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BASIC SCIENCE

The influence of a single 30-pitch session on elbow laxity in adolescent and collegiate baseball pitchers

Peter N. Chalmers, MD[a], Christopher Clinker, BS[a], Adrik Da Silva, BS[a,*], Hiroaki Ishikawa, PT, PhD[a], Daniel M. Cushman, MD[b], Joy English, MD[a]

[a]*Department of Orthopaedics, University of Utah, Salt Lake City, UT, USA*
[b]*Department of Physical Medicine and Rehabilitation, University of Utah, Salt Lake City, UT, USA*

Background: Ulnar collateral ligament (UCL) injuries are a source of significant injury among baseball players, and are increasingly evaluated under ultrasound. The purpose of this study is to determine the effect of a single session of pitching upon UCL thickness and laxity via a cross sectional, controlled ultrasonographic study. We hypothesize that a single session of pitching will cause the ulnar collateral ligament to thicken and become more lax.
Methods: This was a cross sectional comparative study of collegiate and high school pitchers. Pitchers underwent an ultrasonographic assessment of the UCL before and after a thirty-pitch bullpen warm-up. Laxity was measured as the change in the distance between the ulna and the trochlea with and without a 5-pound weight held in hand with the elbow at 30° of flexion. Pre- and post-throwing UCL thickness and medial laxity were statistically compared with paired tests.
Results: Our study included 15 pitchers, 8 collegiate and 7 high school level athletes. All played baseball at least 6 days a week, and nearly all played for at least 10 months a year. Pitchers reported a peak velocity of 89 ± 6 (77 to 98) miles per hour. In the prior season, these pitchers pitched 56 ± 33 (10 to 120) games, throwing 62 ± 34 (25-140) pitches per game on average. After throwing, there was significantly less UCL laxity ($P = .013$). Post-throwing laxity was significantly positively correlated with both peak pitch velocity ($P = .009$) and an average number of pitches thrown per game ($P = .10$).
Conclusion: Throwing 30 pitches significantly decreases medial elbow laxity with stress, possibly due to flexor-pronator activation. Post-throwing medial laxity is correlated with both peak pitch velocity and average number of pitches thrown per game. Future studies should be conducted to determine the number of throws at which laxity begins to increase, as this may provide a workload management guideline for injury prevention.
Level of evidence: Basic Science Study; Kinesiology

Keywords: Ulnar collateral ligament; baseball pitching; flexor-pronator; ultrasound; overhead athlete; ulnar collateral ligament laxity

Pitching-related injuries are highly prevalent, occurring in 30%-74% of pitchers.[5,21] Pitching-related injuries are increasing in frequency and occurring in very young athletes.[18,31] Ulnar collateral ligament (UCL) tears are among the most common pitching-related injuries and often requires surgical treatment.[9,10,12,13] Furthermore, UCL repairs are rapidly increasing in both high school and MLB

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*Reprint requests: Adrik Da Silva, BS, Department of Orthopaedic Surgery, University Orthopaedic Center, 590 Wakara Way, Salt Lake City, Utah 84108, USA.
E-mail address: adrik.dasilva@hsc.utah.edu (A. Da Silva).

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pitchers.[10,28] Developing and optimizing strategies for the identification and prevention of these injuries are thus critical within baseball at all levels.

Workload management is currently one of the most heavily utilized strategies for prevention based upon prior studies demonstrating that high pitch counts and fatigue correlate with pain and injury. Lyman et al. found that "Game pitches were a significant risk factor for shoulder pain, with each pitch resulting in a 1.5% increased risk of shoulder pain and a significant trend per 25 pitches thrown. This was especially apparent when more than 75 pitches had been thrown in a game."[21,22] Furthermore, pitcher biomechanics change with fatigue with a previous study demonstrating increasing pain and lower velocity as pitchers progressed through simulated games.[14] However, it may also be that during a simulated baseball game, damage accumulates within the ligament. If the game is extended, then the ligament tears but given sufficient rest this damage can resolve. Indeed, we have previously demonstrated that a single season of pitching professionally causes the ligament to thicken and become more lax.[4] Conversely, rest from pitching during a single off-season causes the ligament to thin and decrease laxity.[4] However, the time course for these adaptive and de-adaptive changes remains unknown. Reinold et al. demonstrated that even a single session of a weighted ball program can alter the shoulder range of motion.[29] This suggests that even a single session of pitching may cause a similar increase in medial elbow laxity. Therefore, understanding whether this process is occurring during games has implications for workload management and injury prevention, as well as for the etiology of UCL tears.

The purpose of this study is to determine the effect of a single session of pitching on ulnar collateral ligament thickness and laxity via a cross sectional, controlled ultrasonographic study. We hypothesize that a single session of pitching will cause the ulnar collateral ligament to thicken and become more lax.

Methods

Subject recruitment

This was a cross sectional comparative study. Pitchers from a single collegiate and a single high school team were recruited. Pitchers who were not able to throw because of injury were excluded, as were players who had undergone a prior UCL reconstruction or repair. Players were first asked to complete a survey to collect age, height, weight, number of years pitching, reported peak pitch velocity (highly correlated to measured velocity),[2] current shoulder pain, history of shoulder surgery, and history of injury during the current or prior season.

Elbow ultrasound protocol

We evaluated participants in the supine position on the examination table. To efficiently position the elbow, we used a 3D-printed template to hold the arm at 30° 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 (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 UCL thickness (mm) without weight applied and ulnotrochlear distance (mm) both with and without a weight applied. We used a 5-lb load as higher loads were associated with discomfort and difficulty relaxing medial elbow musculature in pilot testing. After applying the load, we measured ulnotrochlear distance ultrasonographically in mm. We performed all measurements on the dominant elbow with the subject in a relaxed state. All examinations were performed by a single ultrasonographer with fellowship training in ultrasound and with extensive experience performing ultrasound of the UCL.[4] We have previously used this protocol successfully and have demonstrated it to have excellent intra-observer reliability.[3]

Throwing protocol

All pitchers were asked to do their standard warm-up shoulder exercises using Theraband tubing (Theraband, Akron, OH, USA). These exercises included external rotation (ER) and internal rotation (IR) at 0° abduction, ER and IR at 90 of horizontal abduction, horizontal adduction, simulated throwing motion, and a reverse throwing motion. Participants then completed their warm-up throws. All throws were performed with a standard weight ball. We then verbally confirmed with each pitcher that they felt their warm-up was completed and that they were ready to throw. Each participant then threw 30 full-velocity fastballs from the mound. Ultrasound was then completed within 10 minutes of protocol completion.

Statistical analysis

Descriptive statistics were calculated. Data normality was evaluated using the Kolmogorov-Smirnov test. Pre- and post-throwing ultrasonographic characteristics were compared using Paired Student's *t*-tests and Related-Samples Wilcoxon Signed Rank tests as appropriate depending upon data normality. Thrower characteristics were also correlated with post-throwing laxity using Pearson's correlation and Spearman's ρ tests. Statistical significance was assessed at the 0.05 level. All analyses were be conducted using Excel 16 (Microsoft, Redmond, WA, USA) and SPSS 29 (IBM, Armonk, NY, USA).

Results

Included pitchers

Our study included 15 pitchers, 8 collegiate and 7 high school level athletes. These players were 73 ± 3 (69-78) inches tall (mean ± standard deviation, range) and 183 ± 28 (130-220) lbs. They started pitching at age 11 ± 3 (7-16) and had been pitching for 8 ± 4 (3-14) years. All played baseball at least 6 days a week, and nearly all played for at least 10 months a

Table I Ultrasonographic characteristics

Variable	Pre-throwing	Post-throwing	Change	*P* value
Thickness (mm)	0.63 ± 0.09	0.61 ± 0.07	−0.18 ± 0.06	.300
Ulnotrochlear Distance without Stress (mm)	0.37 ± 0.06	0.37 ± 0.08	0.02 ± 0.05	.700
Ulnotrochlear Distance with Stress (mm)	0.45 ± 0.12	0.42 ± 0.09	0.04 ± 0.06	.013
Ulnotrochlear Laxity to Stress (mm)	0.08 ± 0.11	0.04 ± 0.08	0.03 ± 0.06	.013

All results are reported as a mean ± standard deviations.

year, except for one high school player who only played for 4 months a year. Over 50% of the pitchers took a month or less off from throwing a year, and only 26% (4/15) took at least 3 months off a year. All but 2 had pitched in showcases, but none had been returned to the mound after being relieved. All of the high school players also played other positions, while only one of the collegiate pitchers also played shortstop. Only a single high school pitcher played any other sports (football and boxing). Most of the pitchers had participated in weighted ball programs (73%, 11/15). Three of the collegiate pitchers had a history of injury, including shoulder inflammation, rotator cuff tendonitis, and an olecranon stress fracture, for which they had undergone PT. A single collegiate pitcher had a remote history of an ulnar nerve transposition 6 years ago while in high school. Pitchers reported an average velocity of 85 ± 7 (70-95) miles per hour and a peak velocity of 89 ± 6 (77-98) miles per hour. In the prior season, these pitchers pitched 56 ± 33 (10-120) games), throwing 62 ± 34 (25-140) pitches per game on average. They reported pitching 30 ± 15 (8-60) pitches per warm-up.

Ultrasound findings

No pitchers had partial or full thickness UCL tears and no calcifications were seen. There was no significant difference between pre- and post-throwing ligament thickness ($P = .300$) or distance between the ulna and trochlea without stress ($P = .700$). However, post throwing distance between the ulna and trochlea with stress was significantly decreased ($P = .013$, Table I). In other words, medial ulnotrochlear laxity (change in the ulnotrochlear distance with stress) was significantly decreased post-throwing as compared to pre-throwing ($P = .013$). Medial ulnotrochlear laxity was not significantly correlated with UCL thickness, player height, player weight, or average pitch velocity (Table II). However, it was significantly positively correlated with both peak pitch velocity ($P = .009$, Fig. 1) and average number of pitches thrown per game ($P = .10$, Fig. 2) suggesting that pitchers who threw harder and threw more had more laxity post-throwing. There were no significant differences between high school and collegiate pitchers in UCL thickness before ($P = 1.000$) or after ($P = .613$) throwing, nor in ulnotrochlear gapping before ($P = .152$) or after ($P = .779$) throwing.

Discussion

This cross sectional ultrasonographic study demonstrates that throwing thirty full-velocity pitches significantly decreases medial laxity with stress, without influencing

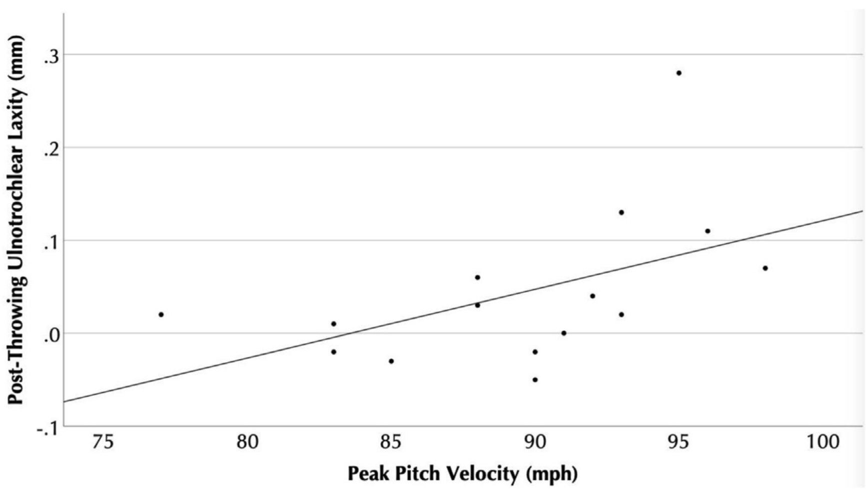

Figure 1 There was a significant correlation between peak pitch velocity in miles per hour (mph) and post-throwing ulnotrochlear laxity (mm), with a Spearman's ρ of 0.645, and $P = .009$.

Table II Correlation coefficients between medial ulnotrochlear laxity to stress post-throwing and each variable

Variable	Correlation Coefficient	*P* value
Post-throwing Thickness (mm)	−0.320	.245
Height (inches)	−0.011	.969
Weight (lbs)	0.408	.132
Average Pitch Velocity (mph)	0.414	.125
Peak Pitch Velocity (mph)	0.645	.009
Average Pitches Thrown Per Game	0.640	.010

mph, miles per hour.

UCL thickness in high school and collegiate pitchers. Future research with pitchers of varying ages throwing varying number of pitches may be useful to understand when flexor-pronator fatigue occurs, as this would likely be associated with an increase in medial laxity. In our study, medial elbow laxity post-throwing was significantly positively correlated with both peak pitch velocity and average number of pitches thrown per game. Our study supports findings by Hattori et al. who found that elasticity significantly increased in the UCL after 100 pitches which is an indicator of increased UCL laxity.[16,17] It is unclear whether this increase in laxity is an adaptation to prevent injury, a prelude to a tear, or perhaps allow for increased pitch velocity.

Our results show that throwing led to decreased medial elbow laxity. Multiple anatomic structures resist valgus stress in the elbow, including the flexor-pronator and the UCL.[24,26,30,32] Given that the force of baseball pitching regularly exceeds the load-to-failure of the native UCL,[11] the flexor-pronator plays a crucial stabilizing role in maintaining elbow integrity. Our results suggest that it may be a primary rather than a secondary stabilizer. This suggests that UCL injury occurs due to flexor-pronator fatigue, resulting in the UCL assuming the burden of valgus stress that the fatigued flexor-pronator no longer can. Historically, injury prevention research has been challenging.[5] Many prior studies have used pain as a secondary marker for injury which has proved to be imperfect in that regard.[5] It has also meant that large studies are necessary to be adequately powered.[21] Our results suggest that, if UCL injury is the target injury to prevent, sequential measurements of medial elbow laxity in varying ages with varying pitch counts could provide a secondary biomarker. This paired design could allow studies with smaller sample sizes to guide pitch count recommendations. It could also be plausible that laxity exhibits a U-shaped curve, where after warm-up laxity decreases, but as fatigue ensues laxity increases, with a higher resultant load born by the UCL. Finally, our own results support prior research that suggests that medial laxity, ie medial joint gapping to stress, can be significantly altered by flexor-pronator activation and thus may have limited utility in the diagnosis of UCL tears.[3,20,23] This is interesting as joint space measurements have been previously reported as useful in assessing UCL flaccidity and damage.[7,27] However, this flexor-pronator activation may explain the contradictory findings where

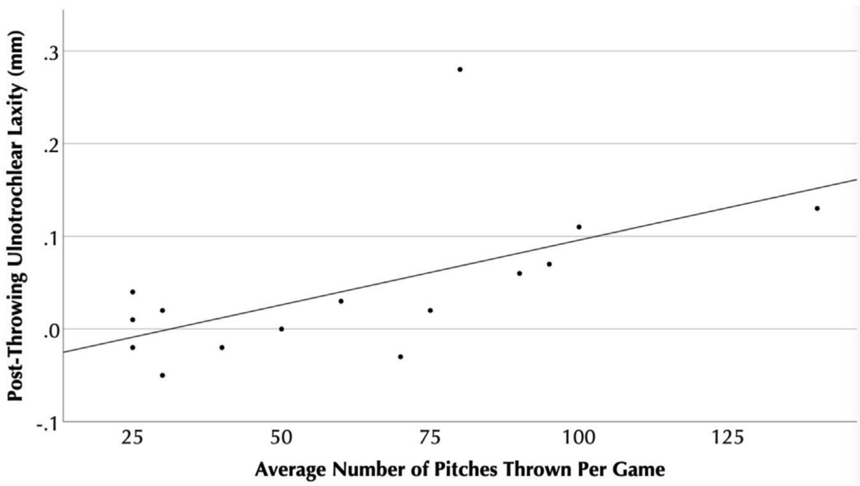

Figure 2 There was a significant correlation between average number of pitches thrown per game and post-throwing ulnotrochlear laxity (mm), with a Spearman's ρ of 0.640, and $P = .010$.

some studies have found individuals with UCL tears display less joint widening under stress compared to the uninjured side.[3]

Within our study, medial elbow laxity post-throwing was significantly positively correlated with both peak pitch velocity and average number of pitches thrown per game. There are several possible explanations for these associations. First, prior studies have demonstrated that creation of pitch velocity is dependent upon the shoulder reaching maximum external rotation in the late cocking phase of the throw.[15,19,25] During this moment in the pitch, the kinetic energy generated with the stride down the mound, the rotation of the hips, and the rotation of the thorax, is stored in a stretch of the soft tissues of the shoulder and elbow.[6] Thus, pitchers with more laxity within the medial elbow may be better able to store energy at this moment, and thus better able to transfer this energy onto the ball and thus able to achieve higher pitch velocities. A second reason could involve increased pressure as a result of increased throws. One study demonstrated that medial elbow laxity was increased by a season of professional baseball and decreased by a season of rest.[4] Thus, the increased pressure on the medial elbow, both via throw volume and velocity, may itself increase laxity. This increase in laxity may be an adaptation to prevent injury, or, alternatively, could be the prelude to a tear. Finally, the increased laxity could be a direct result from the increased load that has already been placed on the pitcher from the increased pitch counts and velocity with each pitch. Further research is necessary to understand whether ultrasonographic UCL morphology can predict injury, as prior studies have been inconclusive.[1,7,8]

This study has several limitations. The first is the limited sample size and lack of an a priori power analysis. However, despite the small sample size, we did find significant differences between pre- and post-throwing due to the paired design. The second is the clinical relevance of these findings. It remains unknown whether the increased laxity seen post-throwing would be associated with an increased risk for UCL injury. Subsequent studies will be necessary to further understand the possible association between flexor-pronator fatigue and UCL injury. The third is the use of ultrasound, which is operator-dependent, but our previous work has identified excellent reliability.[4] Another limitation of the study is that we did not perform testing at multiple timepoints during the season. An additional limitation is heterogeneity in the included pitchers as to whether they pitch year-round. Finally, this static measurement is not necessarily recreating the laxity seen during a pitch, which may be different.

Conclusion

Throwing 30 warm-up pitches significantly decreases medial elbow laxity with stress, possibly due to flexor-pronator activation. Post-throwing medial elbow laxity is positively correlated with both peak pitch velocity and average number of pitches thrown per game. Future studies should be conducted to determine the number of throws at which laxity begins to increase, as this may provide a workload management guideline for injury prevention.

Disclaimers:

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Conflicts of interest: Peter Chalmers is a paid consultant for Depuy-Mitek, Exactech, DJ Orthopaedics, and Smith & Nephew; received intellectual property royalties from Depuy, Exactech, and Responsive Arthroscopy; serves on the editorial board for the *Journal of Shoulder and Elbow Surgery*, and has stock in TitinKM Biomedical. The other authors, their immediate families, and any research foundation 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.

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