Effect of Ulnar Collateral Ligament Reconstruction on Performance in Major League Baseball Pitchers

A 2-Year Analysis of Advanced Pitching Statistics, Velocity, and Spin Rate

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Background: Ulnar collateral ligament reconstruction (UCLR) is a common procedure for Major League Baseball (MLB) pitchers, with a rising incidence and significant financial and performance implications. However, the effect of UCLR on postinjury pitching performance remains controversial, particularly regarding advanced metrics such as spin rate and velocity.

Purpose: To evaluate changes in pitching performance after UCLR and the association between pitch velocity, spin rate, and performance.

Study Design: Case-control study; Level of evidence, 4.

Methods: A total of 43 MLB pitchers who underwent UCLR between 2017 and 2021 were compared with 86 uninjured age-matched controls. Pitching metrics, including fielding independent pitching, skill-interactive earned run average, and walks plus hits per inning pitched, as well as pitch-specific velocity and spin rate were analyzed for 2 seasons before and at least 1 season after UCLR. Principal component analysis was used to assess overall performance.

Results: Pitchers showed a significant decline in overall performance during the first season after UCLR ($P = .032$) but returned to preinjury levels by the second season ($P = .287$). There was a significant decrease in the off-speed pitch spin rate observed in the first season ($P = .041$), but all other pitches demonstrated no significant change throughout the study period. Increases in fastball velocity ($P = .046$), fastball spin rate ($P = .019$), and off-speed pitch velocity ($P = .016$) were associated with superior overall performance.

Conclusion: The current study demonstrated that while pitchers experienced a significant decline in performance during the first season after UCLR, most of those who returned for a second season returned to their baseline preinjury performance. Additionally, increased velocity and spin rate were associated with improved performance in both injured and healthy pitchers, highlighting the value of these metrics in evaluating overall pitching performance.

Keywords: ulnar collateral ligament reconstruction; throwing elbow; Tommy John surgery; baseball; elbow injury

Injuries to the ulnar collateral ligament (UCL) are often the result of repetitive, supraphysiological peak valgus stresses placed on the UCL during the late cocking and early acceleration phases of throwing. As a result of these stresses, approximately 25% of Major League Baseball (MLB) pitchers have been reported to undergo UCL reconstruction (UCLR), commonly referred to as Tommy John surgery, during their career.[8,16,24,34,47] Moreover, with rates of return to previous levels of performance after UCLR ranging from 60% to 90%, an average return-to-play (RTP) time of 12 to 18 months, and cost of approximately $2 million per pitcher, UCL tears represent a substantial competitive and financial burden for players and teams alike.[5,7,9,11,12,27,46] In light of this, significant efforts have been made to expand our understanding of pitching biomechanics, improve arm health, and prevent UCL tears.[3,8,32,37,45,47] Additionally, given the rising incidence

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and associated economic ramifications of UCL injuries as well as the potential for diminished player and team performance, there is substantial interest in improving our understanding of player performance after UCLR.

As the game of baseball has evolved over time, there has been a commensurate evolution in the methods used to evaluate pitching performance. Traditionally, a pitcher's performance was reflected in statistics such as his win-loss record, earned run average, innings pitched (IP), and strikeouts per 9 innings. Today, these statistics are thought to be confounded by variables outside of the pitcher's control such as his team's defensive performance or stadium dimensions and therefore may not accurately reflect a pitcher's individual performance.[5,23,49] These shortcomings lead to the development of pitcher-focused statistics such as walks plus hits per inning pitched (WHIP), fielding independent pitching (FIP), and skill-interactive earned run average (SIERA). WHIP is a simple pitcher-focused metric that quantifies the number of batters allowed to reach a base per inning. FIP provides a more nuanced calculation by focusing solely on outcomes that the pitcher has the most control over: strikeouts, walks, hit-by-pitches, and home runs. SIERA goes beyond the outcome-based metrics used in WHIP and FIP and accounts for batted ball types, strikeout rates, and run expectancy. In 2015, the world of pitching analytics was revolutionized with the introduction of Statcast. This spatiotemporal tracking system uses both camera and radar technology to quantify metrics such as pitch velocity, spin rate, and movement for multiple pitch types.[20] Recent investigations have implemented these metrics to not only assess current pitching performance but also track postinjury performance and predict the likelihood of future shoulder and elbow injuries.[4,5,12,36] However, despite the growing body of literature on pitching performance and pitch metrics after UCLR, the available studies either do not analyze pitch physics data or fail to report sufficient statistics needed for calculating effect sizes.[22,30,32,33]

The primary aim of this study was to evaluate changes in pitching performance after UCLR based on the individual pitcher's preinjury performance, as well as age-matched controls, using advanced pitching statistics, velocity, and spin rate. The secondary aim was to determine the association between velocity, spin rate, and pitching performance. We hypothesized that there would be no significant changes in pitching performance after UCLR. Additionally, we hypothesized that increased velocity and spin rate would be associated with superior pitching performance.

METHODS

UCL injuries in pitchers were identified from the Pro Sports Transactions Archive, which has been used in previous epidemiological studies in professional sports.[1,25,35,41,48] Extracted injuries were those that occurred between 2017 and 2021, a span of 4 full seasons. Using RStudio (Version 2023.03.2; Posit), player injury data that were recorded as "Tommy John" were extracted, including player name, player team, date of injury, and notes on injury reserve status. Of these results, we manually checked each case to ensure that it involved an injury to the UCL.

For each player with a confirmed history of UCL injuries and reconstruction, baseball-reference.com was used to determine each player's position and select only pitchers for further analysis. Individual pitching data were reviewed based on inclusion criteria, which consisted of a minimum of 8.0 MLB IP in each of 2 consecutive seasons before the injury and at least 1 full season after surgery.[31,40] Pitchers who failed to accumulate 8.0 IP in 2 consecutive seasons before the injury and 8.0 IP in at least 1 full season after surgery were excluded from the study cohort. In accordance with previously published investigations on injuries in professional athletes, each pitcher meeting inclusion criteria was then cross-referenced with team press releases or news sources affiliated with the Associated Press to verify that each pitcher underwent UCLR.[1,25,35,41,48] Pitchers who were reported to have undergone UCL repair or revision UCLR were also excluded from the study cohort. For some pitchers who skipped the COVID-19–shortened 2020 season, 2019 and 2021 were considered consecutive seasons. To create a pool of possible control pitchers to choose from, all MLB pitchers born in the same year as a case pitcher who also pitched at least 8.0 MLB innings in the same seasons as the case pitcher were identified. To control for the effect of age on performance, an age-matched 1:2 control group was created by using a random number generator to select 2 random control pitchers for each case pitcher.

Season statistics for both case and control pitchers were obtained from fangraphs.com: FIP, SIERA, WHIP, strikeouts per 9 innings, walks per 9 innings, hits per 9 innings, and home runs per 9 innings. The remainder of the statistics summarizes the rate of outcomes over 9 innings, the length of a standard game, and is considered in the calculation of FIP and SIERA. Wins above replacement is another common metric used to analyze the performance of pitchers by estimating the total value that a player

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brought to a team. However, this was not included in the analysis, as it heavily emphasizes volume over performance quality and is therefore considered a more appropriate metric for other field players rather than pitchers.

Spin rate and velocity data for all pitchers were obtained from baseballsavant.mlb.com, separated by pitcher, season, and pitch type. Baseball Savant tracks a total of 17 pitch types under 5 categories, which include fastball, off-speed pitch (changeup and splitter), curveball, and slider. All 5 categories were also included in the data collection process. Noncompetitive pitches including intentional balls were excluded, and 2 uncategorized pitches, the knuckleball and eephus, were excluded because of the scarcity of data.

Statistical Analysis

Power analysis was conducted to determine the minimum number of pitchers needed to detect a significant difference in pitching performance after UCLR. Using a Cohen *d* of 0.5, which represents a medium effect size, a minimum of 33.4 UCL injuries was required to achieve a power of 0.8. This effect size was chosen because of the absence of sufficient pitch physics data in previous studies to calculate the Cohen *d* directly.[22,30,32,33]

Descriptive statistics of pitchers were calculated. Pitching performance was assessed using principal component analysis (PCA), which is a dimensionality reduction statistical method that compresses several performance metrics into a single value: the first principal component (PC1). Because a lower WHIP, SIERA, and FIP indicate better performance, a lower PC1 also indicates better statistical performance. Multiple orthopaedic studies have used PCA as a method to compare groups across multiple metrics, including studies investigating sports performance.[6,10,13,28,43,50] Performance analysis was based on FIP, SIERA, and WHIP. The change in each of the above performance metrics at 1 and 2 years after the injury was normalized to performance at 1 season before the injury per pitcher. The overall change in pitching performance was measured at 1 and 2 years after the injury using PC1 to compare differences in the performance of injured pitchers versus healthy controls. Age-matched controls were used to account for age-related changes in performance. Additionally, the correlation between age at the time of injury and PC1 was calculated (Pearson correlation coefficient; alpha = .05). Statistical significance for all comparative analyses was set a priori at alpha = .05. All statistical analyses and data visualizations were conducted using Python (Version 3.10; Python Software Foundation).

RESULTS

The initial search of all MLB pitchers from the 2017 to 2021 seasons with a UCL injury resulted in 82 players, of whom 4 were excluded for being nonpitchers and 5 were excluded for having 0 career IP in the MLB. Of the 73 MLB pitchers identified, 6 pitchers were excluded because of surgery occurring before their first MLB appearance, 4 pitchers were excluded for an insufficient IP before the injury, 10 pitchers were excluded because of failure to RTP at the MLB level, and 10 pitchers were excluded for an insufficient IP after UCLR. The remaining 43 pitchers met inclusion criteria for 2 seasons before the injury and 1 season after UCLR and were used for analysis. Among the 43 pitchers who returned for at least 1 season with at least 8.0 IP, only 34 pitchers were able to return for 2 seasons with at least 8.0 IP (Figure 1). The ages for included participants ranged from 21 to 36 years, and the mean age at the time of injury was 27.44 ± 3.06 years.

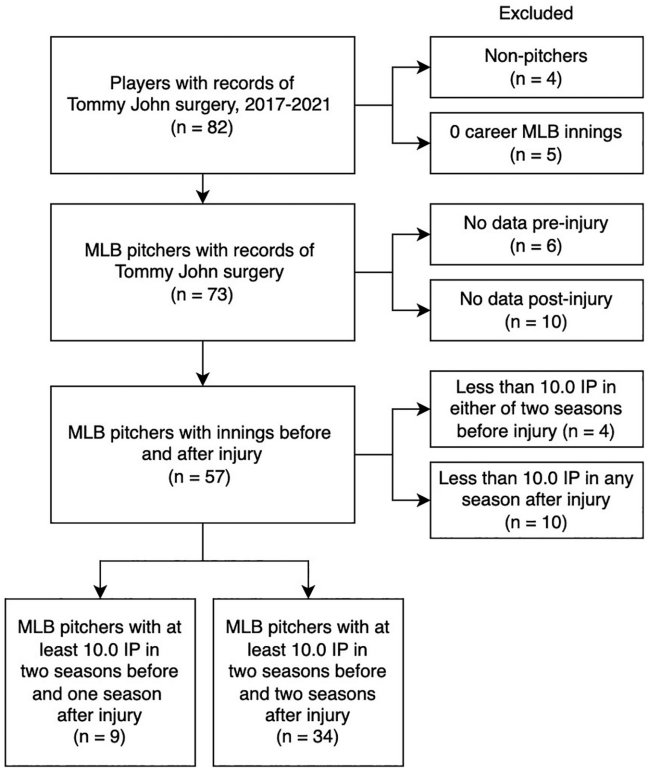

Figure 1. Generation of injured patient cohort based on inclusion and exclusion criteria.

Age and Performance After UCLR

The performance of pitchers was primarily analyzed comparing the aging curves of injured to noninjured pitchers. Age matching control pitchers allows for a comparison of changes in performance while adjusting for age-related decline. Pitching performance was first analyzed by comparing the number of pitches and IP by injured pitchers versus healthy controls (Table 1). Injured pitchers demonstrated a statistically significant decrease in the number of total pitches (925.12 vs 13716.20, respectively; $P = .002$) and IP (55.70 vs 86.53, respectively; $P = .003$) in the first year after UCLR compared with healthy controls but returned to equivalent pitch (1306.59 vs 1326.06, respectively; $P = .917$) and IP (78.47 vs 83.04, respectively; $P =$

TABLE 1
Pitching Workload of Injured Pitchers Versus Healthy Controls

	Average Total Pitches			Average Innings Pitched		
	Injured	Control	*P* Value	Injured	Control	*P* Value
1 season before injury	1417.02	1442.83	.879	86.20	87.40	.975
1 season after injury	925.12	1371.20	.002	55.70	86.53	.003
2 seasons after injury	1306.59	1326.06	.917	78.47	83.04	.826

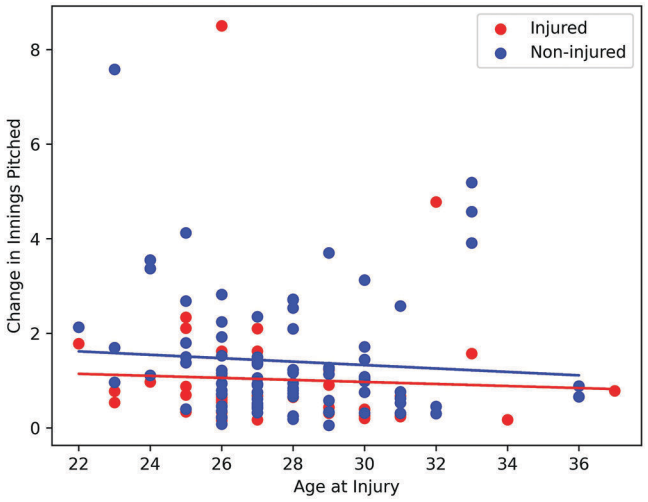

Figure 2. Correlation of age at the time of injury versus the change in innings pitched (IP) at 1 season before and after the injury. The change in IP was determined as the IP in the season after the injury divided by the IP in the season before the injury. Injured pitchers demonstrated no significant difference in IP ($P = .771$), and there was no difference in IP between injured pitchers and healthy controls ($P = .490$).

.826) volumes by the second season after the injury. There was no significant relationship between age at the time of injury and the change in IP ($P = .771$), and Z-transformation to a 2-sample 2-tailed Z-test to compare the correlations between injured and noninjured pitchers demonstrated no significant difference ($P = .890$) (Figure 2). Additionally, PC1 analysis showed no statistically significant correlation between age and change in overall performance ($P = .685$), fastball velocity ($P = .251$), or spin rate ($P = .084$) after UCLR.

Changes in Advanced Pitching Performance Statistics After UCLR

Analysis of basic pitching metrics including the number of strikeouts and hits demonstrated no significant difference between healthy controls and injured pitchers at 1 ($P = .481$ for strikeouts; $P = .819$ for hits) and 2 ($P = .530$ for strikeouts; $P = .350$ for hits) seasons after UCLR. To compare the overall change in pitching performance between injured and noninjured pitchers, FIP, SIERA, and WHIP were used to calculate PC1. At the end of the first season after UCLR, most injured pitchers (25/43 [58.1%]) demonstrated a decline in performance, as shown by an increase in PC1, whereas only 31 of 86 (36.0%) healthy pitchers demonstrated a decline in performance. At the end of the first 2 seasons after UCLR, 17 of 34 (50.0%) injured pitchers and 41 of 68 (60.3%) healthy pitchers demonstrated a decline in performance, as demonstrated by an increase in PC1. Injured pitchers demonstrated a significantly greater decline in performance during their first season after UCLR compared with healthy controls ($P = .032$), but the changes between the 2 groups were not statistically different during the second season after UCLR ($P = .287$). Subgroup analysis of injured pitchers who returned for only 1 season compared with those who returned for $\geq$2 seasons demonstrated no significant difference in PC1 during the first season after the injury ($P = .685$) (Figure 3).

Changes in Pitch Velocity and Spin Rate After UCLR

Changes in pitch velocity and spin rate for both injured pitchers and healthy controls were determined for fastballs, curveballs, sliders, and off-speed pitches. There was no significant difference in changes in fastball velocity or spin rate between injured pitchers and healthy controls at 1 year after the injury ($P = .980$ for fastball spin rate; $P = .580$ for fastball velocity) or 2 years after the injury ($P = .934$ for fastball spin rate; $P = .687$ for fastball velocity) (Figure 4). For off-speed pitches, which include changeups and splitters, at 1 year after UCLR, there was a significant difference in changes in spin rate, with injured pitchers showing a greater decline in the spin rate compared with noninjured pitchers ($P = .041$), but there was no significant difference in changes in velocity ($P = .707$). At 2 years, no significant changes existed between the groups in regard to spin rate ($P = .838$) or velocity ($P = .433$). For curveballs and sliders, there were no significant differences at 1 year in changes in spin rate ($P = .909$ for curveball; $P = .943$ for slider) or changes in velocity ($P = .524$ for curveball; $P = .929$ for slider) or at 2 years (spin rate: $P = .259$ for curveball; $P = .328$ for slider) (velocity: $P = .264$ for curveball; $P = .407$ for slider). Subgroup analysis of injured pitchers who returned for only 1 season compared with those who returned for $\geq$2 seasons demonstrated no significant difference in spin rate or velocity for fastballs ($P = .558$ for fastball spin rate; $P = .874$ for fastball velocity), off-speed

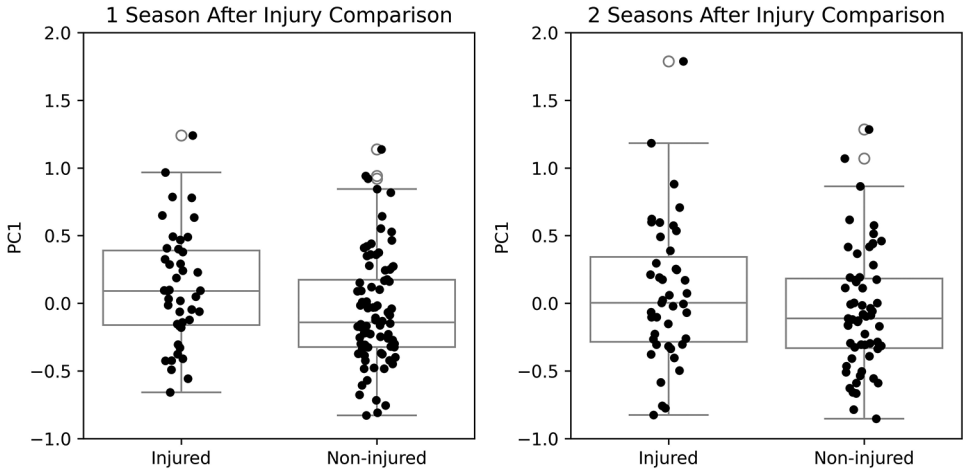

Figure 3. Changes in performance, measured via fielding independent pitching (FIP), skill-interactive earned run average (SIERA), and walks plus hits per inning pitched (WHIP), were compared based on 1 season before, 1 season after, and 2 seasons after the injury. Principal component analysis was used to compare pitchers across multiple metrics and to compress the comparisons into a single global analysis. The first principal component (PC1) represents pitching performance as a combination of FIP, SIERA, and WHIP in which a lower PC1 indicates better performance. Injured pitchers demonstrated a significantly greater decline in performance after 1 season in comparison to healthy controls (P = .032). Changes in performance were not significantly different during the second season after reconstruction compared with healthy controls (P = .287).

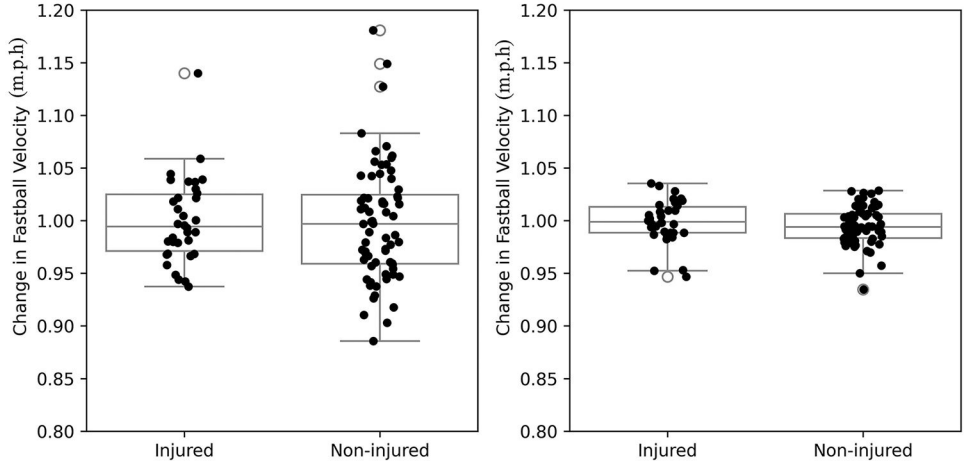

Figure 4. (A) Changes in fastball spin rate expressed as a ratio relative to preinjury values, comparing 1 season before and 2 seasons after the injury for injured pitchers and healthy controls, demonstrating no difference between groups (P = .934). (B) Changes in fastball velocity expressed as a ratio relative to preinjury values, comparing 1 season before and 2 seasons after the injury for injured pitchers and healthy controls, demonstrating no difference between groups (P = .687).

pitches (P = .682 for off-speed spin rate; P = .696 for off-speed velocity), sliders (P = .864 for slider spin rate; P = .396 for slider velocity), or curveballs (P = .630 for curveball spin rate; P = .125 for curveball velocity).

Velocity, Spin Rate, and Pitching Performance

The relationship between velocity, spin rate, and pitching performance was also determined for the entire cohort of pitchers using each of the individual pitch types (Figure 5). For fastballs, increased velocity (P = .046) and spin rate (P = .019) were both associated with superior pitching performance. Similarly, an increased velocity of off-speed pitches was associated with superior performance (P = .016), but there was no association between spin rate and performance (P = .819). There was no association between velocity or spin rate and performance for curveballs (P = .407 for velocity; P = .435 for spin rate) or sliders (P = .564 for velocity; P = .330 for spin rate).

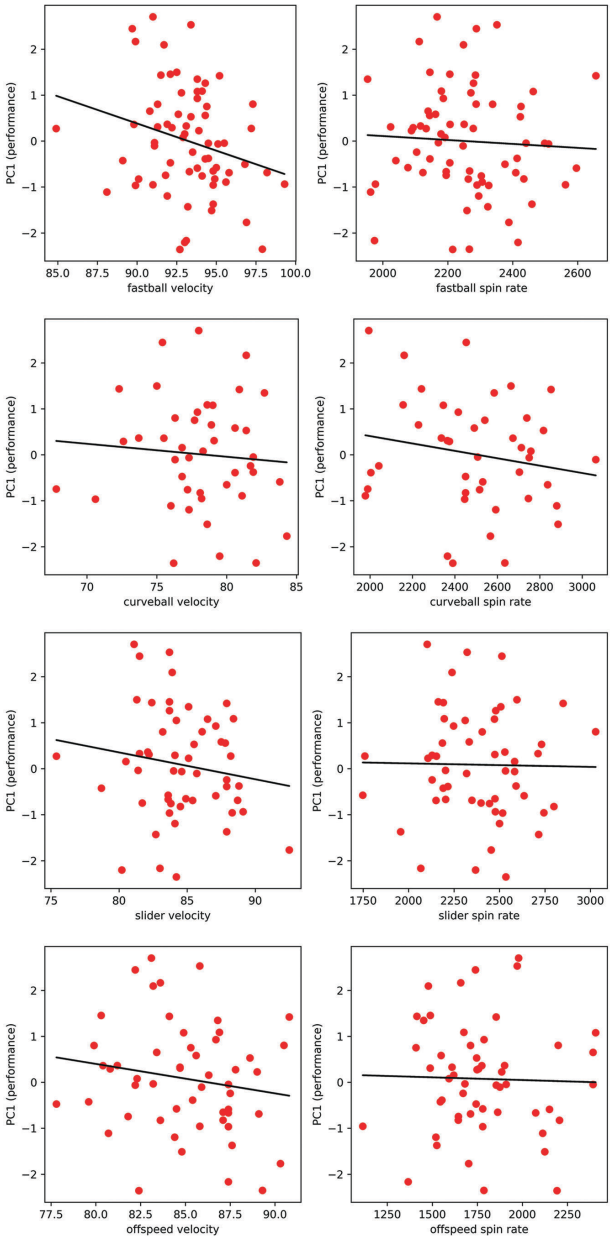

Figure 5. Relationship between velocity or spin rate and pitching performance for all pitchers (both injured and control) for individual pitch types. Pitching performance was determined using principal component analysis, examining fielding independent pitching (FIP), skill-interactive earned run average (SIERA), and walks plus hits per inning pitched (WHIP). Statistically significant relationships were present between the first principal component (PC1) and fastball velocity ($P = .046$), fastball spin rate ($P = .019$), and off-speed pitch velocity ($P = .016$). No other significant associations were present ($P > .05$).

DISCUSSION

The results of the current study demonstrated that compared with age-matched controls, those who underwent UCLR had significantly lower workloads, diminished off-speed pitch spin rates, and inferior overall performance during their first season after UCLR. Among the 43 pitchers who underwent UCLR and achieved RTP for 1 season, 34 (79.1%) pitchers were able to return for a second season. Pitchers who returned for a second season demonstrated improvements in workloads and performance, normalization of spin rates, and maintenance of velocity. Additionally, a higher velocity for fastballs and off-speed pitches and a higher spin rate for fastballs were found to be associated with superior pitching performance for both injured and healthy pitchers alike. Finally, while 86.3% (63/73) of MLB pitchers with confirmed UCLR had sufficient preinjury statistics, 31.7% (20/63) of these pitchers did not return to MLB pitching at all or for a very limited number of innings. Given that these pitchers failed to meet RTP criteria and were subsequently excluded from analysis, it is possible that these pitchers represent a proportion of the UCLR group with substantially diminished velocity, spin rates, and performance after surgery.

Pitching is considered to be a critical skill in baseball, with up to 60% of a team's success attributed to pitching performance according to the Society for American Baseball Research.[44] Moreover, a cost analysis on UCLR in MLB pitchers up to 2014 found that the total economic loss from these injuries was $394 million, which equates to $523 million in 2024 after adjusting for inflation.[34] Given the competitive and financial implications of UCL injuries in pitchers, there are ongoing efforts aimed at improving our understanding of the effect of UCLR on pitching performance. While most of the established literature on this topic has relied on traditional metrics such as earned run average, wins above replacement, and WHIP, some investigators have begun to incorporate advanced statistics, such as FIP and SIERA.[5,12,15,23,42] The results of these studies have been mixed, with some reporting a consistent decline in performance after UCLR, while others have found a decline in the first season after the injury, with a trend toward preinjury performance during the second season.[5,12,15,23,42] However, the interpretation of these results, particularly those using advanced statistics, is limited because of varying methodologies and selected outcome measures.[12,23,42]

In the present study, most pitchers demonstrated a decline in overall performance over the 2-year study period, regardless of their injury status. To more accurately interpret the effect of UCLR on pitching performance, the observed changes in advanced pitching statistics were compared with the expected changes based on preinjury performance. Our finding of increased PC1 during the first season after UCLR represents a statistically significant ($P = .032$) decline in overall performance compared with expected performance. Among the 43 pitchers who were able to return for 1 season, 20.9% (9/43) were unable to return for a second season after UCLR. However, pitchers who returned for a second season demonstrated improved performance, as there was no difference between actual and expected performance ($P = .287$). These findings are consistent with previously published studies on performance after UCLR, most of which have demonstrated RTP

rates ranging from 50% to 90% and a decline in performance during the first season after UCLR.[2,12,23,30,42] However, the RTP rate of 79.1% at 2 years after UCLR in our study cohort must be interpreted with caution, as 20 pitchers with sufficient preinjury data were excluded from analysis because of failure to meet RTP criteria. Considering this, the true RTP rates may be 68.3% (43/63) and 54.0% (34/63) at 1 and 2 years after UCLR, respectively. Nevertheless, our results build on the existing literature through the implementation of multiple advanced pitcher-focused statistics (WHIP, FIP, and SIERA) for PC1 analysis, which provides robust statistical evidence supporting the notion that these elite throwing athletes, particularly those who achieved RTP for at least 2 years after UCLR, are capable of attaining levels of performance that are not statistically different from their projected performance had they remained injury free.

Velocity and spin rate are critical metrics in pitching, with increased velocity reducing a batter's reaction time and higher spin rates creating deviations in pitch trajectory that are often associated with decreased batting performance.[4,14,32] Despite the importance of these metrics, there is ongoing debate regarding the effect of UCLR on velocity and spin rate, as there are conflicting reports in the existing literature. Although most authors have reported no difference in velocity or spin rate for all pitch types after UCLR, some have found declines in both metrics, while others have reported improvements.[§] The results of the current study are in agreement with the broader literature in that there were no significant changes in velocity or spin rate for fastballs, sliders, and curveballs in injured pitchers or healthy controls at both 1 and 2 years. Notably, subgroup analysis between injured pitchers who returned for only 1 season and those who returned for at least 2 seasons also demonstrated no significant differences in spin rate or velocity. However, subgroup analysis may have been underpowered, given the relatively small sample size. One unique aspect of our results was the statistically significant decrease in off-speed pitch (changeup and splitter) spin rate during the first season after UCLR, which has not been previously reported, to our knowledge. Given that pitchers have been shown to throw fewer fastballs after UCLR and 13% of all pitches thrown in 2024 were either changeups or splitters, this finding may have significant implications for pitchers routinely using these pitch types.[20,38] Taken together, velocities and spin rates were generally maintained after UCLR, but larger investigations are required to further evaluate for existing differences between pitchers who return for one versus multiple seasons after UCLR.

Although spin rate has been the subject of several recent investigations, the relationship between velocity, spin rate, and pitching performance after UCLR has not been definitively established. While some studies have suggested improved overall performance with increased velocity, this is highly contingent on the maintenance of pitch accuracy.[12,17,18,21] Moreover, there is a substantial body of literature to suggest that higher velocities are predictive of an increased risk of both shoulder and elbow injuries.[3,8,29,32,39,45] In regard to spin rate, we are not aware of any existing study that has established a relationship between spin rate and overall performance. The results of the current study demonstrated that increased velocity and spin rate were associated with superior overall performance for all pitchers, regardless of their injury status. The association between increased spin rate and overall performance is of particular importance, as this provides new information to the existing literature and is strengthened through the use of advanced pitching-specific statistics in conjunction with PC1. Taken together, the value of increased velocity must be weighed against the effect on pitch accuracy and the associated increased risk of injuries, but an increased spin rate represents a desirable pitch metric that may prove to be predictive of pitching performance, with further studies dedicated to longitudinal analysis.

Limitations

There are several limitations to the current study. First, the 2-year UCLR group consisted of only 34 pitchers, which may limit the generalizability of the findings across a larger population of professional baseball pitchers, despite being appropriately powered. Additionally, as noted earlier in the Discussion, the inclusion criteria requiring RTP for at least 1 season resulted in the exclusion of 20 pitchers after UCLR, which may have been the result of declines in velocity and spin rate. It is possible that declines in pitching performance were underestimated, and subsequent RTP rates for this study cohort are more consistent with previous studies reporting lower RTP rates. Second, there exists the potential for survivorship bias, as performance at 2 years after UCLR still falls within the early follow-up period. Considering this, we are unable to determine if the reported changes were sustained over time or if there was an increased risk of reinjuries at future time points. Third, our reliance on publicly available data from sources such as Baseball Savant and Fangraphs inherently subjects the data collection process to inaccuracies in pitch tracking or classification, particularly for less common pitch types such as off-speed pitches. Similarly, the reliance on publicly available data may limit our knowledge of concomitant abnormalities commonly found in conjunction with UCL injuries. If pitchers underwent additional surgical procedures such as ulnar nerve transposition, loose body removal, or osteophyte resection at the time of UCLR, it is possible that recovery timelines, pitching mechanics, or overall performance may have been impacted. Fourth, while age-matched controls were used to account for age-related performance decline, our results may have been influenced by other confounding factors such as differences in rehabilitation protocols and surgical techniques. Moreover, pre-existing pitcher characteristics such as pitching specialty (starter vs reliever), previous injuries, team dynamics, or coaching strategies may also represent potentially confounding variables, limiting the

[§]References 5, 17, 19, 21, 26, 27, 30, 33, 39, 42.

generalizability of our results. Fifth, our analysis focused primarily on fastballs, curveballs, sliders, and off-speed pitches, but the nuances of some pitch types, such as the 2-seam fastball and 4-seam fastball, were lost, as these were combined. Finally, while our use of PCA to compress multiple performance metrics into a single value (PC1) allows for a comprehensive assessment of overall performance, this method may oversimplify complex interactions between individual statistics such as FIP, SIERA, and WHIP.

CONCLUSION

The current study demonstrated that while pitchers experienced a significant decline in performance during the first season after UCLR, most returned to their baseline preinjury performance level during the second season. Additionally, increased velocity and spin rate were associated with improved performance in both injured and healthy pitchers, highlighting the value of these metrics in evaluating overall pitching performance.

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REFERENCES

1. Bullock GS, Ferguson T, Arundale AH, Martin CL, Collins GS, Kluzek S. Return to performance following severe ankle, knee, and hip injuries in National Basketball Association players. *PNAS Nexus*. 2022;1(4):pgac176.
2. Camp CL, Conte S, D'Angelo J, Fealy SA. Epidemiology of ulnar collateral ligament reconstruction in Major and Minor League Baseball pitchers: comprehensive report of 1429 cases. *J Shoulder Elbow Surg*. 2018;27(5):871-878.
3. Chalmers PN, Wimmer MA, Verma NN, et al. The relationship between pitching mechanics and injury: a review of current concepts. *Sports Health*. 2017;9(3):216-221.
4. Cinque ME, LaPrade CM, Abrams GD, Sherman SL, Safran MR, Freehill MT. Ulnar collateral ligament reconstruction does not decrease spin rate or performance in Major League pitchers. *Am J Sports Med*. 2022;50(8):2190-2197.
5. Coughlin RP, Gohal C, Horner NS, et al. Return to play and in-game performance statistics among pitchers after ulnar collateral ligament reconstruction of the elbow: a systematic review. *Am J Sports Med*. 2019;47(8):2003-2010.
6. Daruwalla ZJ, Courtis P, Fitzpatrick C, Fitzpatrick D, Mullett H. An application of principal component analysis to the clavicle and clavicle fixation devices. *J Orthop Surg Res*. 2010;5:21.
7. Erickson BJ, Gupta AK, Harris JD, et al. Rate of return to pitching and performance after Tommy John surgery in Major League Baseball pitchers. *Am J Sports Med*. 2014;42(3):536-543.
8. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med*. 1995;23(2):233-239.
9. Ford GM, Genuario J, Kinkartz J, Githens T, Noonan T. Return-to-play outcomes in professional baseball players after medial ulnar collateral ligament injuries: comparison of operative versus nonoperative treatment based on magnetic resonance imaging findings. *Am J Sports Med*. 2016;44(3):723-728.
10. Foster BH, Shaw CB, Boutin RD, et al. A principal component analysis-based framework for statistical modeling of bone displacement during wrist maneuvers. *J Biomech*. 2019;85:173-181.
11. Fucaloro SP, Kang AS, Bragg JT, Krivicich L, Salzler MJ. Return to sport after ulnar collateral ligament tears treated with platelet-rich plasma injections is influenced by length of rehabilitation and leukocyte content of injections: a systematic review. *Arthroscopy*. 2025;41(2):343-356.
12. Fury MS, Oh LS, Linderman SE, et al. Return to performance after ulnar collateral ligament reconstruction in Major League Baseball pitchers: a case-control assessment of advanced analytics, velocity, spin rates, and pitch movement. *Orthop J Sports Med*. 2021;9(9):23259671211035753.
13. Goreham JA, Landry SC, Kozey JW, Smith B, Ladouceur M. Using principal component analysis to investigate pacing strategies in elite international canoe kayak sprint races. *Sports Biomech*. 2023;22(11):1444-1459.
14. Higuchi T, Morohoshi J, Nagami T, Nakata H, Kanosue K. The effect of fastball backspin rate on baseball hitting accuracy. *J Appl Biomech*. 2013;29(3):279-284.
15. Hones KM, Kamarajugadda S, Buchanan TR, et al. Variable return to play and sport performance after elbow ulnar collateral ligament reconstruction in baseball players: a systematic review. *Arthroscopy*. 2024;40(7):1997-2006.e1.
16. Jensen AR, LaPrade MD, Turner TW, Dines JS, Camp CL. The history and evolution of elbow medial ulnar collateral ligament reconstruction: from Tommy John to 2020. *Curr Rev Musculoskelet Med*. 2020;13(3):349-360.
17. Jiang JJ, Leland JM. Analysis of pitching velocity in Major League Baseball players before and after ulnar collateral ligament reconstruction. *Am J Sports Med*. 2014;42(4):880-885.
18. Kawamura K, Shinya M, Kobayashi H, Obata H, Kuwata M, Nakazawa K. Baseball pitching accuracy: an examination of various parameters when evaluating pitch locations. *Sports Biomech*. 2017;16(3):399-410.
19. Keller RA, Steffes MJ, Zhuo D, Bey MJ, Moutzouros V. The effects of medial ulnar collateral ligament reconstruction on Major League pitching performance. *J Shoulder Elbow Surg*. 2014;23(11):1591-1598.
20. Lage M, Ono JP, Cervone D, Chiang J, Dietrich C, Silva CT. StatCast dashboard: exploration of spatiotemporal baseball data. *IEEE Comput Grap Appl*. 2016;36(5):28-37.
21. Lansdown DA, Feeley BT. The effect of ulnar collateral ligament reconstruction on pitch velocity in Major League Baseball pitchers. *Orthop J Sports Med*. 2014;2(2):2325967114522592.
22. LaPrade CM, Cinque ME, Chona DV, et al. Revision ulnar collateral ligament reconstruction in Major League Baseball pitchers: effects of fastball velocity and usage. *J Shoulder Elbow Surg*. 2022;31(8):1563-1570.
23. LaPrade CM, Cinque ME, Safran MR, Freehill MT, Wulf CA, LaPrade RF. Using advanced data to analyze the impact of injury on performance of Major League Baseball pitchers: a narrative review. *Orthop J Sports Med*. 2022;10(7):23259671221111169.
24. Leland DP, Conte S, Flynn N, et al. Prevalence of medial ulnar collateral ligament surgery in 6135 current professional baseball players: a 2018 update. *Orthop J Sports Med*. 2019;7(9):2325967119871442.
25. Lin E, Tummala SV, Morikawa L, et al. Strains/sprains and fractures are the most common hand and wrist injuries in National Basketball Association athletes who return to preinjury player efficiency and equal or greater true shooting percentage within two years of injury. *Arthrosc Sports Med Rehabil*. 2023;5(6):100829.
26. Lu Y, Chen P, Sheu H, et al. Fastball quality after ulnar collateral ligament reconstruction in Major League Baseball pitchers. *Am J Sports Med*. 2024;52(10):2611-2619.
27. Makhni EC, Lee RW, Morrow ZS, Gualtieri AP, Gorroochurn P, Ahmad CS. Performance, return to competition, and reinjury after Tommy John surgery in Major League Baseball pitchers: a review of 147 cases. *Am J Sports Med*. 2014;42(6):1323-1332.

28. Mantovani G, Lamontagne M, Varin D, Cerulli GG, Beaulé PE. Comparison of total hip arthroplasty surgical approaches by principal component analysis. *J Biomech*. 2012;45(12):2109-2115.
29. Manzi JE, Dowling B, Wang Z, et al. Pitching mechanics and the relationship to accuracy in professional baseball pitchers. *Am J Sports Med*. 2022;50(3):814-822.
30. Marshall NE, Keller R, Limpisvasti O, Schulz B, ElAttrache N. Major League Baseball pitching performance after Tommy John surgery and the effect of tear characteristics, technique, and graft type. *Am J Sports Med*. 2019;47(3):713-720.
31. Matus I. Fifteen pitches per inning, more or less? Society for American Baseball Research. Accessed September 6, 2024. Available at: https://sabr.org/journal/article/fifteen-pitches-per-inning-more-or-less/.
32. Mayo BC, Miller A, Patetta MJ, et al. Preventing Tommy John surgery: the identification of trends in pitch selection, velocity, and spin rate before ulnar collateral ligament reconstruction in Major League Baseball pitchers. *Orthop J Sports Med*. 2021;9(6):23259671211012364.
33. McKnight B, Heckmann ND, Chen XT, et al. Effect of ulnar collateral ligament reconstruction on pitch accuracy, velocity, and movement in Major League Baseball pitchers. *Orthop J Sports Med*. 2020;8(12):2325967120968530.
34. Meldau JE, Srivastava K, Okoroha KR, Ahmad CS, Moutzouros V, Makhni EC. Cost analysis of Tommy John surgery for Major League Baseball teams. *J Shoulder Elbow Surg*. 2020;29(1):121-125.
35. Morikawa LH, Tummala SV, Brinkman JC, Buckner Petty SA, Chhabra A. Effect of a condensed NBA season on injury risk: an analysis of the 2020 season and player safety. *Orthop J Sports Med*. 2022;10(9):23259671221121116.
36. Oeding JF, Boos AM, Kalk JR, et al. Pitch-tracking metrics as a predictor of future shoulder and elbow injuries in Major League Baseball pitchers: a machine-learning and game-theory based analysis. *Orthop J Sports Med*. 2024;12(8):23259671241264260.
37. Painter DF, Quinn M, Dove JH, et al. Arm health in elite collegiate summer league baseball players assessed by the Kerlan-Jobe Orthopaedic Clinic score. *J Athl Train*. 2024;59(3):255-261.
38. Peterson EE, Handwork P, Soloff L, Schickendantz MS, Frangiamore SJ. Effects of ulnar collateral ligament reconstruction on pitch selection in Major League Baseball pitchers. *Orthop J Sports Med*. 2018;6(11):2325967118810003.
39. Platt BN, Zacharias AV, Conley C, et al. Association between pitch break on the 4-seam fastball and slider and shoulder injury in Major League Baseball pitchers: a case-control study. *Orthop J Sports Med*. 2021;9(10):23259671211038961.
40. Portney DA, Lazaroff JM, Buchler LT, Gryzlo SM, Saltzman MD. Changes in pitching mechanics after ulnar collateral ligament reconstruction in Major League Baseball pitchers. *J Shoulder Elbow Surg*. 2017;26(8):1307-1315.
41. Quinn M, Painter DF, Ahn BJ, et al. National Football League quarterbacks with ulnar collateral ligament injuries have high return-to-play rates, but older players have inferior postinjury performance. *Arthrosc Sports Med Rehabil*. 2024;6(4):100954.
42. Selley RS, Portney DA, Lawton CD, et al. Advanced baseball metrics indicate significant decline in MLB pitcher value after Tommy John surgery. *Orthopedics*. 2019;42(6):349-354.
43. Shalhoub S, Cyr A, Maletsky LP. Correlation between knee anatomy and joint laxity using principal component analysis. *J Orthop Res*. 2022;40(11):2502-2509.
44. Skipper J. Is pitching 75% of baseball? Expert opinions. Society for American Baseball Research. Accessed September 10, 2024. Available at: https://sabr.org/journal/article/is-pitching-75-of-baseball-expert-opinions.
45. Sutter EG, Orenduff J, Fox WJ, Myers J, Garrigues GE. Predicting injury in professional baseball pitchers from delivery mechanics: a statistical model using quantitative video analysis. *Orthopedics*. 2018;41(1):43-53.
46. Thomas SJ, Paul RW, Rosen AB, et al. Return-to-play and competitive outcomes after ulnar collateral ligament reconstruction among baseball players: a systematic review. *Orthop J Sports Med*. 2020;8(12):2325967120966310.
47. Triplet JJ, Labott JR, Leland DP, et al. Factors that increase elbow stress in the throwing athlete: a systematic review of biomechanical and motion analysis studies of baseball pitching and throwing. *Curr Rev Musculoskelet Med*. 2022;16(4):115-122.
48. Tummala SV, Morikawa L, Brinkman JC, et al. Characterization of ankle injuries and associated risk factors in the National Basketball Association: minutes per game and usage rate associated with time loss. *Orthop J Sports Med*. 2023;11(7):23259671231184459.
49. Van Der List JP, Camp CL, Sinatro AL, Dines JS, Pearle AD. Systematic review of outcomes reporting in professional baseball: a call for increased validation and consistency. *Am J Sports Med*. 2018;46(2):487-496.
50. Welch N, Richter C, Moran K, Franklyn-Miller A. Principal component analysis of the associations between kinetic variables in cutting and jumping, and cutting performance outcome. *J Strength Cond Res*. 2021;35(7):1848-1855.