



Do anatomic changes found in the throwing arm after a season of pitching resolve with off-season rest? A dynamic ultrasound study

Lafi S. Khalil, MD ^{a,*}, Kelechi R. Okoroha, MD ^a, Toufic R. Jildeh, MD ^a, Robert N. Matar, MD ^b, Mohsin S. Fidai, MD ^a, Joseph S. Tramer, MD ^a, Chase Ansok, MD ^a, Courtney Scher, DO ^c, Marnix Van Holsbeeck, MD ^c, Eric C. Makhni, MD, MBA ^a, Vasilios Moutzouros, MD ^a

^a Department of Orthopaedic Surgery, Henry Ford Hospital, Detroit, MI, USA

^b Department of Orthopaedic Surgery, University of Cincinnati Medical Center, Cincinnati, OH, USA

^c Department of Musculoskeletal Radiology, Henry Ford Hospital, Detroit, MI, USA

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Hypothesis: Our hypothesis was that seasonal adaptive changes in the ulnar collateral ligament (UCL), ulnohumeral joint space (UHJS), and glenohumeral internal rotation deficit (GIRD) of the pitching extremity would subsequently resolve with off-season rest.

Methods: Eleven collegiate pitchers underwent preseason, postseason, and off-season evaluations including physical examination; dynamic ultrasound imaging of the UCL and UHJS; and the short version of the Disabilities of the Arm, Shoulder and Hand (QuickDASH) questionnaire. Ultrasound images were evaluated by 2 fellowship-trained musculoskeletal radiologists.

Results: All 11 pitchers were included in the final analysis, with an average age of 20.1 years and with 14.1 years of playing experience. After a season of pitching, we found significant increases in GIRD ($P = .004$) and UCL thickness ($P = .033$) and nonsignificant increases in both unloaded ($P = .069$) and loaded ($P = .122$) UHJS. Preseason GIRD correlated with this increase in loaded UHJS ($r = 0.80$, $P = .003$). The increase in UCL thickness was significantly greater in pitchers with GIRD greater than 10° ($P < .05$). After the off-season, UCL thickness returned to baseline and significant decreases were noted in both unloaded ($P = .004$) and loaded ($P = .041$) UHJS, but a progression in GIRD was found ($P = .021$). Pitchers with GIRD of 10° or less showed greater improvement in UHJS after the off-season ($P < .05$).

Conclusions: The pitching season produced adaptive changes in the throwing elbow that subsequently resolved after off-season rest. However, shoulder range-of-motion deficits were progressive and did not resolve. Ultrasound adaptations of the pitching elbow were significantly related to GIRD.

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Throughout the course of a season, pitchers place significant loads and stress on their throwing arm, placing them at risk of medial ulnar collateral ligament (UCL) injury.^{2,6} In an epidemiologic study of 5295 collegiate baseball athletes, the incidence of UCL surgery in 1 year was found to be 2.5 per 100 player-seasons, with significantly higher risks in pitchers than in non-pitchers.¹⁷ Pitchers are at increased risk of UCL reconstruction and missed time from sport because of the volume of overhead activities that place stress on the elbow.⁸ Injuries to the UCL are hypothesized to be related to variable pitching mechanics and shoulder rotation characteristics.^{1,6,11,15,26}

This project was reviewed and approved by the Institutional Review Board at Henry Ford Hospital (study no. 10175).

* Corresponding author: Lafi S. Khalil, MD, Department of Orthopaedic Surgery, Henry Ford Hospital, 2799 W Grand Blvd, Detroit, MI 48202, USA.

E-mail address: lskhalil@gmail.com (L.S. Khalil).

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The overhead repetitive nature of pitching produces measurable adaptations in UCL thickness in the dominant arm of pitchers.^{3,16} Atanda et al⁴ concluded that an increased UCL thickness may be the first abnormality seen in professional baseball pitchers. The majority of ultrasound studies evaluated elbow ultrasounds at a single time point.^{3,4,16} Keller et al¹³ evaluated pitchers' elbows with dynamic ultrasounds in the preseason and postseason and found that after a single season of pitching, UCL thickness was significantly increased. They also found an insignificant increase in the ulnohumeral joint space (UHJS), representing a degenerative trend of elbow laxity, which has recently been implicated as a risk factor for future UCL injury.²¹ As UCL adaptations correlate with workload,^{3,16} ultrasounds provide a quantifiable measurement of UCL pathology. Furthermore, shoulder range of motion (ROM) has been an area of interest in pitching biomechanics and predisposition to upper-extremity injuries.^{5,11,27} Several studies have evaluated

decreases in dominant-arm glenohumeral internal rotation (IR) (glenohumeral internal rotation deficit [GIRD]) relative to the nondominant arm, and GIRD and external rotation gain have been linked to upper-extremity subjective symptoms, pain, and an increased risk of injury in overhead athletes.^{10,12,13,25} However, despite the fact that a relationship between shoulder ROM and subjective symptoms has been described, the effect on measurable characteristics of the UCL has not yet been established.

Dynamic ultrasound imaging has been found to be sensitive and specific for evaluating partial- and full-thickness UCL tears with the added benefit of identifying joint space widening, elbow instability and laxity, and UCL characteristics under various stresses.^{7,9} Studies have taken advantage of this at single time points⁴; with serial preseason assessments⁷; and more recently, before and after a single season.¹³ The adaptations in the UCL observed in prior studies were significant; however, it is unknown whether these changes resolve with rest or continue to progress. Furthermore, the relationship between these ultrasound adaptations and shoulder ROM is not fully understood. This information can direct providers and coaches in their efforts to reduce the risk of injury and chronic overuse in pitchers. The purpose of this study was to measure anatomic adaptations in the throwing arm after 1 season of competitive college pitching and determine whether they resolve after an off-season rest period by use of dynamic ultrasound imaging and physical examination. Our hypothesis was that seasonal adaptive changes in the UCL, UHJS, and GIRD of the pitching extremity would subsequently resolve with off-season rest.

Methods

We performed a prospective observational study. Pitchers from a single National Collegiate Athletic Association Division II college baseball team were recruited for this study and underwent a standardized informed consent process with documentation. Pitchers were included if they were active collegiate pitchers who were not currently symptomatic in their dominant throwing arm and were capable of performing all baseball activity without restrictions. Pitchers who pitched in a live baseball game within 2 months prior to the study period, were experiencing shoulder or elbow pain, were unavailable for imaging prior to the season, or had previous known elbow injury requiring surgery or prolonged absence from sport were not recruited for the study.

Physical examinations were performed by a single orthopedic surgeon. Shoulder rotation was assessed by goniometry with the patient supine and the arm abducted to 90° in the scapular plane and was measured relative to the moving arm along the ulnar border. Players also completed a questionnaire regarding throwing history and arm injury, as well as the short version of the Disabilities of the Arm, Shoulder and Hand questionnaire (QuickDASH). For each pitcher in the study, a complete dynamic ultrasound evaluation of the elbow (Logiq E9; GE Healthcare, Little Chalfont, UK) was performed at the main institution of the primary investigator. Ultrasound examinations were performed by a single, musculoskeletal ultrasound-trained sonographer. All structures were imaged in accordance with American Institute of Ultrasound in Medicine practice guidelines in the short- and long-axis planes relative to the structure being imaged. Images of the anterior band of the UCL were obtained with the player in a seated position, shoulder maximally externally rotated, and arm at 30° of flexion as measured by goniometry. To evaluate the elbow medial joint line and UCL dynamically, the pitcher's elbow was placed in 30° of flexion and a single orthopedic surgeon manually applied a valgus load to the elbow until a functional endpoint (ie, resistance to joint motion) was detected, consistently with previous studies.^{7,13,14,16} Ligament echogenicity and ulnar nerve dimensions were not

evaluated. The same sonographer and orthopedic surgeon examined and performed the ultrasounds and valgus load applications at all testing time points in an effort to standardize the maneuver.

Physical examinations and dynamic ultrasounds were performed in each pitcher at 3 time points: (1) before the start of their college spring season, within a 2-week window prior to their first live game ("preseason 1"); (2) after the season, within 6 days of their final game ("postseason 1"); and (3) after a 2-month off-season of relative arm rest ("preseason 2"). Players did not participate in a study-mandated protocol during the off-season. They were allowed to perform their own off-season activities while away from college for summer vacation; these activities were not restricted for inclusion in the study as long as no pitcher participated in live games during the off-season.

All ultrasound images were deidentified for time of examination, arm dominance, and player name and were evaluated in random order by 2 blinded fellowship-trained musculoskeletal radiologists. Each radiologist evaluated every examination individually; the radiologists then corroborated their findings with one another to determine final consensus measurements for each image. This method was chosen instead of calculation of an average value between 2 separate measurements, given the low number of study subjects. For this reason, only 1 final measurement was produced and, therefore, no inter-rater reliability measurements were attained. Each image was evaluated for UCL thickness and medial UHJS distance in stressed and non-stressed examinations. UCL thickness was measured by the modified Jacobson-Ward technique,²³ whereas UHJS was measured without including bone spurs and from the superior portion of the joint with the cortices parallel. Continuous outcome measures consisted of UCL thickness and area, unloaded UHJS, loaded UHJS, and shoulder ROM measurements.

Data analysis

Ultrasound comparisons were performed using a paired *t* test for continuous measures and Fisher exact test for categorical measures. Preseason 1 represents baseline values, preseason 1 and postseason 1 comparisons represent changes over a season of pitching, and postseason 1 and preseason 2 comparisons represent off-season changes. Differences in ultrasound findings at each time point were correlated with player demographic data, questionnaire responses, and physical examination findings. Ultrasound findings were compared between pitchers with GIRD of 10° or less vs. GIRD greater than 10°, as 10° represented the median value of the cohort. Correlations of the subject demographic characteristics and measures of pitching stress to the ultrasound findings were evaluated using analysis of variance, Spearman correlation, and logistic regression analysis.

Results

Demographic characteristics

Eleven collegiate pitchers met the inclusion criteria. The average age was 20.1 ± 1.3 years, and the average body mass index was 24.8 ± 2.9. The average length of experience was 14.1 ± 2.2 years (Table I). Regarding their pre-collegiate careers, 8 of the 11 pitchers (72.7%) reported playing year-round baseball and 81.8% of pitchers reported a history of arm pain while throwing. No pitcher participated in games or non-collegiate leagues during the collegiate off-season. At the time of the interview, 90.9% of pitchers followed a structured stretching program in college (Table I). No demographic variables were found to correlate to baseline ultrasound imaging findings.

Table I
Subject demographic characteristics and pitching workload survey (N = 11)

	Data
Age, mean ± SD (range), yr	20.1 ± 1.3 (18–22)
Height, mean ± SD (range), cm	73.6 ± 2.1 (70–76)
Weight, mean ± SD (range), kg	191.5 ± 28 (150–230)
BMI, mean ± SD (range)	24.8 ± 2.9 (20–28)
No. of years played, mean ± SD (range)	14.1 ± 2.2 (10–17)
Handedness, n (%)	
Left	3 (27.3)
Right	8 (72.7)
Workload survey, n (%)	
Year-round high school baseball, no/yes	3 (27.3)/8 (72.7)
Other high school sports, no/yes	9 (81.8)/2 (18.2)
History of arm pain while throwing, no/yes	2 (18.2)/9 (81.8)
History of missed games due to arm pain, no/yes	6 (54.6)/5 (45.5)
History of seeking medical advice for arm pain, no/yes	7 (63.6)/4 (36.4)
Currently involved in stretching program, no/yes	1 (9.1)/10 (90.9)
Throw bullpen sessions during off-season, no/yes	2 (18.2)/9 (81.8)
Frequency of throwing during off-season	
1–3 times per week	4 (36.4)
4–6 times per week	7 (63.6)

SD, standard deviation; BMI, body mass index.

Shoulder ROM

At the initial preseason 1 evaluation, dominant- and nondominant-arm IR values were similar ($P > .05$) and GIRD measured 5.64° on average (standard deviation [SD], 11.71°). At subsequent evaluations, dominant-arm IR was significantly less than nondominant-arm IR (postseason 1, $P = .049$; preseason 2, $P = .035$). Throughout the study period, GIRD significantly increased (postseason 1, 17.82° [SD, 18.84°] with $P = .004$; preseason 2, 28.64° [SD, 14.75°] with $P = .021$) and dominant-arm IR progressively decreased during the season (55.6° in preseason 1 vs. 43.4° in postseason 1, $P = .004$) and off-season (32.6° in preseason 2, $P = .021$). Throughout the off-season, dominant-arm external rotation increased significantly (116.0° in postseason 1 vs. 123.2° in preseason 2, $P = .02$) (Table II).

Dynamic ultrasound imaging

At all time points, only 2 pitchers demonstrated findings of loose bodies or bone spurs on ultrasound imaging, which were unchanged at each subsequent examination.

Table II
Dominant shoulder range-of-motion characteristics

Outcome measure	Preseason 1	Postseason 1	Preseason 2	Season changes*	Off-season changes†	Relative to baseline‡
IR, °				$P = .004^\S$	$P = .021^\S$	$P < .001^\S$
D	55.6 ± 9.8	43.4 ± 14.1	32.6 ± 10.3			
ND	61.2 ± 8.5	54.6 ± 13.1	42.4 ± 8.7			
Mean Δ (95% CI)	5.6 (−2.2 to 13.5)	11.2 (0.1 to 22.3)	9.8 (0.8 to 18.8)	12.2 (−19.4 to −5.01) ^{§,}	−10.8 (−19.6 to −2.0) ^{§,}	−23.0 (−31.4 to −14.6) ^{§,}
ER, °				$P = .210$	$P = .020^\S$	$P = .730$
D	122.0 ± 14.8	116.0 ± 11.0	123.2 ± 10.5			
ND	115.6 ± 11.2	108.9 ± 14.9	106.7 ± 14.6			
Mean Δ (95% CI)	−6.4 (−10.8 to −1.9) [§]	−7.1 (−15.8 to 1.6)	−16.5 (−26.5 to −6.4) ^{§,}	−6.0 (−16.0 to 4.0)	7.2 (1.4 to 12.9) ^{§,}	1.2 (−6.1 to 8.5)
GIRD, °	5.6 ± 11.7	17.8 ± 18.8	28.6 ± 14.8	$P = .004^\S$; 12.2 (5.0 to 19.4) ^{§,}	$P = .021^\S$; 10.8 (2.0 to 19.6) ^{§,}	$P < .001^\S$; 23.0 (14.6 to 31.4) ^{§,}

IR, internal rotation; D, dominant; ND, nondominant; Δ, difference; CI, confidence interval; ER, external rotation; GIRD, glenohumeral internal rotation deficit.

Data are presented as mean ± standard deviation unless otherwise indicated. P values compare the dominant shoulder at 2 time points.

* Preseason 1 to postseason 1.

† Postseason 1 to preseason 2.

‡ Preseason 1 to preseason 2.

§ Statistically significant.

|| Measurement is significantly ($P < .05$) different from nondominant measurement.

UCL thickness

At each time point, we found significantly greater UCL thickness of the dominant arm compared with the nondominant arm ($P < .05$, Table III). After a season of competitive pitching, a significant increase in UCL thickness was noted (1.62 mm in preseason 1 vs. 1.80 mm in postseason 1, $P = .033$). Following off-season rest, UCL thickness returned to baseline, showing no significant difference compared with preseason values (1.62 mm in preseason 1 vs. 1.69 mm in preseason 2, $P = .4$; Table III). After a season of pitching, UCL thickness increased significantly more in pitchers with GIRD greater than 10° than in those with GIRD of 10° or less (mean difference, 0.22 mm [95% confidence interval (CI), 0.00–0.44 mm]; Table IV).

Ulnohumeral joint dimensions

Season: preseason 1 to postseason 1

Dynamic ultrasound evaluation of the dominant elbow showed insignificant increases in elbow laxity over the course of the season. UHJS widening insignificantly increased in both unloaded (2.59 mm in preseason 1 vs. 2.94 mm in postseason 1) and loaded (3.91 mm in preseason 1 vs. 4.24 mm in postseason 1) conditions ($P > .05$, Table III). Elbow laxity after a season of pitching significantly correlated with initial preseason 1 GIRD measurements ($r = 0.80$ [Spearman correlation], $P = .003$; Table V).

Off-season: postseason 1 to preseason 2

Dynamic ultrasound evaluation of the dominant elbow after an off-season of rest demonstrated statistically significant decreases in UHJS in both unloaded (2.94 mm in postseason 1 vs. 2.63 mm in preseason 2, $P = .004$) and loaded (4.24 mm in postseason 1 vs. 3.76 mm in preseason 2, $P = .041$) conditions (Table III). Following the off-season, unloaded and loaded UHJS did not differ significantly ($P > .05$) relative to baseline measurements (Table III). After an off-season of rest, unloaded (mean difference, -0.27 mm [95% CI, -0.49 to -0.04 mm]) and loaded (mean difference, -0.73 mm [95% CI, -1.28 to -0.17 mm]) UHJS decreased significantly more in pitchers with GIRD of 10° or less compared with those with GIRD greater than 10° (Table IV). Likewise, IR deficits measured at the postseason 1 time point were significantly associated with subsequent resolution of loaded UHJS during the off-season ($r = 0.61$, $P = .047$; Table V).

Table III
Physical dimensions of dominant UCL and ulnohumeral joint

Outcome measure	Preseason 1	Postseason 1	Preseason 2	Season changes*	Off-season changes†	Relative to baseline‡
UCL thickness, mm				<i>P</i> = .033§	<i>P</i> = .170	<i>P</i> = .400
D	1.62 ± 0.38	1.80 ± 0.39	1.69 ± 0.34			
ND	1.36 ± 0.26	1.41 ± 0.34	1.33 ± 0.26			
Mean Δ (95% CI)	−0.26 (−0.53 to −0.01)§	−0.39 (−0.67 to −0.10)§	−0.36 (−0.66 to −0.06)§	0.18 (0.02 to 0.35)§	−0.11 (−0.28 to 0.06)	0.07 (−0.10 to 0.24)
Unloaded UHJS, mm	2.59 ± 0.59	2.94 ± 0.54	2.63 ± 0.46	<i>P</i> = .070	<i>P</i> = .004§	<i>P</i> = .790
Mean Δ (95% CI)	—	—	—	0.35 (−0.03 to 0.72)	−0.30 (−0.48 to −0.13)§	0.04 (−0.29 to 0.38)
Loaded UHJS, mm	3.91 ± 0.91	4.24 ± 1.07	3.76 ± 0.86	<i>P</i> = .120	<i>P</i> = .040§	<i>P</i> = .420
Mean Δ (95% CI)	—	—	—	0.33 (−0.11 to 0.77)	−0.48 (−0.93 to −0.02)§	−0.15 (−0.53 to 0.24)

UCL, ulnar collateral ligament; D, dominant. ND, nondominant; Δ, difference; CI, confidence interval; UHJS, ulnohumeral joint space.

Data presented as mean ± standard deviation unless otherwise indicated. *P* values compare the dominant elbow at 2 time points.

* Preseason 1 to postseason 1.

† Postseason 1 to preseason 2.

‡ Preseason 1 to preseason 2.

§ Statistically significant.

|| Significantly different (*P* < .05) from nondominant elbow.

QuickDASH scores

QuickDASH scores collected at each time point did not change significantly throughout the study period. No demographic characteristics were found to correlate with QuickDASH scores. QuickDASH scores were not found to correlate with elbow or shoulder adaptations.

Discussion

Our study found that with a 2-month period of relative arm rest in the off-season, adaptive anatomic changes in the elbows of competitive college baseball pitchers demonstrated the potential to return to baseline. However, deficits in shoulder ROM that accumulated after a competitive season were found to progress and did not resolve after off-season rest, contrary to our hypothesis. Furthermore, deficits in shoulder ROM demonstrated significant associations with adaptations in UCL thickness and elbow laxity. This information signifies the importance of off-season rest and identifies an area for further improvement to reduce the risk of injury. The finding that GIRD was associated with UCL and UHJS adaptations and continued to progress throughout the study period advocates focused rehabilitation in baseball pitchers, as rest from live games in the off-season is not sufficient.

The collegiate pitchers in our study demonstrated increased UCL thickness in the dominant arm relative to the nondominant arm at all 3 time points evaluated, consistently with previous studies.^{3,4,7,16,24} In addition, UCL thickness significantly increased

throughout the season in our study. In pitchers with GIRD greater than 10°, the increase in UCL thickness was significantly greater. An interesting finding of our study was that after an off-season of rest, UCL thickness returned to baseline in all pitchers. One prior investigation (Keller et al¹³) similarly found UCL thickness to increase after a season of pitching (1.85 mm in preseason vs. 2.20 mm in postseason, *P* < .05) but did not obtain measurements in the following preseason to evaluate trends in the resolution of these changes. Serial preseason dynamic ultrasound measurements were performed in professional baseball pitchers in a study by Ciccotti et al⁷; they found no significant differences in UCL thickness of the dominant elbow when initial preseason measurements were compared with preseason measurements in subsequent seasons, similarly to our results. However, without postseason measurements, their study was not designed to determine whether resolution of UCL adaptations occurs with rest.

Our study found increases in both the unloaded and loaded UHJS in the dominant elbow of a competitive baseball pitcher throughout the course of a competitive pitching season—albeit statistically insignificant. However, a statistically significant association was found between initial preseason 1 GIRD measurements, with higher preseason GIRD correlating with increases seen in loaded UHJS after the season. Furthermore, both unloaded UHJS and loaded UHJS significantly decreased after an off-season of rest, with pitchers having GIRD of 10° or less showing a significantly greater improvement over the off-season. Previous studies have evaluated UHJS with and without stress at single time points and found no differences related to age or years of experience but did

Table IV
Physical dimensions of elbow in pitchers with GIRD of 10° or less vs. GIRD greater than 10°

Outcome measure	Season changes*	Off-season changes†	Relative to baseline‡
Δ UCL thickness, mm			
GIRD ≤ 10° (n = 5)	0.15 (−0.17 to 0.47)	0.11 (0.43 to 0.21)	0.04 (−0.29 to 0.38)
GIRD > 10° (n = 6)	0.22 (0.00 to 0.44)§	−0.12 (−0.37 to 0.13)	0.10 (−0.14 to 0.34)
Δ Unloaded UHJS, mm			
GIRD ≤ 10° (n = 5)	0.38 (−0.17 to 0.92)	−0.27 (−0.49 to −0.04)§	0.11 (−0.34 to 0.55)
GIRD > 10° (n = 6)	0.31 (−0.52 to 1.14)	−0.35 (−0.77 to 0.07)	−0.04 (−0.81 to 0.73)
Δ Loaded UHJS, mm			
GIRD ≤ 10° (n = 5)	0.63 (0.22 to 1.05)§	−0.73 (−1.28 to −0.17)§	−0.09 (−0.71 to 0.53)
GIRD > 10° (n = 6)	−0.03 (−0.96 to 0.90)	−0.18 (−1.13 to 0.77)	−0.21 (−0.97 to 0.55)

GIRD, glenohumeral internal rotation deficit; UCL, ulnar collateral ligament; UHJS, ulnohumeral joint space; Δ, change.

Data presented as mean difference (95% confidence interval).

* Preseason 1 to postseason 1.

† Postseason 1 to preseason 2.

‡ Preseason 1 to preseason 2.

§ Statistically significant.

Table V
Correlations (*r* values) among demographic factors and clinical assessment with ultrasound changes in pitching elbow during season and off-season

Factor	Correlation (<i>r</i>)					
	Δ preseason 1 to postseason 1			Δ postseason 1 to preseason 2		
	UCL thickness	Unloaded UHJS	Loaded UHJS	UCL thickness	Unloaded UHJS	Loaded UHJS
Seasons	0.48	-0.23	-0.18	0.03	0.21	-0.14
Height	-0.11	-0.29	-0.41	0.15	0.10	0.08
Weight	0.06	-0.13	-0.30	0.14	0.32	0.23
Initial GIRD	-0.20	0.41	0.80*	-0.04	0.08	-0.57
Preseason IR	-0.03	-0.14	-0.41			
Postseason IR				0.06	-0.21	0.61*
Season						
Δ IR	0.05	-0.32	0.17			
Δ ER	-0.36	0.35	0.48			
Δ GIRD	-0.05	0.32	-0.17			
Off-season						
Δ IR				0.52	-0.33	0.08
Δ ER				0.33	-0.22	0.12
Δ GIRD				-0.52	0.33	-0.08

Δ, change; UCL, ulnar collateral ligament; UHJS, ulnohumeral joint space; GIRD, glenohumeral internal rotation deficit; IR, internal rotation; ER, external rotation.

* Significant *r* value.

also find a significant increase in dominant elbow widening compared with the nondominant elbow.⁴ Similarly to our study, Keller et al¹³ found insignificant increases in UHJS with and without stress between preseason and postseason measurements. Ciccotti et al⁷ found a statistically significant increase in UHJS between preseason 1 and preseason 2 measurements in professional pitchers with subsequent ultrasound evaluations. Studies have previously established an association between increased UHJS widening and pain or medial elbow symptoms.^{18,24} Recently, Shanley et al²¹ linked the risk of injury to the UCL with unloaded UHJS widening, as well as demonstrating that increased elbow laxity under valgus load portends a 6-fold greater likelihood of requiring UCL reconstruction. Our study demonstrates that elbow laxity, as measured by UHJS on ultrasound, improves during an off-season of rest—and even more so in pitchers with GIRD of 10° or less—and, therefore, may be a modifiable risk factor for UCL tears. Although more prospective studies are required to delineate this relationship, decreased GIRD may be a protective factor in linking elbow laxity to UCL injuries.

Our study, consistently with previous literature, demonstrated that shoulder ROM is affected by a competitive season of baseball pitching.^{20,22} This finding is significant as shoulder IR deficits have been correlated with injury. Shanley et al²⁰ found the dominant shoulder of injured overhead athletes to have significant decreases in IR, with an IR deficit greater than 25% portending a 4-fold greater risk of upper-extremity injury. In a separate study, Shanley et al²² evaluated the dominant shoulders of professional pitchers during 2 subsequent spring trainings, finding that preseason measurements of external rotation increased whereas IR decreased. Our study found that IR significantly decreased in the dominant arm throughout the season and continued to progressively decrease despite an off-season of rest, paralleled by progressively increasing GIRD. Likewise, external rotation increased during the off-season. One possible explanation may be the variance in collegiate pitchers ranging from their freshman to junior years because presumably the freshman pitchers may have more relative arm rest prior to preseason 1 measurements compared with the more experienced upperclassmen. A greater sample size would be required to stratify per age group to determine the influence of collegiate experience.

There exists a delicate balance between shoulder ROM and elbow function, highlighting that shoulder ROM may be a modifiable risk factor for elbow laxity and UCL injury.^{10,20} Although we are

unable to comment on the risk of injury in our cohort, our findings are significant as GIRD²⁰ and increased side-to-side differences¹⁹ have been shown to be predictive of shoulder or elbow injuries in baseball pitchers. Although elbow measurements on ultrasound resolved with off-season rest in our study, rest alone was not enough to reverse the progressive GIRD. This finding advocates aggressive rest and rehabilitation programs in the off-season to potentially influence shoulder and elbow injuries in a clinically significant manner.

Limitations

There are several limitations to our study. The study was conducted at a single collegiate institution with volunteer recruits, limiting our sample size. In addition, collegiate athletes are not present on campus during the summer, and thus, individual off-season rehabilitation protocols could not be standardized and monitored prior to study initiation, nor was off-season rehabilitation controlled for during the off-season portion of the study period. We attempted to account for these variables using questionnaires and ensuring evaluation at similar time points for each athlete. Another limitation inherent to questionnaires is recall bias and variability in subjective self-assessment. In this study, valgus stress during UHJS evaluation was applied manually rather than using a standardized device. However, this was performed by a single orthopedic surgeon in every pitcher and is consistent with previous studies.^{7,13,14,16} Finally, the radiologists determined consensus measurements for each ultrasound image, and therefore, inter-rater reliability was unable to be calculated. However, this was believed to produce the most accurate single measurement as opposed to calculation of an average measurement, given the low number of study subjects. Furthermore, this study cannot determine the clinical ramifications of changes in UCL thickness by fractions of a millimeter because it is not powered to prospectively assess for future injury or development of symptoms; however, this magnitude of change is consistent with prior studies.^{3,7,13,24}

Conclusion

Our study found that stress on the throwing arm during a competitive pitching season produces adaptive anatomic changes. Although changes in UCL thickness and UHJS were found to resolve after off-season rest, shoulder ROM deficits were found to be

progressive and did not resolve. We found a correlative relationship between increased GIRD and subsequent development of increased UCL thickness and elbow laxity after a season of pitching, as well as a protective effect of decreased GIRD and recovery of elbow laxity during the off-season. Adequate rest and off-season rehabilitation should be emphasized to optimize resolution of adaptive changes in the anatomy of the pitching arm.

Disclaimer

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References

1. Aguinaldo AL, Chambers H. Correlation of throwing mechanics with elbow valgus load in adult baseball pitchers. *Am J Sports Med* 2009;37:2043–8. <https://doi.org/10.1177/0363546509336721>.
2. 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;38:1368–74. <https://doi.org/10.1177/0363546510363402>.
3. Atanda A Jr, Averill LW, Wallace M, Niiler TA, Nazarian LN, Ciccotti MG. Factors related to increased ulnar collateral ligament thickness on stress sonography of the elbow in asymptomatic youth and adolescent baseball pitchers. *Am J Sports Med* 2016;44:3179–87. <https://doi.org/10.1177/0363546516661010>.
4. Atanda A Jr, Buckley PS, Hammoud S, Cohen SB, Nazarian LN, Ciccotti MG. Early anatomic changes of the ulnar collateral ligament identified by stress ultrasound of the elbow in young professional baseball pitchers. *Am J Sports Med* 2015;43:2943–9. <https://doi.org/10.1177/0363546515605042>.
5. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology part I: pathoanatomy and biomechanics. *Arthroscopy* 2003;19:404–20. <https://doi.org/10.1053/jars.2003.50128>.
6. Cain EL Jr, Dugas JR, Wolf RS, Andrews JR. Elbow injuries in throwing athletes: a current concepts review. *Am J Sports Med* 2003;31:621–35. <https://doi.org/10.1177/03635465030310042601>.
7. Ciccotti MG, Atanda A Jr, Nazarian LN, Dodson CC, Holmes L, Cohen SB. Stress sonography of the ulnar collateral ligament of the elbow in professional baseball pitchers: a 10-year study. *Am J Sports Med* 2014;42:544–51. <https://doi.org/10.1177/0363546513516592>.
8. Conte SA, Fleisig GS, Dines JS, Wilk KE, Aune KT, Patterson-Flynn N, et al. Prevalence of ulnar collateral ligament surgery in professional baseball players. *Am J Sports Med* 2015;43:1764–9. <https://doi.org/10.1177/0363546515580792>.
9. DeMoss A, Millard N, Mclivain G, Beckett JA, Jasko JJ, Timmons MK. Ultrasound-assisted assessment of medial elbow stability. *J Ultrasound Med* 2018;37:2769–75. <https://doi.org/10.1002/jum.14631>.
10. Dines JS, Frank JB, Akerman M, Yocum LA. Glenohumeral internal rotation deficits in baseball players with ulnar collateral ligament insufficiency. *Am J Sports Med* 2009;37:566–70. <https://doi.org/10.1177/0363546508326712>.
11. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med* 1995;23:233–9.
12. 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;40:2597–603. <https://doi.org/10.1177/0363546512459175>.
13. Keller RA, Marshall NE, Bey MJ, Ahmed H, Scher CE, van Holsbeeck M, et al. Pre- and postseason dynamic ultrasound evaluation of the pitching elbow. *Arthroscopy* 2015;31:1708–15. <https://doi.org/10.1016/j.arthro.2015.06.019>.
14. Marshall NE, Keller RA, Van Holsbeeck M, Moutzourous V. Ulnar collateral ligament and elbow adaptations in high school baseball pitchers. *Sports Health* 2015;7:484–8. <https://doi.org/10.1177/1941738115604577>.
15. Morrey BF, Tanaka S, An KN. Valgus stability of the elbow. A definition of primary and secondary constraints. *Clin Orthop Relat Res* 1991;265:187–95.
16. Nazarian LN, McShane JM, Ciccotti MG, O’Kane PL, Harwood MI. Dynamic US of the anterior band of the ulnar collateral ligament of the elbow in asymptomatic major league baseball pitchers. *Radiology* 2003;227:149–54. <https://doi.org/10.1148/radiol.2271020288>.
17. Rothermich MA, Conte SA, Aune KT, Fleisig GS, Cain EL Jr, Dugas JR. Incidence of elbow ulnar collateral ligament surgery in collegiate baseball players. *Orthop J Sports Med* 2018;6:2325967118764657. <https://doi.org/10.1177/2325967118764657>.
18. Sasaki J, Takahara M, Ogino T, Kashiwa H, Ishigaki D, Kanauchi Y. Ultrasonographic assessment of the ulnar collateral ligament and medial elbow laxity in college baseball players. *J Bone Joint Surg Am* 2002;84-A:525–31. <https://doi.org/10.2106/00004623-200204000-00003>.
19. Shanley E, Kissenberth MJ, Thigpen CA, Bailey LB, Hawkins RJ, Michener LA, et al. Preseason shoulder range of motion screening as a predictor of injury among youth and adolescent baseball pitchers. *J Shoulder Elbow Surg* 2015;24:1005–13. <https://doi.org/10.1016/j.jse.2015.03.012>.
20. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS, Garrison JC, Thigpen CA. Shoulder range of motion measures as risk factors for shoulder and elbow injuries in high school softball and baseball players. *Am J Sports Med* 2011;39:1997–2006. <https://doi.org/10.1177/0363546511408876>.
21. Shanley E, Smith M, Mayer BK, Bailey LB, Thigpen CA, Tokish JM, et al. Using stress ultrasonography to understand the risk of UCL injury among professional baseball pitchers based on ligament morphology and dynamic abnormalities. *Orthop J Sports Med* 2018;6:2325967118788847. <https://doi.org/10.1177/2325967118788847>.
22. Shanley E, Thigpen CA, Clark JC, Wyland DJ, Hawkins RJ, Noonan TJ, et al. Changes in passive range of motion and development of glenohumeral internal rotation deficit (GIRD) in the professional pitching shoulder between spring training in two consecutive years. *J Shoulder Elbow Surg* 2012;21:1605–12. <https://doi.org/10.1016/j.jse.2011.11.035>.
23. Shukla M, Keller R, Marshall N, Ahmed H, Scher C, Moutzourous VB, et al. Ultrasound evaluation of the ulnar collateral ligament of the elbow: which method is most reproducible? *Skeletal Radiol* 2017;46:1081–5. <https://doi.org/10.1007/s00256-017-2656-z>.
24. Tajika T, Yamamoto A, Oya N, Ichinose T, Shimoyama D, Sasaki T, et al. The morphologic change of the ulnar collateral ligament of elbow in high school baseball pitchers, with and without symptoms, by sonography. *J Shoulder Elbow Surg* 2016;25:1223–8. <https://doi.org/10.1016/j.jse.2016.04.013>.
25. Tonin K, Strazar K, Burger H, Vidmar G. Adaptive changes in the dominant shoulders of female professional overhead athletes: mutual association and relation to shoulder injury. *Int J Rehabil Res* 2013;36:228–35. <https://doi.org/10.1097/MRR.0b013e32835d0b87>.
26. Werner SL, Murray TA, Hawkins RJ, Gill TJ. Relationship between throwing mechanics and elbow valgus in professional baseball pitchers. *J Shoulder Elbow Surg* 2002;11:151–5. <https://doi.org/10.1067/mse.2002.121481>.
27. Wilk KE, Macrina LC, Fleisig GS, Aune KT, Porterfield RA, Harker P, et al. Deficits in glenohumeral passive range of motion increase risk of shoulder injury in professional baseball pitchers: a prospective study. *Am J Sports Med* 2015;43:2379–85. <https://doi.org/10.1177/0363546515594380>.