

Effect of Ulnar Collateral Ligament Reconstruction on Pitch Accuracy, Velocity, and Movement in Major League Baseball Pitchers

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Background: Ulnar collateral ligament (UCL) reconstruction is frequently performed on Major League Baseball (MLB) pitchers. Previous studies have investigated the effects of UCL reconstruction on fastball and curveball velocity, but no study to date has evaluated its effect on fastball accuracy or curveball movement among MLB pitchers.

Purpose/Hypothesis: The primary purpose of this study was to determine the effects of UCL reconstruction on fastball accuracy, fastball velocity, and curveball movement in MLB pitchers. Our hypothesis was that MLB pitchers who underwent UCL reconstruction would return to their presurgery fastball velocity, fastball accuracy, and curveball movement. The secondary purpose of this study was to determine which factors, if any, were predictive of poor performance after UCL reconstruction.

Study Design: Case-control study; Level of evidence, 3.

Methods: MLB pitchers who underwent UCL reconstruction surgery between 2011 and 2012 were identified. Performance data including fastball velocity, fastball accuracy, and curveball movement were evaluated 1 year preoperatively and up to 3 years of play postoperatively. A repeated-measures analysis of variance with a Tukey-Kramer post hoc test was used to determine statistically significant changes in performance over time. Characteristic factors and presurgery performance statistics were compared between poor performers (>20% decrease in fastball accuracy) and non-poor performers.

Results: We identified 56 pitchers with a total of 230,995 individual pitches for this study. After exclusion for lack of return to play ($n = 14$) and revision surgery ($n = 3$), 39 pitchers were included in the final analysis. The mean presurgery fastball pitch-to-target distance was 32.9 cm. There was a statistically significant decrease in fastball accuracy after reconstruction, which was present up to 3 years postoperatively ($P = .007$). The mean presurgery fastball velocity of 91.82 mph did not significantly change after surgery ($P = .194$). The mean presurgery curveball movement of 34.49 cm vertically and 5.89 cm horizontally also did not change significantly ($P = .937$ and $.161$, respectively).

Conclusion: Fastball accuracy among MLB pitchers significantly decreased after UCL reconstruction for up to 3 years postoperatively. There were no statistically significant differences in characteristic factors or presurgery performance statistics between poor and non-poor performers.

Keywords: ulnar collateral ligament; Tommy John surgery; Major League Baseball; elbow; pitching; baseball/softball

The anterior band of the ulnar collateral ligament (UCL) provides primary stability to valgus stress at the elbow between 20° and 120° of flexion.²⁰ Repetitive valgus forces are thought to cause microtrauma to the UCL over time,^{2,17} weakening its integrity and predisposing it to acute or chronic rupture. It is not surprising that UCL injuries are common among baseball pitchers, as the biomechanics of

overhead throwing subject the elbow to significant valgus force, regardless of pitch selection.^{9,23} Historically, rupture of the UCL was a career-ending injury for a Major League Baseball (MLB) pitcher, as pain and loss of stability inhibited professional-level performance. In 1974, Dr Frank Jobe performed the first successful UCL reconstruction on a Los Angeles Dodgers pitcher, forever changing the prognosis of UCL rupture and giving the procedure its colloquial name—Tommy John surgery.¹⁵

Since then, UCL reconstruction has remained a popular topic among orthopaedic surgeons, athletes, and the media.

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Recently, much of this attention has been focused on the increasing rates of UCL reconstruction among baseball players of all skill levels. As many as 10% to 25% of active MLB pitchers report a history of UCL reconstruction, and there has been an estimated 10-fold increase in cases among professional players since 2000.^{5,7} Similar trends have been seen in the general population, with a recent study indicating a 193% increase in incidence of UCL reconstruction from 2002 to 2011.¹³ The etiology of this trend is likely multifactorial, but it has been suggested that public perception of the success of the surgery may be a driving factor. Up to 25% of media members who cover professional baseball and up to 51% of active high school players believe that UCL reconstruction can enhance pitching performance.^{1,6} However, this common belief is not substantiated in the literature.

Several studies have attempted to evaluate pitching performance after UCL reconstruction. Return-to-play can be expected in 63% to 87% of MLB pitchers postsurgery,^{11,16,19} and studies^{8,16,19} examining basic performance metrics including earned run average (ERA), balls/strikes, and wins per season have yielded conflicting results. A recent study by Jiang and Leland¹⁴ suggested that fastball velocity may decrease after UCL reconstruction, although not above pair-matched controls. Other pitch characteristics including movement and accuracy contribute largely to performance and have not yet been explored in the orthopaedic literature.

The primary purpose of this study was to determine the effects of UCL reconstruction on fastball accuracy, fastball velocity, and curveball movement in MLB pitchers. Our hypothesis was that MLB pitchers who underwent UCL reconstruction would return to their presurgery levels of fastball velocity, fastball accuracy, and curveball movement. The secondary purpose of this study was to determine which factors, if any, were predictive of poor performance after UCL reconstruction.

METHODS

At the start of the 2010 season, MLB began collecting data on each pitch thrown in every official game using a visual pitch tracking tool, COMMANDf/x (Sportsvision Inc). COMMANDf/x uses cameras to track, among many things, pitch velocity, movement, location of the glove when the pitch is released, and location of the pitch when it crosses the strike zone. This method of measuring pitch location is precise to within 1.26 cm and has been previously described

in the orthopaedic literature.³ Nonpublic data from this tool were used with permission in the present study. After approval by our institutional review board, all MLB pitchers who were on the MLB disabled list in the 2011 and 2012 seasons with an elbow injury were screened for inclusion. These 2 seasons were selected to provide 1 year of presurgery data and up to 3 years of postsurgery data. Injury reports and press releases submitted by each player's respective team were reviewed for UCL reconstruction, or Tommy John surgery. The MLB Players Association requires team physicians to submit official injury reports to the commissioner of MLB, assuring a high degree of reliability.

Mean performance data including fastball velocity, fastball accuracy, and curveball horizontal and vertical movements were evaluated for each year in which they were used by each pitcher. Total curveball movement was calculated using the Pythagorean theorem. The magnitude of difference (cm) between the initial location of the glove and the resultant location of the pitch (ie, pitch-to-target distance) was used to determine fastball accuracy. A higher mean pitch-to-target distance indicates decreased accuracy. Seasons with <100 pitches thrown were omitted from analysis, as this was considered an inadequate number of pitches to form a representative sample for that year.

Pitchers were deemed particularly poor performers if their postsurgery fastball accuracy was >20% worse than was their presurgery fastball accuracy. This value represented a postsurgery accuracy >1 SD worse when compared with that of the remainder of the cohort. Rest time before return to MLB play; presurgery ERA; number of pitches and percentage of fastballs thrown during the presurgery year; and characteristic factors including age at surgery, years of MLB experience, handedness, and position (ie, relief or starting pitcher) were compared between poor and non-poor performers. These same factors were also compared between pitchers who did not return to play at the major league level for at least 3 seasons and those who did.

Statistical Analysis

One year of presurgery pitching performance was compared with postsurgery performance using a 1-way repeated-measures analysis of variance. A Tukey-Kramer post hoc test was used to determine year-to-year changes. Standard comparative statistical techniques including a Student *t* test for continuous variables and chi-square or

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Ethical approval for this study was obtained from the University of Southern California (proposal No. HS-15-00285).

TABLE 1
 Characteristics by Command Performance After Ulnar Collateral Ligament Reconstruction^a

	Non-poor Performers (n = 25)	Poor Performers (n = 14)	P
Age at surgery, y	28.2 ± 5.9	26.1 ± 3.8	.244
MLB experience at surgery, y	5.6 ± 4.6	4.1 ± 3.2	.295
Handedness, n (%)			.218
Right	18 (72)	13 (93)	
Left	7 (28)	1 (7)	
Type of pitcher, n (%)			.095
Starting	18 (72)	6 (43)	
Relief	7 (28)	8 (57)	
Rest time before return to MLB play, mo	15.4 ± 4.1	16.6 ± 5.3	.464
ERA in the presurgery year	4.60 ± 1.29	4.24 ± 1.33	.419
Pitches thrown in the presurgery year	1723 ± 1107	1135 ± 728	.083
Fastballs thrown in the presurgery year, %	55.8	64.7	.063

^aData are reported as mean ± SD unless otherwise indicated. Pitchers were deemed poor performers if their postsurgery fastball accuracy was > 20% worse than was their presurgery fastball accuracy, representing a postsurgery accuracy >1 SD worse compared with that of the remainder of the cohort. ERA, earned run average; MLB, Major League Baseball.

Fisher exact test for categorical variables were used to compare the characteristic and pitching factors between poor and non-poor performers. All statistical analysis was completed using Stata (Version 13.0; StataCorp). Statistical significance was determined based on *P* < .05.

RESULTS

A total of 56 MLB pitchers underwent UCL reconstruction between 2011 and 2012, with a total of 230,995 individual pitches available for analysis. Fourteen (25%) were excluded because they did not return to pitch at the major league level. Three (5%) were excluded because the procedure was a revision surgery. After exclusions, 39 pitchers were included in the final analysis. Of them, 39 (100%) pitched at least 1 season after surgery, 32 (82%) pitched at least 2 seasons after surgery, and 24 (62%) pitched at least 3 seasons after surgery. The mean age at surgery was 27 years, with a mean experience in MLB of 5 years. The mean rest time before return to major league play was 15.8 months. Pitchers who continued to pitch 3 years after surgery were younger (aged 26 years versus 29 years; *P* = .047) and had less rest time (14 months versus 19 months; *P* = .001) compared with pitchers who did not return to pitch at least 3 years postsurgery. There were no statistically significant differences in characteristic factors or presurgery performance statistics between poor and non-poor performers (Table 1).

In the year before surgery, the mean fastball velocity was 91.8 mph, and the mean pitch-to-target distance was

TABLE 2
 Fastball Accuracy and Velocity After Ulnar Collateral Ligament Repair^a

	Velocity, mph	<i>P</i> ^b	Pitch-to-Target Distance, cm	<i>P</i> ^b
Timepoint				
Presurgery (n = 39)	91.8 ± 3.1	.194	32.9 ± 3.1	.007
1 y postsurgery (n = 39)	91.5 ± 3.3	.269	36.1 ± 7.0	.004
2 y postsurgery (n = 32)	91.8 ± 2.5	.184	34.3 ± 4.1	.128
3 y postsurgery (n = 24)	91.8 ± 2.0	.082	36.0 ± 5.2	.023

^aData are reported as mean ± SD. Individual timepoints tested against presurgery values using Tukey-Kramer post hoc analysis. Pitch-to-target distance: magnitude of difference between the setup location of the catcher’s glove and the resultant location of the pitch. All data were collected with using COMMANDfx (Sportsvision Inc).

^bTotal *P* values calculated using repeated-measures analysis of variance.

32.9 cm (Table 2). The range of average pitch-to-target distance was 23.8 cm for the most accurate pitcher and 56.9 cm for the least accurate pitcher. After UCL reconstruction, there was a statistically significant decrease in fastball accuracy (*P* = .007) and no significant change in fastball velocity (*P* = .194). The difference in fastball accuracy was secondary to a larger pitch-to-target distance of fastballs in the first year of return postsurgery (36.1 cm; *P* = .004) and in the third year of return postsurgery (36.0 cm; *P* = .023) (Figure 1).

In the year before surgery, the mean horizontal curveball movement was 5.9 cm, and the mean vertical movement was 34.5 cm, resulting in a mean total curveball movement of 35.1 cm. After UCL reconstruction, there was no significant change in curveball movement across all years examined (Table 3).

DISCUSSION

The major finding of this study was that fastball accuracy in MLB pitchers significantly decreased in years 1 and 3 after UCL reconstruction compared with preoperative performance. However, there were no significant postoperative changes in fastball velocity or curveball movement within 3 years. Pitching performance at the professional level carries broad implications for both the athlete and the organization for which the athlete pitches. MLB pitchers are a central component of every roster; the health and effectiveness of these elite athletes is inextricably linked to team performance, morale, and media viewership. As such, the performance of professional pitchers has significant financial implications.

Several studies have sought to analyze pitching performance after UCL reconstruction using a variety of different metrics including ERA, walks plus hits per inning pitched, batting average against, and innings pitched. However, the current literature has shown conflicting results. Makhni

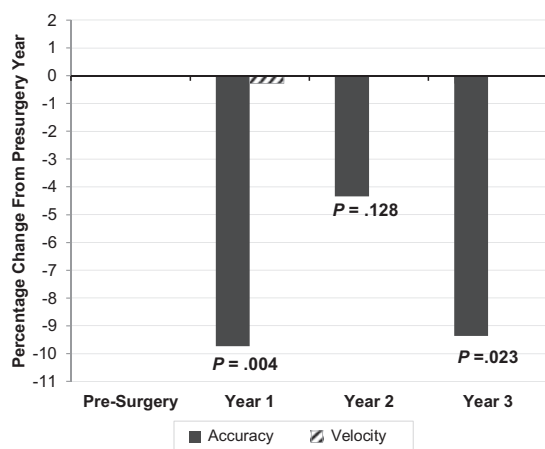


Figure 1. Fastball accuracy and velocity after ulnar collateral ligament reconstruction.

TABLE 3
Curveball Movement After Ulnar Collateral Ligament Repair^a

	Presurgery (n = 27)	Postsurgery			<i>P</i> ^b
		Year 1 (n = 27)	Year 2 (n = 22)	Year 3 (n = 20)	
Horizontal, cm	5.9 ± 2.3	5.9 ± 2.3	6.8 ± 2.1	6.9 ± 2.7	.161
Vertical, cm	34.5 ± .45	34.8 ± 4.8	34.3 ± 4.4	34.4 ± 4.4	.937
Total movement, cm ^c	35.1 ± 4.5	35.3 ± 4.8	35.0 ± 4.4	35.1 ± 4.5	.901

^aData are reported as mean ± SD.

^b*P* values calculated using repeated-measures analysis of variance.

^cTotal movement calculated as the hypotenuse of a right triangle using the Pythagorean theorem.

et al¹⁹ reported significant postoperative declines in ERA, walks plus hits per inning pitched, and batting average against compared with the year before surgery. These findings were contrary to previous findings of Gibson et al¹² who identified no such decline and Erickson et al⁸ who noted an improvement in postoperative performance. While these studies drew from similar sources of publicly available data, differences in study design, such as exclusion criteria and follow-up time, likely resulted in the inconsistent findings. For example, Erickson et al⁸ included all pitchers who appeared in at least 1 MLB game and reported on data over the course of pitchers' careers. In contrast, Makhni et al¹⁹ reported only on players pitching postoperatively in at least 10 games during a single season. Both methodologies have their strengths and weaknesses, and it is difficult to conclude which methodology is superior.

A pitcher's ability to locate his fastball is of great importance—nowhere more so than in the MLB. In the past, the percentage of balls versus strikes thrown and bases on balls per nine innings pitched have been used as surrogates for measuring accuracy after UCL reconstruction.¹⁴ These

methods of measuring accuracy are flawed because they incorrectly classify intentional walks and intentional balls as inaccurate while classifying unintentional or poorly placed strikes as accurate. By comparing the distance of a pitch from its intended target (eg, the setup location of the catcher's glove to the resultant location of the pitch), we are able to quantitatively measure subtle inaccuracies on a pitch-by-pitch basis. In order to control for differences in the way that pitchers aim their pitches in reference to the catcher's glove setup location, we have presented the change in accuracy as a percentage of preoperative pitch-to-target distance. This allows for individualized control values with which to evaluate the effect of surgery on accuracy. Our finding that fastball accuracy decreased by a mean of >9% (*P* = .007; ~3 cm per pitch) was a novel finding that has, to our knowledge, not been reported elsewhere. Moreover, the finding that this decrease in accuracy persisted up to 3 years postoperatively may represent a long-term sequela for some pitchers that can significantly affect their ability to perform at the highest level of competition. Portney et al²¹ utilized a similar methodology using public data on 50 MLB pitchers who underwent UCL reconstruction and found no postoperative difference in fastball accuracy. However, members of their cohort were required to have >100 pitches in postoperative years 2 and 3 in order to meet inclusion criteria, which may have selected for players with inherently better outcomes and biased results toward better accuracy. We attempted to identify factors, such as age, years of MLB experience, rest time before return-to-play, and preoperative ERA, that predisposed pitchers to diminished postoperative accuracy; however, no factors analyzed were found to be statistically significant. A higher percentage of fastballs thrown in the presurgery year (*P* = .060) trended toward predicting poor accuracy, while a higher pitch count in the presurgery year (*P* = .083) and being a starting pitcher (*P* = .095) trended toward predicting better accuracy, although these associations were ultimately not significant. Additional research with larger sample sizes and more factors analyzed is needed to identify the determinants of postoperative performance.

In addition to accuracy, changes in fastball velocity can have a large effect on a pitcher's effectiveness. Jiang and Leland¹⁴ analyzed fastball velocity after UCL reconstruction and found that velocity decreased postoperatively but not above that of pair-matched controls. In contrast, Portney et al²¹ found no change in fastball velocity between players after UCL reconstruction and controls. Our findings agree with the latter study, indicating that fastball velocity does not change after UCL reconstruction. The discrepancy between our results and those of Jiang and Leland¹⁴ may be attributable to our larger and more recent cohort. It is also possible that players from their cohort had differences in surgical technique and rehabilitation protocols, which has been implicated to affect clinical outcomes.²³

The UCL provides stability to the elbow in order to offset the large valgus forces caused by overhead throwing.²⁰ While pitching kinematics of fastballs and curveballs are slightly different, the valgus forces generated at the elbow

are similar.¹⁰ While a past study¹⁴ has demonstrated a slight decrease in curveball velocity after UCL reconstruction, no study to date has analyzed other characteristics of curveballs. Our finding that curveball movement was maintained postoperatively suggests that the UCL-reconstructed elbow is able to withstand the valgus torque needed to generate the forces that contribute to curveball movement. However, it is important to note that the accuracy of curveballs was not analyzed in the present study. While the distance from the catcher's glove to the resultant pitch location is a good metric to evaluate fastball accuracy, we did not believe it was an adequate metric for evaluating curveball accuracy. Pitchers often intend for curveballs to start their break in the strike zone and reach the plate in a location that is difficult for an opposing batter to hit, especially when pitchers are ahead in the count. Thus, this measurement of accuracy does not necessarily translate to efficacy of a curveball, making it a poor metric for evaluating this type of pitch.

The underlying cause for a decrease in fastball accuracy with a relative maintenance of curveball movement and fastball velocity after UCL reconstruction is unclear. Past studies^{4,18} have indicated the UCL-reconstructed elbow is able to resist physiologic valgus stress similarly to the native UCL. As such, it is likely that pitchers are able to generate the preinjury levels of torque above the elbow needed to maintain professional-level pitch movement and velocity. Additionally, multiple elements within the kinetic chain involved in overhand pitching, such as shoulder, chest, lower extremity, and core musculature, may provide compensatory strength and coordination.²² The decrease in fastball accuracy is likely a consequence of several factors including strength rehabilitation and conditioning. It is also possible that subtle changes in proprioception after reconstruction using denervated graft could alter a pitcher's ability to accurately throw a pitch.

There are several limitations to this study. First, as this is a retrospective study, there are inherent limitations to the conclusions that can be drawn from our analysis. Second, we only analyzed data from pitchers who continued to play at the major league level after surgery, indicating potential selection bias. It is likely that pitchers who did not return had decreases in performance, prohibiting their continued participation in MLB (ie, decreased accuracy, velocity, and/or movement). This would have the effect of underrepresenting the decreased performance reported. We also did not have any information regarding symptoms of the pitchers. Given the natural progression of UCL injury, it is likely that some pitchers experienced symptoms from their injury that limited their performance in the year preceding surgery compared with their asymptomatic baseline.¹⁶ Because of this, the decrease in performance noted is likely underrepresenting the true loss of performance from a preinjury, asymptomatic baseline. Third, we were unable to identify factors that were predictive of decreased performance postoperatively, which may be related to inadequate power conferred by our small sample size or because the correct factors were not investigated. While we used all data available at this time, future studies involving a larger number of pitchers may be able to identify pitchers at risk

of losing accuracy after UCL reconstruction. Fourth, our study did not have a control group. As such, the observed decrease in accuracy may be the result of the "natural history" of MLB pitchers as they progress through their careers. Fifth, factors, such as rehabilitation protocols and surgical techniques, were not evaluated in this study. A previous study²³ has found varying clinical results between the docking and the figure-of-eight techniques and with a muscle-splitting approach compared with a flexor mass release.

CONCLUSION

MLB pitchers returning from UCL reconstruction were found to have decreased fastball accuracy up to 3 years postoperatively. There was no significant change in fastball velocity or curveball movement. While UCL reconstruction remains the treatment of choice for pitchers with a known UCL injury, the findings outlined here should be discussed with patients in order to provide a complete understanding of postoperative expectations.

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