

Comparison of Biomechanical Factors Before and After UCL Surgery in Baseball Athletes

A Systematic Review With Meta-analysis

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Background: Ulnar collateral ligament (UCL) reconstruction (UCLR) and repair (UCLr) are the gold standards in the treatment of UCL injuries. Although return-to-play timelines after UCLR have been established, pitching biomechanical variables are speculated to change after surgical intervention.

Purpose/Hypothesis: To synthesize the literature and investigate changes in pitching biomechanics in baseball pitchers after UCLR or UCLr. We hypothesized that differences in pitching biomechanics would be observed for both intra- and interpatient comparisons.

Study Design: Systematic review; Level of evidence, 3.

Methods: We searched 4 electronic databases (PubMed, Web of Science, SCOPUS, and Sports Medicine & Education Index) from inception to February 2020. Data extracted included author and year of publication, study design, sample size, study population, and primary outcome variables. Meta-analysis was performed to produce random pooled effect sizes (Δ).

Results: We identified 1010 original articles for inclusion. A total of 5 studies were included in the systematic review; of these, 3 studies were included in the meta-analysis. No differences were found in shoulder range of motion (ROM) between post-UCLR and control pitchers (dominant arm external rotation Δ , 0.13°; 95% CI, -0.15° to 4.02°; $P = .36$); dominant arm internal rotation Δ , -0.20°; 95% CI, -0.74° to 0.35°; $P = .48$). Mean fastball velocity as well as pitches thrown decreased after UCLR in professional pitchers. Significant differences in elbow extension, elbow extension velocity, and shoulder internal rotation velocity were found among amateur pitchers.

Conclusion: The results of this systematic review and meta-analysis show that limited differences exist in pitchers before and after UCLR as well as in post-UCLR pitchers and healthy, age-matched controls. UCLR may influence throwing velocity, but it had no effect on either the throwing biomechanics or the ROM of baseball pitchers. Although trends appear to be forming, further evidence is needed to understand the effect of UCLR on throwing biomechanics.

Keywords: baseball; pitching; UCLR; biomechanics

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Arm injuries can have a devastating effect on the careers of baseball players. These injuries occur throughout the life-span of these athletes, increasing in probability from youth to professional players. It has been shown that 25% of all baseball injuries are considered severe, resulting in a large reduction in sport participation.⁵ When an injury requires ulnar collateral ligament (UCL) reconstruction (UCLR) or repair (UCLr), this proves costly: It is estimated that \$1.5 billion is spent annually on the treatment of injuries in Major League Baseball (MLB) pitchers.²⁹ Of all players on the injured list (IL), pitchers were found to make up 48.4% of all IL reports, with shoulder and elbow injuries making up 49.8% of all IL injuries.³ These injury trends are not restricted to the MLB, as a 143% increase in UCLR in youth baseball players has been observed.²⁰ Thereby, understanding how these injuries occur will allow clinicians and researchers to identify effective methods to prevent arm injuries.

The influence of biomechanical factors on UCL injury has been well-documented in baseball players.^{2,33,35,39} The pitching motion is a complex blend of segmental interactions that create a kinematic and kinetic chain throughout the body, leading to a transfer of momentum to the baseball.²⁸ Pitchers produce large forces, or torques, at the shoulder and elbow that are coupled with high velocities and extensive ranges of motion in the trunk and upper extremity as they effectively transfer momentum to the baseball.³⁵ Key indicators within the throwing motion allow researchers to efficiently monitor player mechanics and improve any movement deficiencies. For example, improper timing between foot contact, pelvic rotation, and upper trunk rotation has been associated with decreased throwing velocity, increased force experienced throughout the kinetic chain, and increased risk of injury.^{8,35,38} Similarly, poor shoulder external rotation at the time of foot contact may indicate poor timing, resulting in increased arm forces and decreased performance.¹¹

Throwing velocity is a compounding factor to pitching biomechanics, because stresses can amass within the upper extremity as the arm accelerates forward into ball release. This notion is further explained by findings from Chalmers et al,¹ who observed that a 10 mile-per-hour (mph) increase in velocity in adolescent pitchers exhibited a linear relationship to an increased likelihood of a history of injury by 12%. If faulty pitching mechanics are present, segments further along the kinetic chain are required to work harder to catch up to the kinematic velocities of the throwing motion.^{2,33,35,39} Quantitative data, such as throwing biomechanics and velocity, can help monitor pitcher performance to screen for signs of kinetic and kinematic deficiencies that, if left untreated, can presumably increase the chance of developing a UCL tear.

Both UCLR and UCLr are considered the gold standards in the treatment of UCL injuries, and as many as 25% of MLB pitchers have undergone at least 1 intervention.³ The rate of return to pitching after UCLR is roughly 80%, a result of vast improvements in operative procedures.^{34,37} Although pitchers often successfully return to play, the biomechanical changes observed after injury are disputed. The reconstructed UCL often exhibits diminished stiffness compared with preoperative measurements, leading to changes in upper extremity range of motion (ROM).²⁵ Ultimately, this may influence biomechanical patterns of pitchers when throwing after surgery. Several studies have reported the effects of UCLR and UCLr on performance outcomes; however, the effects of UCLR and UCLr on pitching biomechanics are largely unknown. Therefore, given the impact of UCLR on baseball athletes, the purpose of this systematic review and meta-analysis was to investigate changes in biomechanical factors in baseball pitchers after UCLR or UCLr.

METHODS

Information Sources

We conducted a systematic review and meta-analysis of the published literature in accordance with the PRISMA

(Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.²⁶ We searched 4 databases (PubMed, Web of Science, SCOPUS, and Sports Medicine & Education Index) to identify studies that included data on risk factors for baseball pitchers after UCL intervention. Papers published before the initial search date of February 2020 were included in the search. Language was restricted to English, but date of publication was not restricted. The search criteria used for each database were *Baseball OR pitch* AND UCL OR ulnar-collateral AND biomechanics*. We decided not to include search terms such as *kinematics, kinetics, and range of motion* to simplify the search process: Preliminary searches indicated that the overarching term *baseball* was broad and returned all studies pertaining to baseball pitchers.

Study Selection

Study selection involved a multistep process conducted by 1 author (T.J.H.). Reviewers screened eligible studies in 3 steps. For the first step, the investigators evaluated titles and abstracts for predetermined inclusion and exclusion criteria. Inclusion criteria included the following six items: (1) studies on baseball pitchers, (2) studies that reported outcomes of UCL injury, (3) studies of pitching biomechanics, (4) any experimental study design except case studies or reviews, (5) articles written in English, and (6) articles written in full text. Studies on athletes from all levels of play (youth to professional) were included as well. Exclusion criteria included the following six items: (1) studies that did not include upper extremity injuries or focused on traumatic injury (eg, injury to the eyes or face); (2) articles describing return-to-play protocol; (3) studies exclusively reporting performance outcomes; (4) studies that did not include baseball pitchers; (5) study designs that were not cross-sectional, cohort, or case-control; and (6) studies that analyzed the effectiveness of an intervention or surgical procedure. All abstracts were evaluated independently by 1 reviewer (T.J.H.) and were either included or excluded. In the second step, 2 reviewers (T.J.H., S.C.) independently read all full-text articles included in the first step and evaluated each for search criteria. In the third step, a manual search was completed on the final articles to examine whether any manuscripts remained that the initial search did not register. One reviewer (T.J.H.) searched the references of each included study to check for cited studies that would have met the inclusion criteria of this systematic review and meta-analysis.

A total of 1055 titles were identified, and 1010 titles were included after duplicate removal. Ultimately, 5 studies, which included 268 baseball players, were included in the review. Figure 1 shows the flowchart of the study selection process.

Data Acquisition

Data extracted from the selected articles included author and year of publication, study design, sample size, description of the study population, and primary outcome variables. Shoulder ROM, throwing velocity, pitch selection,

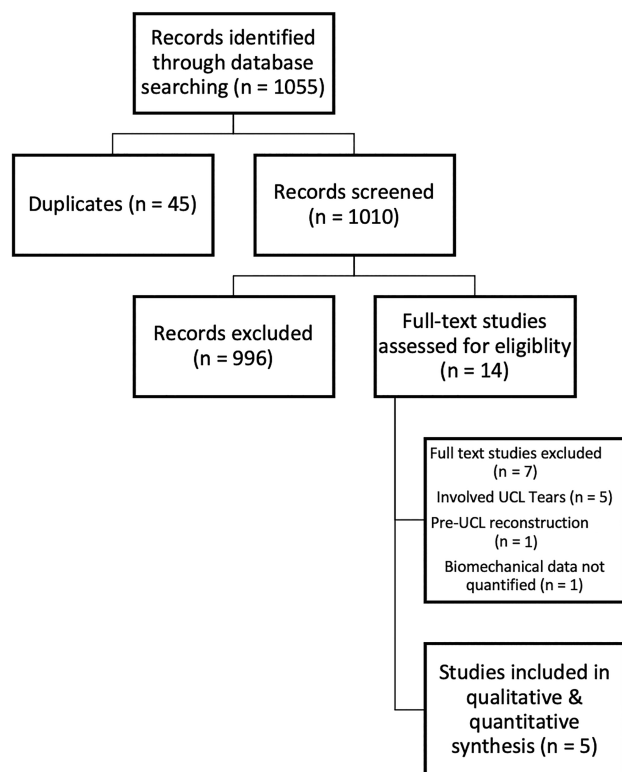


Figure 1. CONSORT (Consolidated Standards of Reporting Trials) diagram of selection process for database articles. UCL, ulnar collateral ligament; UCLR, UCL reconstruction.

and lower extremity balance were included as outcome measures of this study due to their implications for pitching biomechanics. ROM, especially in reference to the shoulder's ability to externally and internally rotate, is vital to the pitching motion. As the pitcher's throwing arm is preparing to accelerate forward into ball release, the throwing shoulder reaches extreme ranges of external rotation before internally rotating at extreme rates.^{15,24,33} Throwing velocity has implications for throwing biomechanics as well as the forces exerted on the body while achieving high velocities.^{6,33} Pitch selection, or the number of times these high-force movements are replicated, quantifies the amount of times the body exerts and withstands force.

Risk-of-Bias Assessment

Risk of bias was assessed with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) scale by 1 author (T.J.H.). This scale was chosen due to its robust ability to address multiple study designs, those being cohort, case-control, and cross-sectional study designs.³⁶ The STROBE contains a 22-item checklist addressing title and abstract (1 item), introduction (2 items), methods (9 items), results (5 items), discussion (4 items), and funding sources (1 item).³⁶ Each article included in this study was awarded 1 point if it met bias

assessment criteria and received 0 if it did not. Studies were classified as low risk if they scored >15 , whereas studies that scored <8 were considered high risk. Studies that scored between 8 and 15 inclusively were considered to have moderate or unclear risk.

Statistical Analysis

The relationship between shoulder ROM of UCLR pitchers and controls was assessed through a random-effects model with inverse variance. A total of 4 random effects models were generated for external rotation of the dominant arm, external rotation of the nondominant arm, internal rotation of the dominant arm, and internal rotation of the nondominant arm. Individual Hedge g effect sizes were calculated, providing a standardized mean difference corrected for small sample sizes.¹⁶ Pooled Hedge g effect sizes for small sample bias were reported (mean Δ) with 95% CIs.⁴ Heterogeneity was assessed using the Cochrane Q and I^2 , with significant heterogeneity denoted by $P < .05$ and $I^2 > 50\%$.¹⁹ Funnel plots were used to assess standard error by Hedge g for each statistical model. All analyses were performed using Comprehensive Meta-Analysis software (Biostat).

RESULTS

Characteristics of Included Studies

Demographic data of the 5 included studies are displayed in Table 1. Three studies were case-control studies,^{7,12,14} and 2 were prospective cohort studies.^{22,30} Study quality results from the STROBE assessment averaged 14.2 ± 1.92 of a maximum of 22 (Table 1). Of the included studies, 4 studies presented moderate overall risk of bias,^{7,12,14,22} and 1 study showed low risk.³⁰ All 5 studies compared metrics after pitchers underwent UCL surgery, with 4 studies performing UCLR^{7,12,22,30} and 1 study performing UCLr.¹⁴ In 3 studies, investigators compared ROM in the dominant shoulder.^{7,12,14} In 2 studies, investigators compared biomechanical variables in the pitching motion versus age-matched controls.^{12,14} In 3 studies, investigators compared throwing velocity.^{12,14,22}

Range of Motion

We found that 3 of the included studies investigated the relationship between shoulder ROM in baseball players with UCLR or UCLr and healthy controls^{7,12,14} (Table 2). The pooled random-effects assessment did not exhibit a significant difference when we examined external rotation between dominant arms of UCLR and control pitchers (mean Δ , 0.13° ; 95% CI, -0.15° to 4.02° ; $P = .36$) with low heterogeneity between studies ($Q = 0.53$; $I^2 = 0.00\%$; $P = .77$) (Figure 2). This pooled effect size demonstrated that UCLR was not significantly associated with increased or decreased external rotation within the dominant shoulder when compared with healthy controls. For internal rotation of the dominant arm between groups, the overall

TABLE 1
Summary of Evidence for Each Included Study^a

Lead Author (Year)	Study Design	Participants (Age)	Methods	Main Results	STROBE Score
Dines ⁷ (2009)	Case-control	11 professional, 10 college, and 8 high school pitchers (21.17 ± 5.58 y)	(1) Inability to participate in athletic activity due to medial-side elbow pain. (2) Clinical examination findings consistent with UCL insufficiency. (3) Documented MRI findings of UCL insufficiency. Follow-up: 1 week	Significant difference in dominant arm IR deficit between UCL and control groups ($P < .001$). Total ROM was significantly decreased in UCL group.	11
Fleisig ¹⁴ (2019)	Case-control	33 amateur pitchers (18 ± 2 y)	Baseball pitchers who had undergone UCLr by the coauthors; no elbow pain at the time of study. Follow-up: 9.8 ± 2.6 months	No differences in passive ROM and joint kinetics. UCL group produced less elbow extension ($P = .03$), less elbow extension velocity ($P = .02$), and less shoulder IR velocity ($P = .49$) compared with controls.	14
Fleisig ¹² (2015)	Case-Control	39 professional pitchers (23.4 ± 1.9 y)	Participants had to be active pitchers in spring training who had UCLR up to 4 years ago. Follow-up: 30.5 weeks	No differences between groups in pitching biomechanics; no differences in passive ROM.	15
Lansdown ²² (2014)	Cohort	80 professional pitchers (29.2 ± 4.51 y)	All MLB pitchers for whom there were public reports of a UCLR between 2003 and 2011. Follow-up: 2.98 years	Mean fastball velocity was significantly decreased after UCLR ($P = .003$). Greatest observed difference was in pitchers older than 35 y, with fastball velocity decreasing from 91.7 to 88.8 mph ($P = .004$).	15
Peterson ³⁰ (2018)	Cohort	87 professional pitchers (28.2 ± 3.5 y)	(1) MLB pitchers who underwent UCLR between 2003 and 2014. (2) Required to have 2 consecutive years of competitive MLB pitching experience before and after surgery. Follow-up: 1-2 years	Significant difference in percentage of fastballs thrown before and after surgery ($P = .02$).	16

^aAge is expressed as mean ± SD. Follow-up is expressed as mean or mean ± SD. IR, internal rotation; MLB, Major League Baseball; ROM, range of motion; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology; UCL, ulnar collateral ligament; UCLR, ulnar collateral ligament reconstruction; UCLr, ulnar collateral ligament repair.

TABLE 2
Summary Statistics for Range of Motion

Subgroup	Mean Δ (95% CI), deg	P	Q	I ²
Dominant arm external rotation (n = 3)	0.128 (−0.146 to 0.402)	.36	0.529	0.000
Dominant arm internal rotation (n = 3)	−0.198 (−0.742 to 0.346)	.476	7.672	73.933

pooled assessment did not exhibit a significant difference (mean Δ, −0.20°; 95% CI, −0.74° to 0.35°; $P = .48$) with high heterogeneity between studies ($Q = 7.67$; $I^2 = 73.93\%$; $P = .02$) (Figure 3).

Throwing Velocity

In total, 3 of the included studies investigated differences in throwing velocity^{12,14,22} (Table 3). There were 2 studies that examined fastball throwing velocities between pitchers who had undergone UCLR or UCLr and healthy, age-matched controls.^{12,14} No significant differences were found between pitchers who had

undergone UCLR or UCLr and healthy control amateur pitchers (78.38 ± 7.29 vs 77.19 ± 5.39 mph, respectively; $P = .46$) or between pitchers who had undergone UCLR or UCLr and healthy control professional pitchers (84.77 ± 3.8 vs 85.67 ± 3.13 mph, respectively; $P = .26$). Additionally, 1 study examined throwing velocities between the 2 years before UCLR and the 2 years after UCLR in professional pitchers.²² Mean fastball throwing velocity was significantly decreased after UCLR (pre- vs post-UCLR, 40.81 vs 40.5 m/s, respectively; $P = .003$) with larger decreases observed in pitchers older than 35 years of age (pre- vs post-UCLR, 40.99 vs 39.7 m/s, respectively; $P = .005$). Pitch velocity did not change

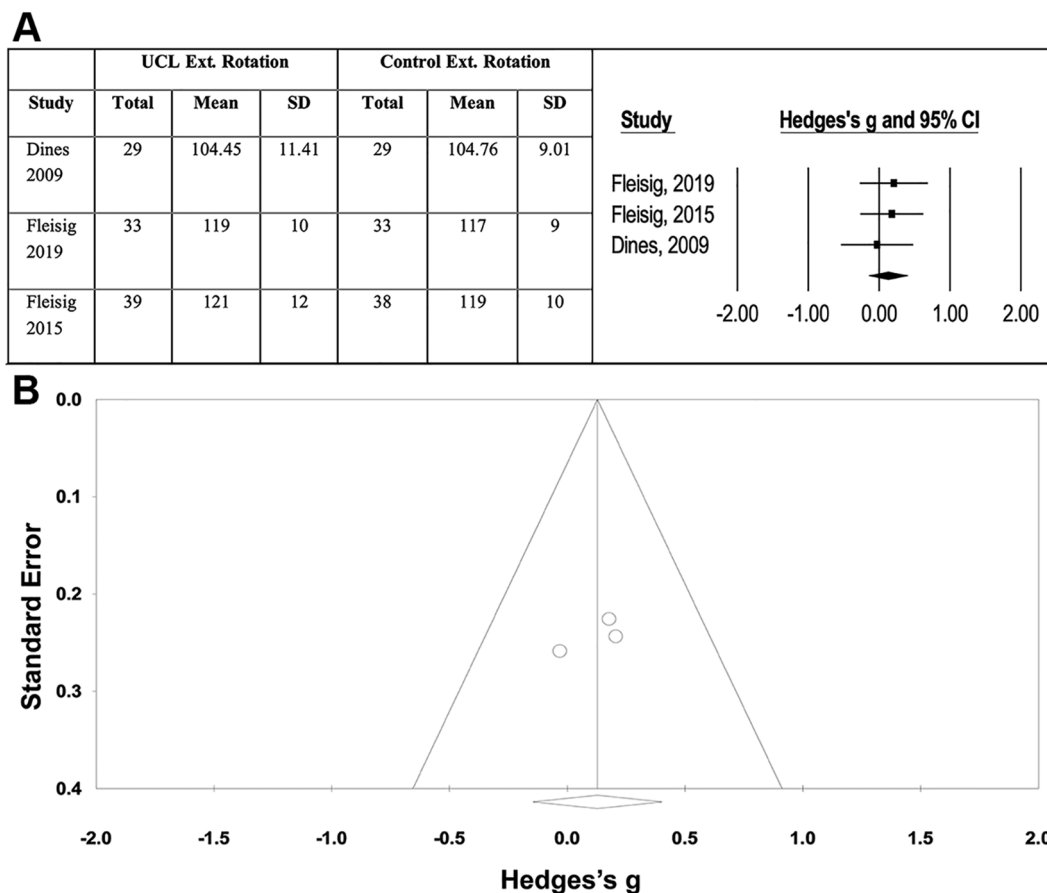


Figure 2. Dominant arm external rotation (A) meta-analysis and (B) funnel plot. Ext, external; UCL, ulnar collateral ligament.

significantly after UCLR for curveballs ($P = .29$), changeups ($P = .5$), and sliders ($P = .68$).

Pitch Selection

With respect to pitch selection, 2 studies investigated the effect of UCLR on pitch selection in professional pitchers (Table 4) with 1 study examining total pitches from pre- to post-UCLR (3026.2 ± 1606.8 vs 2219.9 ± 1484.2 , respectively; $P < .001$),³⁰ while the second study examined pitch type from pre- to post-UCLR (fastball, 80; curveball, 50; changeup, 72; slider, 70).²² A significant difference was observed in the total number of pitches thrown before and after UCLR.³⁰ Both studies found that pitchers threw fewer fastballs after UCLR, with fastballs comprising 64.8% of total pitches thrown preoperatively and 60.4% of total pitches postoperatively ($P = .008$ and $.02$, respectively).^{22,30} A significant increase was observed in curveballs thrown between the first (7.5%) and second year (8.8%) postoperatively ($P = .01$).³⁰

Pitching Biomechanics

We found that 2 of the included studies investigated a comprehensive range of pitching biomechanical variables of interest during the throwing motion.^{12,14} All pitching

biomechanical variables examined between studies are listed in Table 5. One study reported no differences in kinetic values during pitching between collegiate and high school pitchers who had undergone UCLR and healthy age-matched controls.¹⁴ This same study found 3 kinematic variables to be significantly different between groups: The UCLR group produced less elbow extension (flexion, $27^\circ \pm 6^\circ$ vs $24^\circ \pm 4^\circ$, respectively; $P = .03$), lower elbow extension velocity (2442 ± 367 vs 2631 ± 292 deg/s, respectively; $P = .02$), and lower shoulder internal rotation velocity (6273 ± 1093 vs 6771 ± 914 deg/s, respectively; $P = .049$) compared with controls. These findings conflict with those of Fleisig et al,¹² who found no differences in these same biomechanical variables between professional pitchers who had undergone UCLR and professional, healthy, age-matched controls.

DISCUSSION

The results of this systematic review and meta-analysis show that limited differences in throwing biomechanics existed between pitchers who had undergone UCLR and healthy, age-matched controls. Interestingly, UCLR might cause a decrease in throwing velocity but had little effect on the throwing biomechanics and ROM of baseball pitchers.

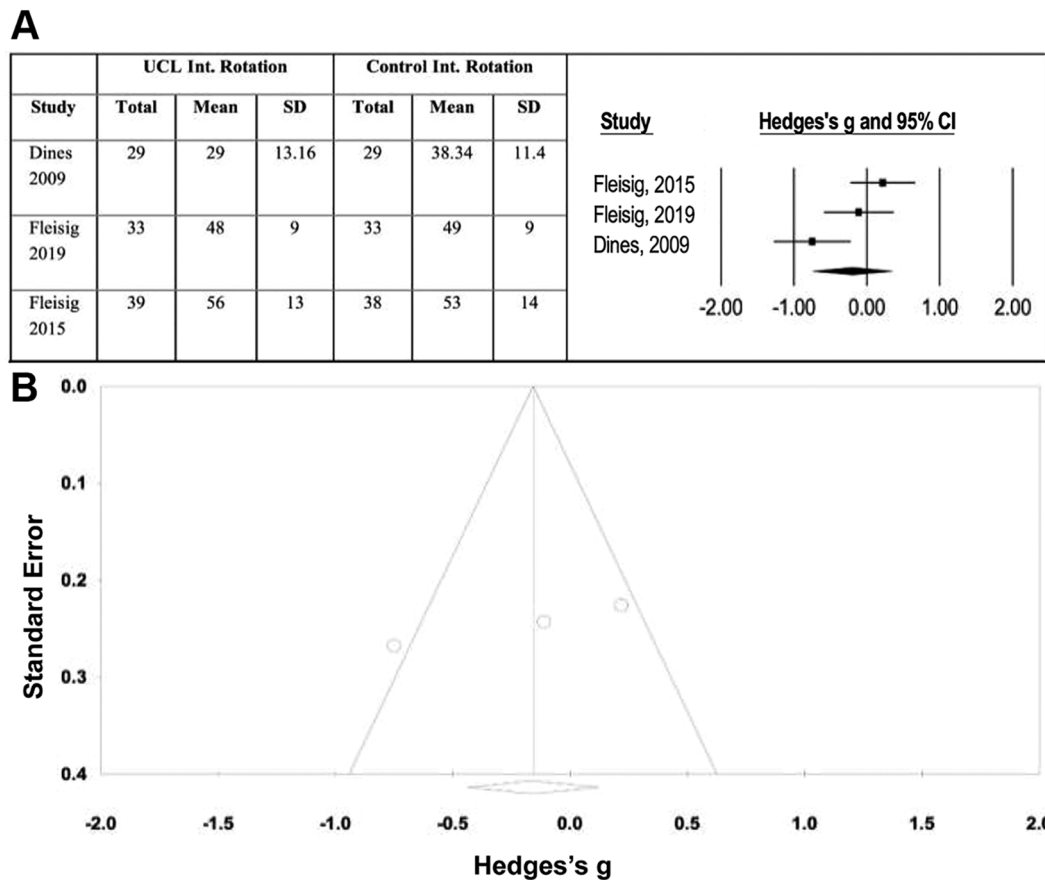


Figure 3. Dominant arm internal rotation (A) meta-analysis and (B) funnel plot. Int, internal; UCL, ulnar collateral ligament.

TABLE 3
Pitch Velocity Comparisons Across Studies^a

	Fastball	Curveball	Changeup	Slider
Fleisig et al ¹²				
Control	85.7 ± 3.1	—	—	—
UCLR	84.8 ± 3.8	—	—	—
Fleisig et al ¹⁴				
Control	77.2 ± 5.4	—	—	—
UCLR	78.4 ± 7.3	—	—	—
Lansdown and Feeley ²²				
Before UCLR	91.3 ± 2.61	76.9 ± 4.14	82.3 ± 2.62	82.9 ± 2.49
After UCLR	90.6 ± 2.55	76.3 ± 3.1	82.5 ± 2.76	82.7 ± 2.54

^aValues are expressed as mean ± SD miles per hour. Dashes indicate data not reported. UCLR, ulnar collateral ligament reconstruction; UCLR, ulnar collateral ligament repair.

Most noteworthy, biomechanical parameters of throwing did not change from pre- to post-UCLR, suggesting that other measures may be responsible for the differences observed within this study.

High school, collegiate, and professional pitchers who had UCLR displayed no significant differences in shoulder external and internal ROM when compared with healthy, age-matched controls. Rotation deficits are commonly found between extremities in pitchers.^{23,27,40,41} Wilk et al^{40,41} examined the effects of rotational deficits on the

shoulder and elbow and concluded that pitchers with deficits were no more likely than controls to experience injury. These findings suggest that other biomechanical variables may have a greater effect on a pitcher's likelihood to undergo UCLR.

Differences were observed within participants, as fast-ball velocity and frequency decreased from pre- to postoperative UCLR. Decreases in fastball velocity were small yet significant, with those players older than 35 years of age losing a mean of 1.29 m/s (2.89 mph) after UCLR. Previous

TABLE 4
Comparison of Pitch Frequencies Before and After UCLR^a

	2 y Before UCLR ^b	1 y Before UCLR ^b	1 y After UCLR ^b	2 y After UCLR ^b	Before UCLR ^c
Fastball	64.3 ± 1.19	62.2 ± 1.14	61.6 ± 1.28	61.3 ± 1.22	64.8
Curveball	8.3 ± 0.98	8.2 ± 1.03	7.5 ± 0.96	8.8 ± 1.07	11 ^d
Changeup	8.5 ± 0.78	9.0 ± 0.9	9.4 ± 0.99	8.7 ± 0.87	10 ^d
Slider	14.6 ± 1.15	15.1 ± 1.3	15.5 ± 1.53	15.9 ± 1.36	14 ^d

^aValues are expressed as mean ± SD percentages. UCLR, ulnar collateral ligament reconstruction.

^bPitch frequencies from Peterson et al.³⁰

^cPitch frequencies from Lansdown and Feeley.²²

^dValues were estimated from published figures.

TABLE 5
Pitching Biomechanical Variables Examined Between Studies^a

	UCL Repair or Reconstruction		Control	
	Amateur	Professional	Amateur	Professional
Stride length, % height	81 ± 6.7	83 ± 5	79 ± 5.8	83 ± 5
Maximum elbow flexion, deg	104 ± 11	102 ± 15	107 ± 11	99 ± 11
Maximum shoulder external rotation, deg	158 ± 8	176 ± 9 ^b	161 ± 11	174 ± 9
Maximum shoulder horizontal adduction, deg	21 ± 5	14 ± 6 ^b	21 ± 6	16 ± 7
Shoulder external rotation at foot contact, deg	60 ± 27	45 ± 33 ^c	55 ± 25	48 ± 29
Shoulder abduction at ball release, deg	88 ± 8	94 ± 7 ^b	88 ± 8	92 ± 8
Trunk forward tilt at ball release, deg	33 ± 9	35 ± 7	34 ± 8	33 ± 8
Trunk lateral tilt at ball release, deg	26 ± 12	22 ± 9	19 ± 17	21 ± 8
Maximum elbow extension after ball release, deg	27 ± 6	—	24 ± 4	—
Maximum elbow varus torque, Ncm	82.7 ± 21	99 ± 17 ^b	82.1 ± 19.4	99 ± 16
Maximum shoulder internal rotation torque, Ncm	84.1 ± 20.9	101 ± 18 ^b	83 ± 19.3	102 ± 17
Maximum shoulder horizontal adduction torque, Ncm	95.5 ± 29.2	103 ± 22	89.7 ± 16.5	106 ± 20
Maximum elbow extension velocity, deg/s	2442 ± 367	2270 ± 270 ^{c,d}	2631 ± 292	2300 ± 230 ^d
Maximum shoulder internal rotation velocity, deg/s	6273 ± 1093	6600 ± 790 ^d	6771 ± 914	6730 ± 900 ^d
Maximum shoulder proximal force, N	967 ± 245	1250 ± 140 ^b	947 ± 175	1280 ± 170

^aData from Fleisig et al.^{12,14} Data are expressed as mean ± SD. Dashes indicate data not reported. UCL, ulnar collateral ligament.

^bStatistically significant difference between amateur and professional pitchers who had undergone UCL repair or reconstruction ($P < .001$).

^cStatistically significant difference between amateur and professional pitchers who had undergone UCL repair or reconstruction ($P = .05$ to $.01$).

^dStatistically significant difference between amateurs who had undergone UCL repair or reconstruction and control amateur pitchers ($P < .05$).

research has noted no difference in throwing kinetics between fastballs, curveballs, and changeups but did determine different kinematic parameters between pitch types.¹³ Kinematic variables such as maximum angular velocities of pelvic rotation, upper trunk rotation, shoulder internal rotation, and elbow extension were all higher when pitchers threw a fastball.¹³ The summation of speed principle states that momentum generated by the lower segments transfers up the kinetic chain as segments initiate movement when the adjacent proximal segment reaches its maximum angular velocity.³¹ Because of this principle, pitchers who have undergone UCLR could be innately imparting slower rotational velocities. The observed decrease in fastball frequency might be related, in part, to a previous finding that a 1% increase in fastballs thrown results in a 2% increase in UCL injury risk.²¹ Additionally, pitching >48% fastballs was shown to be a

significant predictor of UCL injury in baseball pitchers.²¹ Although no differences in pitching biomechanics were observed between players who had undergone UCLR and healthy controls, this could provide direction for further research efforts.

High school and collegiate baseball pitchers who had undergone UCLR displayed similar kinetics and fastball velocity but showed significantly lower degrees of elbow extension, lower elbow extension velocities, and lower shoulder internal rotation velocities when compared with healthy controls. Fleisig et al¹⁴ noted that the lesser degree of elbow motion may explain why the UCLR group generated less elbow extension velocity. As mentioned, the pitching motion starts from the ground up as momentum is transferred from the plant leg up through the kinetic chain. Balance deficits observed before UCLR in the lower limbs of amateur baseball players could have implications for as to

why we see lower degrees of elbow extension and lower elbow extension velocities. The inability of the lower limbs to work efficiently due to balance deficits may cause compensation to start at the beginning of the pitching motion and create havoc on the rest of the kinetic chain as the nearest rotational segment, the torso, works harder to get energy transfer to an optimal position going into ball acceleration. The lack of elbow extension could also be a by-product of the lower velocity of shoulder internal rotation.

Rapid elbow extension is a key component of effective momentum transfer as energy propagates from the shoulder to the elbow and then to the wrist during the acceleration phase.³⁵ The inability of the elbow to reach optimal amounts of extension by the instant of ball release may affect the pitcher's ability to achieve high amounts of shoulder internal rotation velocity. Those who consistently achieve high amounts of shoulder internal rotation velocity are able to achieve this due to extreme consistencies in pitching mechanics. The observed decrease in velocity after UCLR could also be attributed to strength deficits. Previous work has noted decreased isometric rotator cuff strength related to internal and external shoulder rotation in the dominant and nondominant arms in pitchers who have undergone UCLR compared with healthy controls.¹⁷ A separate study examining shoulder rotator cuff strength deficits found that young baseball pitchers who experienced elbow pain had significantly greater internal and external rotation strength measurements in both their dominant and nondominant arms compared with healthy controls.¹⁸ As we found in the current study, professional pitchers who underwent UCLR had similar pitching biomechanics, fastball velocities, and passive ROM when compared with healthy, age-matched controls. Discrepancies between professional pitchers who had UCLR and control amateur pitchers could therefore stem from a wider gap in talent at the amateur level.

These observed differences could also be due to study design. In a similar study, amateur pitchers were tested roughly 9.8 months after UCLR, whereas professional pitchers were tested approximately 30.5 months after UCLR.^{12,14} Of note, standard rehabilitation protocols for UCLR were found to average around only 6 to 7 months compared with the lengthier UCLR protocol.^{9,10,32} This discrepancy in duration of rehabilitation could allow for the professional pitchers to seek more rehabilitation and training. It is also worth noting the ability of players at each skill level to adjust pitching mechanics in a timely manner. Professional athletes tend to make adjustments more easily because they are already highly skilled in their craft. Professional pitchers exhibit optimal mechanics, such as increased repeatability of their pitching delivery and improved throwing mechanics, that allow them to compete at high levels.

Limitations

Although this study presents meaningful trending implications, some limitations exist. Foremost, we limited our search to articles written in English as well as articles available in full text. Baseball is a sport played and

researched across many countries, and it is possible that additional studies exist on pitching biomechanics after UCLR. Additionally, the small sample size of studies included within this review precludes robust findings. The limited number of studies and participants available for meta-analysis made it challenging to perform subgroup analyses and identify underlying inter- and inpatient differences. Finally, differences in skill levels between high school, college, and professional pitchers may affect findings, because pitchers of higher skill levels exhibit biomechanical variables and strengths not present in amateur pitchers.

CONCLUSION

In this review, we sought to investigate changes in biomechanical factors in baseball pitchers after UCLR and UCLr in hopes of highlighting the implications that these surgeries have on the performance of baseball pitchers. Although interesting trends appear to be forming, further evidence is needed to understand the effect of UCLR and UCLr on throwing biomechanics. Providing further evidence will advance efforts to develop more accurate biomechanical landmarks. Although we were able to reach some conclusions, a lack of statistical significance throughout this study indicates the need for increased biomechanics research within the sport of baseball. Ultimately, key biomechanical markers in the pitching motion may be developed to keep pitchers healthy and performing at their highest level for longer.

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