Increased Pitch-Specific Velocity, Spin Rate, and Horizontal Movement Lead to Increased Odds of Undergoing Ulnar Collateral Ligament Reconstruction in Professional Baseball Pitchers Using Baseball Savant Data

Maxwell Harrell, B.S., Clay Rahaman, B.A., Dev Dayal, B.S., Patrick Elliott, M.D., Caleb Berta, B.S., Nathaniel Buchanan, B.S., Eugene Brabston, M.D., Thomas Evely, D.O., Walter Smith, M.D., Aaron Casp, M.D., and Amit Momaya, M.D.

Purpose: To evaluate advanced pitch-specific metrics to uncover which are associated with pitchers undergoing ulnar collateral ligament reconstruction (UCLR). **Methods:** A retrospective analysis was conducted using Major League Baseball pitchers who underwent UCLR between 2017 and 2024. Preinjury pitch metrics, including velocity, spin rate, movement profiles, and pitch use, were collected from the public database Baseball Savant and compared with league averages. To be included, pitchers must have had pitching data recorded in the Baseball Savant public database. Pitchers were excluded from the study if no data were found in Baseball Savant. Mann-Whitney *U* tests and logistic regression models were used to assess statistical differences and identify significant predictors of undergoing UCLR. **Results:** A total of 132 pitchers who underwent UCLR were analyzed against 6,001 league-average pitchers. Pitchers with UCLR displayed greater average velocities for 4-seamers (94.6 miles per hour [mph] vs 93.2 mph, Δ1.4), sinkers (94.4 mph vs 92.7 mph, Δ1.7), cutters (90.0 mph vs 88.6 mph, Δ1.4), sliders (85.5 mph vs 84.4 mph, Δ1.1), changeups (86.9 mph vs 85.3 mph, Δ1.6), and curveballs (79.7 mph vs 78.5 mph, Δ1.4) ($P < .001$). Increased spin rate for 4-seamers (2,301.3 revolutions per minute [rpm] vs 2,253.2 rpm, Δ 48.1, $P = .0004$) and changeups (1810.8 rpm vs 1757.4 rpm, Δ 52.6, $P = .04$) also was noted. Decreased glove-side horizontal movement on cutters (1.3 inches vs 3.0 inches, Δ 1.7 inches, $<.0001$) and increased arm-side movement of changeups (14.1 inches vs 13.2 inches, Δ0.9 inches, $P = .01$) significantly increased odds of UCLR. Increased sinker velocity (odds ratio [OR] 1.30, 95% confidence interval [CI] 1.16-1.40), 4-seamer velocity (OR 1.27, 95% CI 1.18-1.37), changeup velocity (OR 1.20, 95% CI 1.12-1.28), and decreased glove-side cutter horizontal break (OR 0.64, 95% CI 0.54-0.77) increased a pitcher's odds of undergoing UCLR. **Conclusions:** This study demonstrates that specific pitch characteristics, including increased velocity, increased spin rate, reduced glove-side horizontal movement of cutters, and increased arm-side horizontal movement of changeups, are associated with an increased likelihood of a pitcher undergoing UCLR. **Level of Evidence:** Level III, retrospective comparative series.

Ulnar collateral ligament (UCL) reconstruction (UCLR) is common in overhead athletes such as baseball players, who are subjected to high valgus stresses placed on the elbow during pitching.[1] Pitchers experience high rates of UCL injury requiring reconstruction, with an increasing incidence reported over the past decade.[2] Roughly 25% of Major League Baseball (MLB) pitchers had a history of UCL injury requiring reconstruction in 2015, which has continued to increase up to 35% in more recent years.[3] This high rate of injury has resulted in the identification of risk factors for UCLR, such as increased velocity, pitch count, and workload.[4-7]

In recent years, the MLB has equipped every stadium with motion-capture technology capable of recording advanced analytic measures to produce detailed player statistics, which help to inform player performance.[8]

From the Department of Orthopaedic Surgery, University of Alabama at Birmingham, Birmingham, Alabama, U.S.A. (M.H., C.R., D.D., P.E., C.B., E.B., T.E., W.S., A.C., A.M.); and University of Alabama at Birmingham, Heersink School of Medicine, Birmingham, Alabama, U.S.A. (N.B.).

Received March 6, 2025; accepted July 17, 2025.

Address correspondence to Amit Momaya, M.D., Orthopaedic Specialties Building, 1313 13th St. South, Birmingham, AL 35205, U.S.A. E-mail: amit.momaya@gmail.com

0749-8063/25458/$36.00

https://doi.org/10.1016/j.arthro.2025.07.022

These advanced metrics are published for every season and player by the MLB in the Baseball Savant[8] public database, which includes pitch-specific movement profiles, spin rate, velocity, and arm angles. Teams have invested heavily in analyzing these advanced metrics to determine which are associated with superior on-field performance. Although the association between increased valgus stress on the elbow and increased workloads with UCLR has long been established.[9,10] the detailed analysis of pitch characteristics and their association with UCL injury has not been described.

This study aims to evaluate advanced pitch-specific metrics to uncover which are associated with pitchers undergoing UCLR. We hypothesized that pitchers who throw a greater percentage of breaking balls at high velocity with high spin rate would have increased odds of undergoing UCLR.

Methods

Study Design

A retrospective cohort analysis of professional pitchers was conducted from the MLB seasons of 2016 to 2024. To be included in the study, pitchers must have had a full season of statistics available in Baseball Savant. Pitchers were excluded if there was no pitch-specific data available on Baseball Savant, or if pitchers in the UCLR group did not have a full season of statistics for the season before they underwent UCLR. For example, if a pitcher missed time in 2017 because of UCLR, they must have had Baseball Savant data from 2016. Pitchers who underwent UCLR were identified from public databases that have been cross-referenced with official press releases.[11,12] A "healthy" league average group was pooled using Baseball Savant data for all pitchers in the MLB who did not undergo UCLR from 2016 to 2024.

Data Collection

Data were collected from Baseball Savant[8] for the desired variables: handedness, pitch usage, pitch-specific horizontal movement, vertical movement with gravity, induced vertical movement, velocity, spin rate, and arm angle. Arm angle data started to be recorded in 2020, so previous seasons were not available for analysis of this variable. Spin rate measures revolutions of the baseball per minute, movement data was reported in inches, and velocity was measured in miles per hour. Horizontal movement was recorded as a negative value if the pitch moved toward the throwing arm side of the pitcher and a positive value if the pitch moved toward the glove side of the pitcher. For example, a pitch thrown by a left-handed pitcher that moved towards the first-base side of home plate would receive a negative value, and a pitch that moves towards the third-base side of home plate would receive a positive value. Vertical movement with gravity describes the vertical movement of the pitch from where the pitch is released to where it crosses home plate, with negative values indicating downward movement. Induced vertical movement is a representation of how the pitch moves without gravity, capturing the vertical movement created by the pitcher (Fig 1). Arm angles, or "arm slots," are calculated as the angle between a horizontal line extending from the pitcher's throwing shoulder and the location of the ball at release (Fig 2).

Statistical Analysis

Data were analyzed by a Ph.D. statistician using SAS (2023, SAS 9.4M8; SAS Institute Inc., Cary, NC). Mann-Whitney *U* tests were used for comparison between league averages and players who underwent UCLR for the desired variables described previously. A binary logistic regression also was performed to assess the relationship between the aforementioned variables and the likelihood of undergoing UCLR surgery. The model employed a logit link function to estimate odds ratios, with significance assessed using the likelihood ratio test, Wald test, and Score Test. Model performance was evaluated using the Akaike Information Criterion, -2 log likelihood, and the c-statistic, providing insight into the goodness of fit and predictive discrimination. Significant values were set at an alpha of 0.05.

Results

Demographics

Table 1 describes the characteristics of pitchers who underwent UCLR from 2017 to 2024, stratified by year. Overall, 132 players were included in the UCLR group, 84% were right-handed, and their average age at surgery was 26.6 ± 2.9 years. Healthy pitchers used to create the "league average" group totaled 6,001 pitchers from 2016-2023, with 75% being right-handed, and were 28.0 ± 3.6 years old on average. Significant differences were noted between groups for age and handedness ($P < .0001$, $P = .03$). Forty pitchers were excluded from the study because they did not have statistics recorded in Baseball Savant from the year before them undergoing UCLR.

Group Comparisons (Pitch Characteristics)

Table 2 describes comparisons between pitchers who underwent UCLR from 2017 to 2024 (n = 132) and healthy league averages from 2016 to 2023 (n = 6,001). Significant differences were noted between healthy controls and pitchers who underwent UCLR

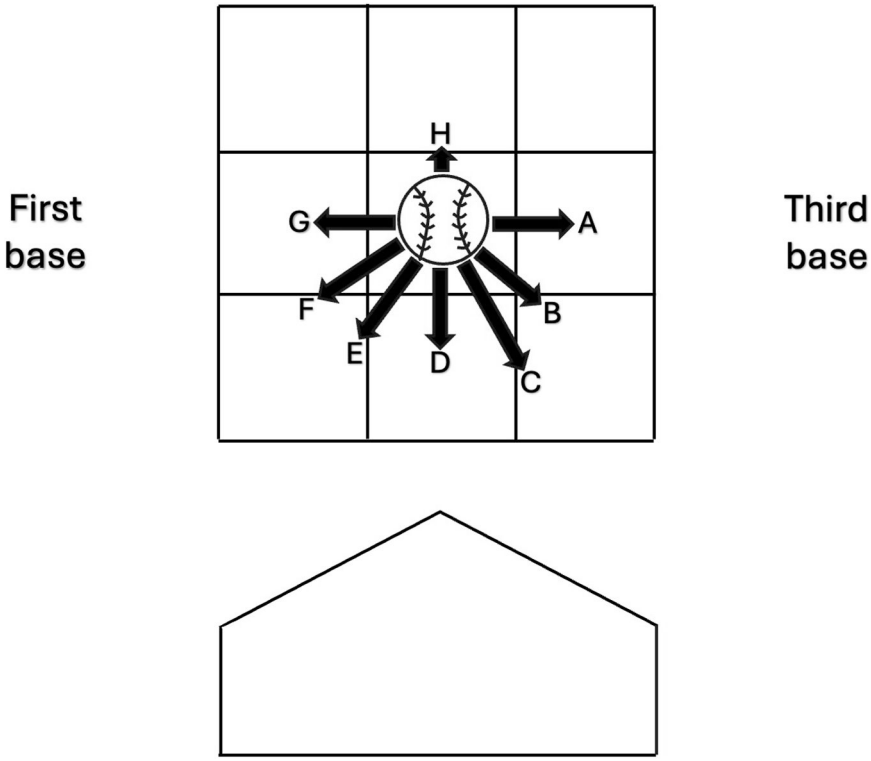

Fig 1. Depiction of the general movement profiles of pitch types, with a sinker (A), changeup (B), splitter (C), curveball (D), sweeper (E), slider (F), cutter (G), and 4-seamer (H) shown.

for 4-seam fastball usage ($P = .0065$); horizontal pitch movement for cutters ($P < .0001$), changeups ($P = .01$), and splitters ($P = .02$); vertical movement with gravity for sliders ($P = .04$); velocity for 4-seamers ($P < .0001$), sinkers ($P < .0001$), cutters ($P = .003$), changeups ($P < .0001$), sliders ($P = .0004$), and curveballs ($P = .004$); and spin rate for 4-seamers ($P = .0005$) and changeups ($P = .04$).

Fig 2. Visualization of how arm angles were calculated, with a horizontal line drawn at a pitcher's shoulders and the location of the hand at release, with the vertex of the angle at the throwing shoulder. A positive (right) and negative (left) arm angle are depicted.

Table 1. Group Characteristics for Pitchers Who Underwent UCLR

Season Missed	Number of Pitchers	Handedness, n (%)		Average Age, yr
		Right	Left	
2017	16	12 (75%)	4 (25%)	26.6 ± 1.8
2018	13	11 (85%)	2 (15%)	26.2 ± 2.1
2019	12	12 (100%)	0 (0%)	24.9 ± 1.24
2020*	20	17 (85%)	3 (15%)	26.0 ± 3.2
2021	15	13 (87%)	2 (13%)	27.9 ± 3.7
2022	9	6 (67%)	3 (33%)	28.2 ± 3.7
2023	20	16 (80%)	4 (20%)	26.5 ± 2.8
2024	27	24 (89%)	3 (11%)	26.9 ± 2.8

NOTE. Values are presented as mean ± standard deviation.
UCLR, ulnar collateral ligament reconstruction.
*Season was only 60 games due to COVID-19.

Group Comparisons (Arm Angles)

Table 3 describes comparisons between healthy controls from 2020 to 2023 and players who underwent UCLR from 2021 to 2024. There were no significant differences between groups for any pitch's arm angle.

Regression Analysis

Pitch Mix

Only the increasing usage of a 4-seamer significantly impacted the odds of undergoing UCLR ($P = .0067$, odds ratio [OR] 1.01, 95% confidence interval [CI] 1.00-1.02, C-statistic = 0.57).

Pitch Movement

Decreased glove side horizontal break when throwing a cutter ($P < .0001$, OR 0.64, 95% CI 0.54-0.77, C-statistic = 0.64), increased arm side horizontal break when throwing a changeup ($P = .01$, OR 1.09, 95% CI 1.02-1.15, C-statistic=0.56), increased glove side horizontal movement when throwing a splitter ($P = .02$, OR 1.14, 95% CI 1.02-1.27, C-statistic = 0.61), and increased vertical break with gravity when throwing a slider all significantly affected the odds of undergoing UCLR ($P = .04$, OR 1.04, 95% CI 1.00-1.07, C-statistic = 0.55).

Velocity

Increased 4-seamer velocity ($P < .0001$, OR 1.27, 95% CI 1.18-1.37, C-statistic = 0.66), increased sinker velocity ($P < .0001$, OR 1.30, 95% CI 1.16-1.40, C-statistic = 0.67), increased cutter velocity ($P < .0001$, OR 1.18, 95% CI 1.06-1.32, C-statistic = 0.63), increased changeup velocity ($P < .0001$, OR 1.20, 95% CI 1.12-1.28, C-statistic = 0.64), increased slider velocity ($P = .0003$, OR 1.13, 95% CI 1.06-1.21, C-statistic = 0.60), increased curveball velocity ($P = .003$, OR 1.11, 95% CI 1.04-1.20, C-statistic = 0.58) significantly affected the odds of undergoing UCLR.

Spin Rate

Increased 4-seam spin rate ($P = .0004$, OR 1.002, 95% CI 1.001-1.003, C-statistic = 0.59) and increased changeup spin rate ($P = .04$, OR 1.001, 95% CI 1.000-1.002, C-statistic = 0.57) significantly affected the odds of undergoing UCLR.

Discussion

The most important finding of this study is that pitchers who throw pitches with increased velocity, spin, and horizontal movement are more likely to undergo UCLR when compared with healthy league averages. Overall, we found that the average velocity of sinkers was the most predictable, with a 1-mile-per-hour (mph) increase in average sinker velocity resulting in a 30% increase in the odds of requiring UCLR.

Increased fastball velocity is a known risk factor for UCL injury.[13,14] The current study showed that the link not only exists for 4-seam velocity but also for the velocity of different types of fastballs (sinkers and cutters), as well as changeups, sliders, and curveballs. This is important because increased velocity of these pitches above league averages resulted in significantly greater odds of undergoing UCLR. These odds ranged from an 11.1% increase per mph above league average for curveball velocity to a 30% increase per mph above league average for sinker velocity. These findings are relevant clinically as pitchers are under constant pressure to push their bodies to extreme physical limits, chasing velocity throughout their entire pitch arsenal in order to succeed across all levels of competition. However, the pursuit of maximal velocity should be met with an abundance of caution, as demonstrated by the findings of this study regarding the increased odds of undergoing UCLR.

One pitching metric that has garnered a lot of interest recently is the spin rate of different pitch types. Spin is a result of hand position (or grip) on the baseball, arm slot, finger pressure, and arm speed during the throwing motion. Different spins result in the ball moving in a variety of directions at various speeds, with increasing spin generally leading to increased and sharper pitch movement.[15,16] Increased 4-seam fastball spin has become desirable because most of the spin generated by this pitch is backspin, resulting in the pitch appearing to "rise," thus making it more difficult to hit.[17] However, our study has shown that pitchers who throw a 4-seam fastball with an average spin 100 rpm above league average have a 20% increase in their odds of undergoing UCLR. This is in contrast to a biomechanical analysis by Hodakowski et al,[18] which found no relationship between spin rates of fastballs, curveballs, change-ups, or sliders and increased valgus loads placed on the elbow. Of note, spin rates of pitches in their study were much lower across each pitch than our UCLR group, necessitating a further analysis of the

Table 2. Comparisons Between League Averages and Pitchers Who Underwent UCLR

	UCLR Pitchers (n = Number of Pitchers Who Threw the Respective Pitch)	League Average (n = Number of Pitchers Who Threw the Respective Pitch)	*P* Value
Pitch mix, %			
Four-seam	42.9 (127)	38.1 (5655)	**.0065**
Sinker	21.2 (71)	24.8 (4106)	.13
Cutter	19.8 (34)	20.0 (1746)	.93
Changeup	12.6 (97)	13.2 (4645)	.56
Slider	26.4 (110)	24.4 (4518)	.16
Curveball	12.8 (72)	15.1 (3627)	.09
Splitter	16.7 (15)	16.7 (511)	.99
Sweeper	22.5 (11)	20.7 (531)	.71
Fastball*	57.8 (132)	58.7 (6001)	.43
Breaking ball†	30.8 (132)	29.3 (6001)	.25
Off-speed‡	11.1 (132)	11.7 (6001)	.61
Horizontal movement, inches			
Four-seam	−8.2 (127)	−7.7 (5655)	.11
Sinker	−14.5 (71)	−14.4 (4106)	.75
Cutter	1.3 (34)	3.0 (1746)	**<.0001**
Changeup	−14.1 (97)	−13.2 (4645)	**.01**
Slider	5.4 (110)	5.4 (4518)	.99
Curveball	8.5 (72)	8.7 (3627)	.74
Splitter	−8.1 (15)	−10.3 (511)	**.02**
Sweeper	15.1 (11)	14.0 (531)	.32
Vertical movement w/ gravity, inches			
Slider	−36.0 (110)	−37.1 (4518)	**.04**
Curveball	−52.9 (72)	−54.0 (3627)	.21
Sweeper	−40.4 (11)	−41.1 (531)	.61
Vertical movement induced, inches			
Slider	1.8 (110)	1.9 (4518)	.89
Curveball	-8.9 (72)	-8.5 (3627)	.47
Sweeper	1.1 (11)	0.6 (531)	.66
Velocity, mph			
Four-seam	94.6 (127)	93.2 (5655)	**<.0001**
Sinker	94.4 (71)	92.7 (4106)	**<.0001**
Cutter	90.0 (34)	88.6 (1746)	**.003**
Changeup	86.9 (97)	85.3 (4645)	**<.0001**
Slider	85.5 (110)	84.4 (4518)	**.0004**
Curveball	79.7 (72)	78.5 (3627)	**.004**
Splitter	86.1 (15)	85.8 (511)	.64
Sweeper	81.5 (11)	81.4 (531)	.87
Spin rate, rpm			
Four-seam	2,301.3 (127)	2,253.2 (5655)	**.0005**
Sinker	2,197.0 (71)	2,170.3 (4106)	.17
Cutter	2,341.6 (34)	2,333.1 (1746)	.80
Changeup	1,810.8 (97)	1,757.4 (4645)	**.04**
Slider	2,384.6 (110)	2,359.7 (4518)	.29
Curveball	2,451.1 (72)	2,448.3 (3627)	.93
Splitter	1,285.4 (15)	1,403.3 (511)	.17
Sweeper	2,566.2 (11)	2,527.5 (531)	.59

NOTE. Values in bold values represent a significant difference between groups.

mph, miles per hour; UCLR, ulnar collateral ligament reconstruction.

*Fastball% is the summation of 4-seam %, sinker %, and cutter %.

†Breaking ball% is the summation of slider %, curveball %, and sweeper %.

‡Off-speed% is the summation of changeup % and splitter %.

Table 3. Arm Angle Comparisons

Pitch Type	UCLR Arm Angle (n = Number of Pitchers Who Threw The Respective Pitch)	League Average Arm Angle (n = Number of Pitchers Who Threw The Respective Pitch)	*P* Value
Four-seam	39.2° (67)	39.1° (541)	.73
Sinker	33.4° (31)	34.4° (387)	.76
Cutter	41.4° (18)	38.5° (222)	.60
Changeup	37.4° (47)	36.4° (422)	.62
Slider	38.0° (58)	38.3° (444)	.70
Curveball	45.4° (39)	44.9° (252)	.74
Splitter	43.2° (10)	40.9° (68)	.74
Sweeper	31.8° (11)	33.9° (193)	.97

UCLR, ulnar collateral ligament reconstruction.

relationship between pitching biomechanics and spin rates.

Similarly, different pitch movements were associated with increased odds of undergoing UCLR. Increased average arm-side movement of cutters resulted in the most predictable odds of injury requiring surgery, with a 1-inch increase in arm side movement above league average, resulting in a 36% increase in the odds of undergoing UCLR. This is interesting, because cutters typically break toward the glove side of a pitcher. One reason for this discrepancy may be secondary to excessive forearm pronation at ball release and increased velocity. Similarly, throwing a changeup with 1 inch more of arm side movement on average than a league average changeup resulted in a 9% increase in requiring UCLR. Again, excessive forearm pronation at ball release would account for this discrepancy. Although forearm pronation at maximal extension (ball release) has not shown to increase valgus stress at the elbow in cadaveric studies,[19] additional studies need to be conducted to evaluate the biomechanical effect that forearm pronation has at high velocities concerning valgus stresses at the elbow.

Increased valgus loads placed on the elbow during pitching result in increased strain placed on the UCL, leading to a thought that arm angles may impact the forces placed on the UCL.[20-22] This was further explored by Aguinaldo and Chambers,[20] who determined that "sidearm" pitchers, or pitchers with a low arm angle, exhibit greater valgus torque placed on their elbow than pitchers who throw more overhand. Our study found no significant difference for any pitch type between the arm angles of healthy league average and those who underwent UCLR, suggesting that arm angle alone is not a reliable predictor of UCLR risk.

Given the financial implications, time to return to sport, and competitive outcomes after UCLR,[23-26] managers and team personnel should consider our findings when evaluating pitchers. Although workload

is a known risk factor for UCL injury,[4] accurately quantifying true workload is beyond the scope of this study as (1) it is impossible to truly control for pitch volume as pitchers may throw year-round either in training or for winter and fall leagues and (2) pitchers may be called up to the major league mid-season and their pitch volume in the minor leagues has just as much of an impact on their elbow as pitches thrown in the major leagues. Aware of the limitation of strictly relying on counting in-season throwing totals, innovative efforts to control pitchers' workloads, such as wearable technology, are already being used throughout the season and offseason to quantify arm wear and tear and optimize recovery. Our study may also aid in decreasing UCLR rates by possibly guiding pitchers and coaches to select an appropriate pitch mix when building a pitch arsenal that will lead to career success and longevity. Lastly, while our statistical models were significant, their predictive ability remains modest, suggesting that additional kinematic and kinetic data may enhance future analyses.

Limitations

This study is not without limitations. The main limitation of this study is the lack of control for injury history besides UCLR, fatigue, or biomechanical differences that could account for discrepancies in the desired metrics.[27,28] In addition, there are no established minimal clinically important differences of these findings regarding UCLR risk, which may limit the strength of conclusions drawn concerning our results. The retrospective nature of this study is also prone to be influenced by unknown confounders and introduces retrospective bias.

In addition, although age and handedness were significantly different between groups, we did not control for these variables, because there is no biomechanical or clinical rationale for why handedness would affect UCLR risk. Similarly, although pitchers in the UCLR group were significantly younger than those in the healthy league average group, this is somewhat counterintuitive, given that UCL injury typically develops over time. A nonmatched analysis was pursued intentionally, as the study aimed to compare pitchers who underwent UCLR to a representative healthy league cohort.

Furthermore, 40 pitchers were excluded from the study because they did not have statistics recorded in Baseball Savant from the year before undergoing UCLR, which may further limit generalizability. The nature of the injury and the subsequent UCLR technique are also unknown, given our dataset.

Conclusions

This study demonstrates that specific pitch characteristics, including increased velocity, increased spin rate, reduced glove-side horizontal movement of cutters, and increased arm-side horizontal movement of changeups, are associated with an increased likelihood of undergoing UCLR.

Disclosures

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: A.M. reports other from CONMED Corporation and editorial or governing board of *Arthroscopy*. A.C. reports consulting or advisory with Arthrex and board or committee member, American Orthopaedic Society for Sports Medicine. E. B. reports board membership with EBSCO and consulting or advisory with Link Orthopaedics and Orthopaedic Design. All other authors (M.H., C.R., D. D., P.E., C.B., N.B., T.E., W.S.) declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. van Trigt B, van Goethem JV, van den Bekerom MMPJ, Veeger DHEJ, Hoozemans MMJM. The ulnar collateral ligament response to valgus stress, repetitive pitching, and elbow muscle contraction in asymptomatic baseball pitchers. *JSES Rev Rep Tech* 2024;4:189-195.
2. Rothermich MA, Fleisig GS, Conte SA, Hart KM, Cain EL, Dugas JR. Short-term trends in elbow ulnar collateral ligament surgery in collegiate baseball players: An analysis of 25,587 player-years. *Orthop J Sports Med* 2021;9:23259671211016846.
3. American Medical Association. What doctors wish patients knew about Tommy John surgery. July 12, 2024. https://www.ama-assn.org/delivering-care/public-health/what-doctors-wish-patients-knew-about-tommy-john-surgery. Accessed May 19, 2025.
4. Whiteside D, Martini DN, Lepley AS, Zernicke RF, Goulet GC. Predictors of ulnar collateral ligament reconstruction in major league baseball pitchers. *Am J Sports Med* 2016;44:2202-2209.
5. Keller RA, Marshall NE, Guest JM, Okoroha KR, Jung EK, Moutzouros V. Major League Baseball pitch velocity and pitch type associated with risk of ulnar collateral ligament injury. *J Shoulder Elbow Surg* 2016;25:671-675.
6. Bushnell BD, Anz AW, Noonan TJ, Torry MR, Hawkins RJ. Association of maximum pitch velocity and elbow injury in professional baseball pitchers. *Am J Sports Med* 2010;38:728-732.
7. Conte SA, Fleisig GS, Dines JS, et al. Prevalence of ulnar collateral ligament surgery in professional baseball players. *Am J Sports Med* 2015;43:1764-1769.
8. Baseball Savant: Statcast, Trending MLB Players and Visualizations. baseballsavant.com, https://baseballsavant.mlb.com/. Accessed February 7, 2025.
9. Regan WD, Korinek SL, Morrey BF, An KN. Biomechanical study of ligaments around the elbow joint. *Clin Orthop* 1991;271:170-179.

10. Olsen SJ, Fleisig GS, Dun S, Loftice J, Andrews JR. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *Am J Sports Med* 2006;34:905-912.
11. Tommy John Surgery List (@MLBPlayerAnalys). Google Docs, https://docs.google.com/spreadsheets/d/1gQujXQQGOVNaiuwSN680Hq-FDVsCwvN-3AazykOBON0/edit?usp=embed_facebook. Accessed February 7, 2025.
12. TJ Surgery: AllTime MLB List. MLB Reports. April 21, 2012. https://mlbreports.com/tj-surgery/. Accessed February 7, 2025.
13. Chalmers PN, Erickson BJ, Ball B, Romeo AA, Verma NN. Fastball pitch velocity helps predict ulnar collateral ligament reconstruction in Major League Baseball pitchers. *Am J Sports Med* 2016;44:2130-2135.
14. DeFroda SF, Kriz PK, Hall AM, Zurakowski D, Fadale PD. Risk stratification for ulnar collateral ligament injury in Major League Baseball players: A retrospective study from 2007 to 2014. *Orthop J Sports Med* 2016;4:2325967115627126.
15. Nagami T, Higuchi T, Nakata H, Yanai T, Kanosue K. Relation between lift force and ball spin for different baseball pitches. *J Appl Biomech* 2016;32:196-204.
16. Jinji T, Sakurai S. Direction of spin axis and spin rate of the pitched baseball. *Sports Biomech* 2006;5:197-214.
17. Neiswender K. A Deeper Dive into Fastball Spin Rate. Driveline Baseball. February 2019;1, https://www.drivelinebaseball.com/2019/01/deeper-dive-fastball-spin-rate/. Accessed February 14, 2025
18. Hodakowski AJ, Dowling B, Streepy JT, et al. Pitch types and their influence on elbow varus torque and spin rate in professional baseball pitchers. *Am J Sports Med* 2025;53:543-548.
19. Selley R, Owusu-Akyaw K, Lawton C, Kontaxis A, Meyers K, Carr J. Poster 188: The effect of forearm supination versus pronation at the time of UCL reconstruction graft tensioning on post-surgical medial elbow joint gapping in a biomechanical cadaveric model. *Orthop J Sports Med* 2022;10:23259671215S00749 (7 suppl 5).
20. Aguinaldo AL, Chambers H. Correlation of throwing mechanics with elbow valgus load in adult baseball pitchers. *Am J Sports Med* 2009;37:2043-2048.
21. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med* 1995;23:233-239.
22. Werner SL, Fleisig GS, Dillman CJ, Andrews JR. Biomechanics of the elbow during baseball pitching. *J Orthop Sports Phys Ther* 1993;17:274-278.
23. Spotrac. MLB Rankings. spotrac.com. 2025. https://www.spotrac.com/mlb/rankings/_/year/2025. Accessed February 25, 2025.
24. 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;9:23259671211035753.
25. 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;8:2325967120966310.
26. 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;29:121-125.
27. Giordano K, Nebel AR, Fava A, Oliver GD. Tall and fall versus drop and drive strategy in college baseball pitchers for velocity and elbow valgus torque. *Am J Sports Med* 2024;52:3110-3117.
28. Aguinaldo A, Escamilla R. Segmental power analysis of sequential body motion and elbow valgus loading during baseball pitching: Comparison between professional and high school baseball players. *Orthop J Sports Med* 2019;7:2325967119827924.