]
Laxity @ 30°	0.906 [0.799-0.956]	0.799 [0.616-0.900]	0.747 [0.529-0.873]
Laxity @ 90°	0.910 [0.807-0.958]	0.751 [0.535-0.875]	0.838 [0.684-0.921]

ICC, intraclass correlation coefficient; *UCL*, ulnar collateral ligament.

Table II Univariate and multivariate regression analysis relating pitcher characteristics to outcomes at baseline (time point 1)

Analysis	Outcome	Predictors	Coefficients (95% CI)	*P* value
Univariate	UCL thickness	Peak velocity	0.37 (0.02, 0.72)	.038
		Years pitching	−0.03 (−0.08, 0.03)	.320
		Prior UCLR	1.02 (0.01, 2.03)	**.047**
	Valgus laxity at 30°	Peak velocity	1.79 (−0.27, 3.85)	.090
		Years pitching	0.28 (−0.01, 0.58)	.060
		Prior UCLR	1.94 (−4.10, 7.97)	.520
	Valgus laxity at 90°	Peak velocity	0.07 (−1.94, 2.08)	.940
		Years pitching	0.01 (−0.28, 0.29)	.970
		Prior UCLR	0.11 (−5.70, 5.91)	.970
Multivariate	UCL thickness	Peak velocity	0.38 (0.03, 0.73)	**.031**
		Years pitching	−0.05 (−0.10, 0.00)	.051
		Prior UCLR	1.18 (0.16, 2.21)	**.024**
	Valgus laxity at 30°	Peak velocity	1.51 (−0.58, 3.60)	.150
		Years pitching	0.25 (−0.06, 0.56)	.11
		Prior UCLR	−0.01 (−6.21, 6.19)	1.00
	Valgus laxity at 90°	Peak velocity	0.07 (−2.00, 2.13)	.95
		Years pitching	0.00 (−0.30, 0.31)	.98
		Prior UCLR	0.07 (−6.08, 6.21)	.98

UCL, ulnar collateral ligament; *UCLR*, UCL reconstruction; *CI*, confidence interval.
Significant results are bolded.

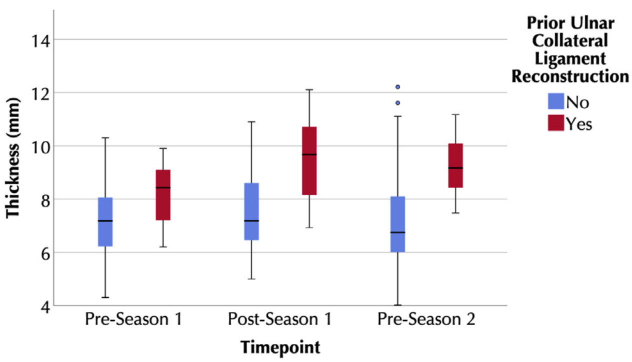

Figure 3 Boxplot of ulnar collateral ligament thickness at each time point for those with (*red*) and without (*blue*) prior surgery. The top and bottom borders of the boxes represent the interquartile range, with the center line representing the median. The whiskers represent the furthest nonoutlier, nonextreme value. The outliers, those values between 1.5 and 3 box lengths from either end of the box, are denoted with circles.

the season, and significantly decreased during the off-season, even after accounting for a history of UCLR. Although prior studies have suggested an association between tendon/ligament thickness and mechanical stress,[2,3,10,40,41,49,50] our prospective study design and the ‘‘natural experiment’’ offered by the combination of the stress of a professional baseball season and the rest of the off-season avoids the selection bias inherent to many prior cross-sectional studies. The role of ligament thickening in the prevention of injury remains unclear. In a prior comparative study, there were no significant differences in the UCL thickness between pitchers who subsequently sustained an injury and those who did not.[10] Within our study, thickness was associated with peak velocity both at baseline and during the study in univariate and multivariate analyses. It remains unclear how this relates to the connection between velocity and injury.[6,7] Our own research showing this response to be adaptive suggests that prospectively following ligament thickness may allow cross-correlation between work load and the extent of the

Table III Univariate and multivariate (generalized estimated equations) analysis of ulnar collateral ligament thickness.

Analysis	Variable	Coefficients (95% CI)	*P* value
Univariate	Peak velocity	0.41 (0.17, 0.66)	**<.001**
	Years pitching	0.02 (−0.01, 0.06)	.220
	Prior UCLR	2.11 (1.59, 2.62)	**<.001**
	Preseason 1	−0.44 (−0.80, −0.07)	**.021**
	Preseason 2	−0.22 (−0.63, 0.19)	.300
Multivariate	Peak velocity	0.37 (0.12, 0.62)	**.003**
	Years pitching	−0.03 (−0.07, 0.01)	.140
	Prior UCLR	2.13 (1.50, 2.75)	**<.001**
	Preseason 1	−0.52 (−0.85, −0.20)	**.002**
	Preseason 2	−0.51 (−0.81, −0.20)	**.001**

UCLR, ulnar collateral ligament reconstruction; *CI*, confidence interval.
Postseason 1 (time point 2) is used as reference. Significant differences are bolded.

Table IV Univariate and multivariate (generalized estimated equations) analysis of valgus laxity at 30° of elbow flexion

Analysis	Variable	Coefficients (95% CI)	*P* value
Univariate	Peak velocity	−1.01 (−2.35, 0.33)	.14
	Years pitching	0.03 (−0.16, 0.22)	.76
	Prior UCLR	−1.66 (−5.19, 1.87)	.36
	Preseason 1	−4.10 (−6.95, −1.24)	**.005**
	Preseason 2	−2.48 (−4.90, −0.06)	**.045**
Multivariate	Peak velocity	−0.91 (−2.35, 0.53)	.21
	Years pitching	0.09 (−0.12, 0.29)	.41
	Prior UCLR	−2.16 (−6.18, 1.86)	.29
	Preseason 1	−4.68 (−7.66, −1.71)	**.002**
	Preseason 2	−2.87 (−5.45, −0.29)	**.029**

UCLR, ulnar collateral ligament reconstruction; *CI*, confidence interval.
Postseason 1 (time point 2) is used as reference. Significant differences are bolded.

ligament's adaptive thickening to identify at-risk pitchers with abnormal adaptive responses. However, the current clinical significance of ligament thickness remains unknown. Finally, within our study, the UCL thickness was correlated with prior UCLR, likely because of scarring and the addition of graft tissue. Our own results suggest this tissue to also be responsive to load in a similar manner to native, non-reconstructed UCL tissue. Because of this finding, we accounted for the history of UCLR within a multivariable model, and the changes in UCL thickness during the season and off-season were significant after accounting for changes in thickness due to a history of UCLR.

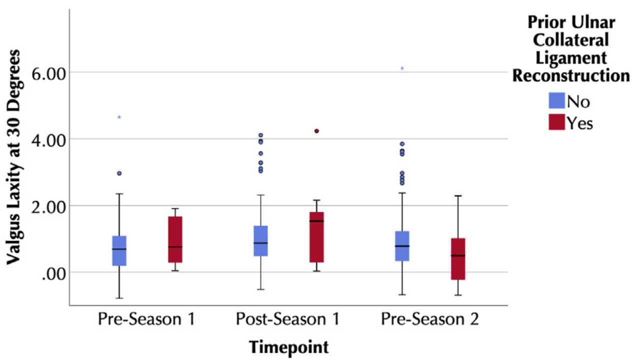

Figure 4 Boxplot of valgus laxity at 30° (mm) at each time point for those with (*red*) and without (*blue*) prior surgery. The top and bottom borders of the boxes represent the interquartile range, with the center line representing the median. The whiskers represent the furthest nonoutlier, nonextreme value. The outliers, those values between 1.5 and 3 box lengths from either end of the box, are denoted with circles.

UCL laxity

Within our study, UCL laxity at 30° increased during the season and decreased during the off-season. This finding was counter to our hypothesis and bears further study. The association between UCL laxity and the stress of pitching has been previously shown.[3,9,10] In addition, the ligament stiffness is known to be hormonally dependent and is relatively rapidly alterable.[34] Our prospective study design and the "natural experiment" offered by the combination of the stress of a professional baseball season and the rest of the off-season allow the assignment of causality to this in vivo relationship between increased stress and increased ligament laxity. However, the increase in laxity is discordant with prior research and should be further investigated, especially in post-UCLR players, where these changes may be less reversible. Because of this finding, we accounted for the history of UCLR within a multivariable model, and the changes in laxity during the season and off-season were significant after accounting for changes in laxity due to a history of UCLR. Prior in vivo studies have also suggested that increased load increases tendon stiffness and thus decreases laxity.[35,36,38,48] The relationship between laxity and subsequent injury remains unclear—in a prior comparative study, there were no significant differences in UCL laxity between pitchers who subsequently sustained an injury and those who did not.[10] These results suggest that the relationship between tendon and ligament laxity and stress may be more complex than previously suggested.

Degree of flexion

Within our study, laxity at 30° of flexion increased during the season and decreased during the off-season, whereas laxity at 90° of flexion did not. Our findings at 30° of flexion confirm prior research.[2,3,10,40] Ninety degrees of elbow flexion better matches the position of the elbow at the late cocking/early acceleration phase when maximum valgus stress is applied to the elbow.[17,24,25,51] Biomechanically, the ligament is as much or more important for valgus stability at 90° of flexion as at 30° of flexion.[1,27,32,39,43,45] The authors speculate that pitchers are better able to muscularly compensate for stress at 90° of elbow flexion despite our attempts at maintaining a fully relaxed arm, and thus testing at this degree of flexion is likely more reflective of flexor-pronator strength and less of ligament laxity.[5,47]

Limitations

Our study has several important limitations. First, this study includes only a single MLB organization and thus may be underpowered for some comparisons. Second, many patients were lost to follow-up because of player movement into and out of the system. This introduces some selection bias, does not perfectly track pitcher over time, and makes our study more of a cross-sectional study. A total of 46% (86 of 184) pitchers have data from at least 2 time points. This limitation is inherent to studying this patient population as players frequently leave and enter the system. This is the only patient population that subjects this ligament to stress of this magnitude, and thus this limitation is inherent to this research question in this setting. Third, our study only includes ultrasound data and not magnetic resonance data that may show changes elsewhere in the elbow, such as within the chondral surfaces; however, the inter- and intra-rater reliability of the ultrasound measurements were excellent. In addition, ultrasound data provide dynamic data on ligament laxity that cannot be gathered from magnetic resonance imaging. Fourth, our study involves only professional pitchers and may not be generalizable to youth, adolescent, and collegiate pitchers. Fifth, we have purposefully included pitchers who underwent prior UCLR within our cohort. Exclusion of these pitchers creates substantial selection based as 22% of the cohort underwent UCLR. To mitigate this limitation, this variable has been included in each of our multivariate analyses. Inclusion of this variable within a multivariate model allows us to conclude that significant thickness and laxity changes observed in our study are present even after accounting for the thickness and laxity differences expected in players with a history of UCLR. Sixth, we have only evaluated the dominant elbow as the purpose of this study was to understand changes in the ligament over time and not to understand differences between the dominant and nondominant sides. Seventh, we have only peak velocity data from the time of inclusion and thus cannot analyze the change in ligament thickness data in view of potentially changing peak velocity within players. Thus ligament thickening during the season may secondarily correlate with increases in peak velocity such that velocity is the main factor that explains ligament thickness. Further studies will be necessary to elucidate this effect. Eighth, reliability was performed for the measurement of the same ultrasound images and not ultrasound images taken by different observers on different occasions. To mitigate this limitation, all ultrasound images within our study were taken by the same ultrasonographer. Ninth, we did not conduct an a priori power analysis as all pitchers within our system were enrolled.

Conclusion

The UCL responds to stress in professional pitchers by becoming thicker and more lax, and responds to rest by becoming thinner and less lax.

Disclaimer

This study was supported by a grant from the research committee for Major League Baseball.

This investigation was supported by Major League Baseball, the University of Utah Population Health Research (PHR) Foundation (Angela P. Presson, Chong Zhang), with funding in part from the US National Center for Research Resources and the US National

Center for Advancing Translational Sciences, US National Institutes of Health, through Grant 5UL1TR001067-05 (formerly 8UL1TR000105 and UL1RR025764).

Peter N. Chalmers is a paid consultant for Arthrex and Mitek, serves on the editorial board for the *Journal of Shoulder and Elbow Surgery*, is a paid speaker for Depuy, and receives intellectual property royalties from Depuy.

Steve Yoon is a paid consultant and speaker for Arthrex.

Brian Schulz is a paid speaker for Fidia Pharma USA, receives research support from Depuy, and receives other support from Smith & Nephew, Arthrex, and Stryker.

Bernard Li is employed by the Los Angeles Angels.

The other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2020.06.027.

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