

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

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ABSTRACT (281 words)

Introduction: Ulnar collateral ligament (UCL) reconstruction, Tommy John surgery, is a frequent operation amongst Major League Baseball (MLB) pitchers. Previous studies have suggested that UCL reconstruction can potentially affect pitch velocity, however, no study to date has evaluated fastball accuracy or curveball movement amongst MLB pitchers.

Methods: MLB pitchers who underwent UCL reconstruction surgery between 2011-2012 were identified. Performance data including fastball velocity, fastball accuracy, and curveball movement were evaluated 1 year preoperatively and up to 3 years of play following UCL reconstruction. A repeated measures ANOVA with a Tukey-Kramer post-hoc test assessed for statistically significant changes in performance over time. Demographic factors and pre-surgery performance statistics were compared between poor performers and non-poor performers.

Results: A total of 56 pitchers with a total of 230,995 individual pitches were identified. After exclusion for lack of return to play (14) and revision surgery (3), 39 pitchers were included in the final analysis. The mean presurgery fastball pitch to target distance was 33.15 cm. There was a statistically significant decrease in fastball accuracy following UCL reconstruction, which was present up to 3 years postoperatively ($p=0.007$). The mean pre-surgery fastball velocity was 91.82 miles per hour which did not significantly change ($p=0.194$). The mean pre-surgery curveball movement was 34.49cm vertically and 5.89cm horizontally. There was no significant change in vertical ($p=0.937$) or horizontal ($p=0.161$) curveball movement. There were no statistically significant differences in demographic factors or pre-surgery performance statistics between poor performers and non-poor performers.

Conclusion: Fastball accuracy amongst MLB pitchers significantly decreased following UCL reconstruction for up to 3 years postoperatively. Fastball velocity and curveball movement did not significantly change.

Keywords: Tommy John; Pitching; Major League Baseball; Throwing; Ulnar Collateral Ligament; Elbow Injury

INTRODUCTION

The anterior band of the UCL provides primary stability to valgus stress at the elbow between 20° and 120° of flexion[Morrey CORR 1991]. Repetitive valgus forces are thought to cause microtrauma to the UCL over time[Bruce JAAOS 2014, Kooima AJSM 2004], 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[Fleisig AJSM 1995]. 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*[Jobe JBJS 1986].

Since then, UCL reconstruction has remained a popular topic amongst orthopaedic surgeons, athletes, and the media. Recently, much of this attention has 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 the year 2000[Conte AJSM 2015, Dugas CSM 2010]. 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[Hodgins AJSM 2016]. 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[Conte PhysSportsmed 2015, Ahmad PhysSportsmed 2012]. However, this common belief is not substantiated in the literature.

A number of studies have attempted to evaluate pitching performance after UCL reconstruction. Return-to-play can be expected in 63% to 87% of MLB pitchers post-surgery [Makhni AJSM 2014, Keller JSES 2014, Ford AJSM 2016] and studies examining basic performance metrics including earned run average (ERA), balls/strikes, and wins per season have yielded conflicting results[Keller JSES 2013, Makhni AJSM 2014, Erickson AJSM 2014]. A recent study by Jiang et al suggests that fastball velocity may decrease after UCL reconstruction, though not above pair-matched controls[Jiang AJSM 2014]. Other pitch characteristics including movement and accuracy contribute largely to performance and have not yet been explored in the orthopaedic literature.

The purpose of this study was to determine the effects of UCL reconstruction on fastball accuracy and curveball movement in MLB pitchers. The secondary purpose of the study was to determine which factors, if any, were predictive of poor performance following 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, Chicago, Illinois, USA). COMMANDf/x uses cameras to track, among many things, pitch velocity, movement, the location of the mitt when the pitch is released, and the location of the pitch when it crosses the strike zone. Non-public data from this tool was used with permission in the present study. After approval by our Institutional Review Board, all MLB pitchers who were reported to the MLB disabled list in the 2011 and 2012 seasons with an elbow injury were screened for inclusion. These two seasons were selected to provide 1 year of pre-surgery data and up to 3 years of post-surgery data. Injury reports and press releases submitted by each player's respective teams 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 Major League Baseball, assuring a high degree of reliability.

Mean performance data including fastball velocity, fastball accuracy, and curveball horizontal and vertical movement 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 mitt and the resultant location of the pitch (i.e. pitch to target distance) was used to determine fastball accuracy. A higher mean pitch to target distance indicates decreased accuracy. Seasons with fewer than 100 pitches thrown were omitted from analysis as this was felt to be an inadequate number of pitches to form a representative sample for that year.

Pitchers were deemed poor performers if their post-surgery accuracy was more than 20% worse than their pre-surgery accuracy. Rest time before return to MLB play, pre-surgery earned run average (ERA), number of pitches and percent fastballs thrown during the presurgery year, and demographic factors including age at surgery, years of MLB experience, handedness, and position (i.e. relief or starting pitcher) were compared between poor performers 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 that did.

Statistical Analysis

One year of pre-surgery pitching performance was compared to post-surgery performance using a one-way repeated measures ANOVA. A Tukey-Kramer post-hoc test was used to determine year-to-year changes. Standard comparative statistical techniques including a Student's t test for continuous variables and chi-square or Fisher's exact test for categorical variables were used to compare demographic and pitching factors between poor and non-poor performers. All statistical analysis was completed using Stata (version 13.0; StataCorp, College Station, TX, USA). Statistical significance was determined based on $P < 0.05$.

RESULTS

A total of 56 MLB pitchers underwent UCL reconstruction between 2011 and 2012 with a total of 230,995 individual pitches. 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 old with a mean experience in major league baseball 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 (26 versus 29; $p=0.047$) and had less rest time (14 months versus 19 months; $p=0.001$) compared to pitchers who did not return to pitch at least 3 years post-surgery. There were no statistically significant differences in demographic factors or pre-surgery performance statistics between poor performers and non-poor performers (Table I).

Table I - Demographics by Command Performance after UCL Reconstruction			
	Non-low Performers n=25	Low Performers n=14	P-Value
Age at surgery	28.2 ± 5.9	26.1 ± 3.8	0.244
Years of MLB experience at surgery	5.6 ± 4.6	4.1 ± 3.2	0.295
Handedness			0.218
Right	18 (72%)	13 (93%)	
Left	7 (28%)	1 (7%)	
Type of pitcher			0.095
Starting pitcher	18 (72%)	6 (43%)	
Relief pitcher	7 (28%)	8 (57%)	
Rest time before return to MLB play (months)	15.4 ± 4.1	16.6 ± 5.3	0.464
ERA (pre-surgery year)	4.60 ± 1.29	4.24 ± 1.33	0.419
Pitches thrown (pre-surgery year)	1723 ± 1107	1135 ± 728	0.084
Percent fastballs thrown (pre-surgery year)	55.8	64.7	0.060

In the year prior to surgery, the mean fastball velocity was 91.8 mph with a mean pitch to target distance of 32.9 cm (Table II). After UCL reconstruction, there was a statistically significant decrease in fastball accuracy ($p=0.007$) with no significant change in fastball velocity ($p=0.194$). The difference in fastball accuracy was secondary to a larger pitch to target distance of fastballs in the first year of return post-surgery (36.1 cm, $p=0.004$) and in the third year of return post-surgery (36.0 cm, $p=0.023$) (Figure 1).

Table II - Fastball Accuracy and Velocity Following Ulnar Collateral Ligament Repair				
	Velocity (mph)	P-Value*	Distance of pitch from target (cm)	P-Value*
Timepoint		0.194		0.007
Pre-surgery (n=39)	91.8 ± 3.1		32.9 ± 3.1	
1 year post-surgery (n=39)	91.5 ± 3.3	0.269	36.1 ± 7.0	0.004
2 years post-surgery (n=32)	91.8 ± 2.5	0.184	34.3 ± 4.1	0.128
3 years post-surgery (n=24)	91.8 ± 2.0	0.082	36.0 ± 5.2	0.023
*Total p-values calculated using repeated measures anova; Individual timepoints tested against pre-surgery values using Tukey-Kramer post-hoc analysis; <i>Difference of pitch from target</i> - Magnitude difference of the catchers mitt set up location and the resultant pitch location; All data collected with COMMANDf/x (Sportsvision Inc, Chicago, Illinois, USA)				

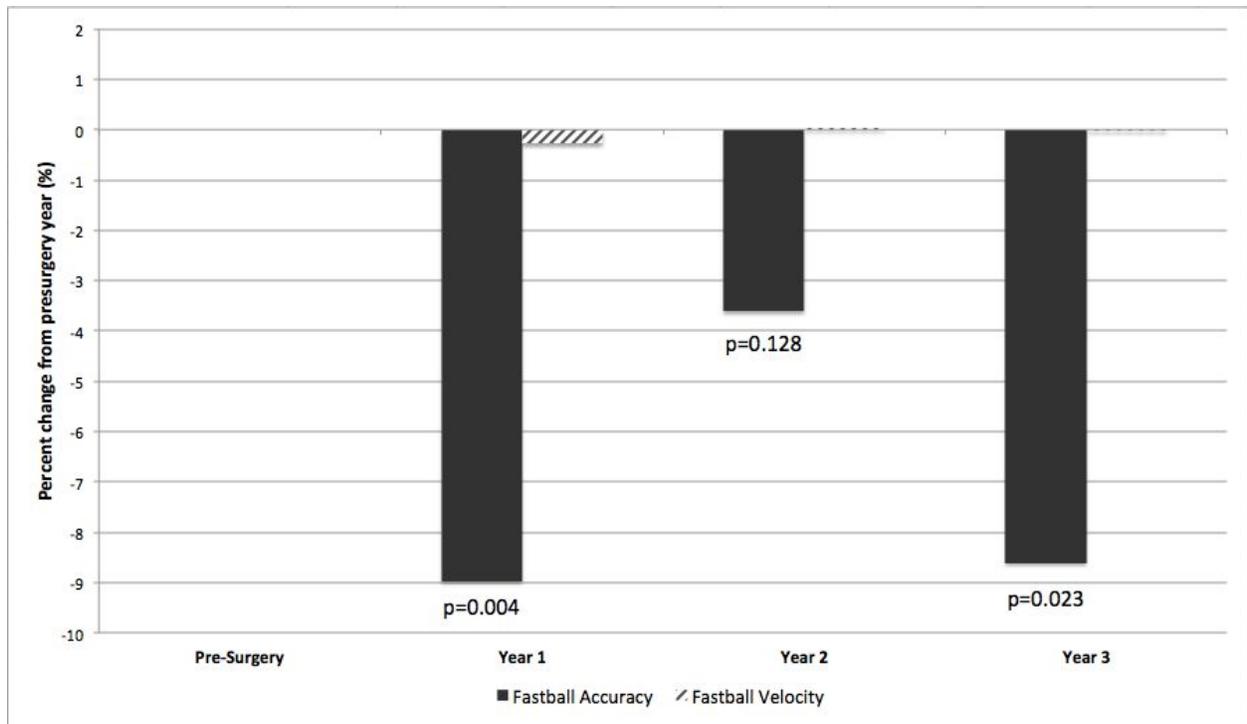


Figure 1: Fastball accuracy and velocity following ulnar collateral ligament reconstruction

In the year prior to 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 III).

Table III - Curveball Movement Following Ulnar Collateral Ligament Repair					
	Pre-Surgery n=27	Post-Surgery			P-Value*
		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	0.161
Vertical (cm)	34.5 ± .45	34.8 ± 4.8	34.3 ± 4.4	34.4 ± 4.4	0.937
Total Movement (cm)†	35.1 ± 4.5	35.3 ± 4.8	35.0 ± 4.4	35.1 ± 4.5	0.901

*P-Values calculated using repeated measures anova; †Total Movement calculated as the hypotenuse of a right triangle using the Pythagorean theorem

DISCUSSION

Pitching performance at the professional level carries broad implications for both the athlete and the organization for which they pitch. 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.

A number of studies have sought to analyze pitching performance following UCL reconstruction using a variety of different metrics including ERA, walks plus hits per inning pitched (WHIP), batting average against (BAA), and innings pitched. However, the current literature shows conflicting results. Makhni et al[Makhni AJSM 2014] reported significant postoperative declines in ERA, WHIP, and BAA compared to the year prior to surgery. These findings were contrary to prior findings from Gibson et al[Gibson AJSM 2007] who identified no such decline and Erickson et al[Erickson AJSM 2014] who noted an improvement in postoperative performance. While these studies all drew from similar sources of publically available data, differences in study design - such as exclusion criteria and follow-up time - likely resulted in the inconsistent findings. For example, Erickson et al[Erickson AJSM 2014] 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 al[Makhni AJSM 2014] reported only on players pitching in at least 10 games during a single season postoperatively. Both of these methodologies have their strengths and weaknesses, however evaluating which methodology is best is beyond the scope of this paper.

In the past, walks per 9 innings pitched (BB/9) has been used as a metric for evaluating pitching accuracy after UCL reconstruction[Jiang AJSM 2014]. While accuracy does contribute to BB/9, small changes in accuracy may not alter BB/9 despite having a meaningful impact on performance. Our finding that fastball accuracy decreases by a mean of more than 9% ($p=0.007$; approximately 3 cm per pitch) is a novel finding that has, to our knowledge, not been reported elsewhere. A pitcher's ability to locate his fastball is of great importance - nowhere more so than in Major League Baseball. Moreover, the finding that this decrease in accuracy persisted up to 3 years postoperatively may represent a long term sequelae for some pitchers that can significantly affect their ability to perform at the highest level of competition. We attempted to identify factors that predisposed pitchers to diminished postoperative accuracy and although a higher percentage of fastballs thrown in the pre-surgery year was trending toward predicting poor accuracy ($p=0.060$), no factors analyzed were found to be statistically significant.

In addition to accuracy, changes in fastball velocity can have a large impact on a pitcher's effectiveness. Jiang and Leland[Jiang AJSM 2014] analyzed fastball velocity following UCL reconstruction and found that velocity decreased post-operatively, but not above that of pair-matched controls. Our findings differ, indicating that fastball velocity does not change following UCL reconstruction. This may be a result of reporting on a 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[Vitale AJSM 2008].

The UCL provides stability to the elbow in order to offset the large valgus forces caused by overhead throwing.[Morrey AJSM 1983] While pitching kinematics of fastballs and

curveballs are slightly different, the valgus forces generated at the elbow are similar[Fleisig AJSM 2006]. While past studies have demonstrated a slight decrease in curveball velocity following UCL reconstruction [Jiang AJSM 2014], none to date has analyzed other characteristics of curveballs. Our finding that curveball movement is 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 mitt to the resultant pitch is a good metric to evaluate fastball accuracy, we did not believe it to be 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 in 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 indicate the UCL reconstructed elbow is able to resist physiologic valgus stress similarly to the native UCL.[Lynch AJSM 2013; Ciccotti JSES 2009] As such, it is likely that pitchers are able to generate the pre-injury levels of torque about the elbow needed to maintain professional level pitch movement and velocity. The decrease in fastball accuracy is likely a consequence of a number of factors including strength rehabilitation and conditioning. It is also possible that subtle changes in proprioception after reconstruction with denervated graft could alter a pitcher's ability to accurately throw a pitch.

There are several limitations of this study that warrant mention. 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 major league baseball (i.e. decreased accuracy, velocity, and/or movement). This would have the effect of under-representing the decreased performance reported. 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. 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 following UCL reconstruction. Additionally, 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. Finally, factors such as rehabilitation protocols and surgical techniques were not evaluated in this study. Previous studies have 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[Vitale AJSM 2008].

In conclusion, MLB pitchers returning from UCL reconstruction were found to have decreased fastball accuracy up to three 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 have a complete understanding of post-operative expectations.