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The effects of medial ulnar collateral ligament reconstruction on Major League pitching performance

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Background: Medial ulnar collateral ligament (MUCL) reconstruction is commonly performed on Major League Baseball (MLB) pitchers. Previous studies have reported that most pitchers return to presurgical statistical performance levels after MUCL reconstruction.
Methods: Pitching performance data—specifically, earned run average (ERA), walks and hits per inning pitched (WHIP), winning percentage, and innings pitched—were acquired for 168 MLB pitchers who had undergone MUCL reconstruction. These data were averaged over the 3 years before surgery and the 3 years after surgery and also acquired from 178 age-matched, uninjured MLB pitchers.
Results: Of the pitchers who had MUCL reconstruction surgery, 87% returned to MLB pitching. However, compared with presurgical data, pitching performance declined in terms of ERA ($P = .001$), WHIP ($P = .011$), and innings pitched ($P = .026$). Pitching performance also declined in the season before the surgery compared with previous years (ERA, $P = .014$; WHIP, $P = .036$; innings pitched, $P < .001$; winning percentage, $P = .004$). Compared with age-matched control pitchers, the MUCL reconstruction pitchers had significantly more major league experience at the same age ($P < .001$).
Conclusion: MUCL reconstruction allows most players to return to pitching at the major league level. However, after MUCL reconstruction, there is a statistically significant decline in pitching performance. There appears to be a statistically significant decline in pitching performance the year before reconstructive surgery, and this decline is also a risk factor for requiring surgery. In addition, there is an increased risk of MUCL reconstruction for pitchers who enter the major leagues at a younger age.
Level of evidence: Level III, Retrospective Case-Control Design, Treatment Study.

Keywords: Elbow; ulnar collateral ligament; injury; pitcher; baseball

The medial ulnar collateral ligament (MUCL) is the elbow's primary stabilizer to valgus stress between 20° and 120° of elbow flexion.[23] In particular, the anterior bundle of the MUCL is the primary checkrein to valgus stress.[20-23] During overhead baseball pitching, the elbow is subjected to a

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tremendous amount of valgus stress.[14] As a result of these repetitive stresses that occur during overhead throwing, it is not surprising that MUCL injures permeate the sport of baseball. Not only do these injuries cause pain and performance issues, but many require surgical intervention and may stop a player from being able to perform the sport altogether.

It has been well established that elbow injuries are common in overhead athletics such as baseball.[2,5,8] The first description of elbow injuries involved with playing baseball was by Bennett in 1941.[4] Later, in 1946, Waris was the first to describe MUCL injuries of the elbow when he evaluated a cohort of javelin throwers.[27] Historically, MUCL elbow injuries were career ending for baseball pitchers. This was the case until 1974, when Dr. Frank Jobe performed the first MUCL reconstruction in a professional pitcher by the name of Tommy John.[16] After surgical reconstruction, Tommy John went on to play 14 more seasons, winning 164 games, and finished his career with the record for the most seasons played, 26, which was later broken by Nolan Ryan.

Since the first "Tommy John" surgery in 1974, many professional pitchers have undergone MUCL reconstruction. A report by *USA Today* estimated that 1 in 9 Major League Baseball (MLB) pitchers in the early 2000s had undergone MUCL reconstruction.[9] Previous research suggests that approximately 80% to 90% of pitchers who have MUCL reconstruction return to their previous level of sports participation.[3,5,10,11,19,26] Pitching success by MLB pitchers who have undergone MUCL reconstruction has guided the public perception of this surgical procedure. In fact, many in the general public believe that MUCL reconstruction may make a pitcher even better than the preinjury level.[1]

Few studies have investigated the effects of MUCL reconstruction on statistical pitching performance in MLB pitchers.[11,15,19] These studies contrast in regard to performance outcomes after reconstruction. The first study, by Gibson et al, reported a trend toward return to presurgical statistical levels.[15] More recently, Erickson et al and Makhni et al described cohorts similar to this study's cohort with contrasting results; the study of Erickson et al demonstrated increased statistical performance markers after surgery, whereas the study of Makhni et al found decreased performance. Consequently, the primary objective of this study was to investigate the effects of MUCL reconstruction on pitching performance in a large cohort of MLB pitchers.[11,19] A secondary objective was to identify risk factors for MUCL injury in MLB.

Materials and methods

We conducted a retrospective case-control study.

MUCL-reconstructed pitchers

A cohort of 168 MLB pitchers who pitched in at least 1 major league game before undergoing MUCL reconstruction between the years of 1982 and 2010 were identified. Previous studies have used similar temporal cohorts.[5,11] Reconstructed pitchers were identified by team websites, press releases indicating that players had undergone MUCL reconstruction, personal websites, and baseball statistical websites including baseballreference.com. In finding the cohort, Tommy John surgery was considered an acceptable reference. To verify each pitcher's surgery date, we cross-referenced each player's reported surgical date with a gap in pitching statistics. We excluded players who had a second MUCL reconstruction and players who had not performed in the major leagues before their reconstruction.

For each pitcher, we recorded the year of MUCL reconstruction, the pitcher's age, and the number of years of MLB experience. In addition, we recorded each pitcher's height, weight, body mass index (BMI), pitching arm, and pitching role (starting pitcher vs relief pitcher). We also assessed whether the pitcher returned to MLB pitching after MUCL reconstruction.

Pitching statistics were evaluated in the 3 seasons before surgery and the 3 seasons after return from surgery. As in the previously published study of MLB pitchers,[15] 3 seasons worth of pitching data were used to attain an adequate trend in pitching performance. Only major league performance statistics were evaluated. The major league pitching data that were recorded for each pitcher included the number of wins, number of losses, winning percentage, earned run average (ERA), number of innings pitched, walks plus hits per inning pitched (WHIP), and salary. These data were averaged for the 3 years of pitching before MUCL reconstruction and for the 3 years of pitching after return from MUCL reconstruction.

Control pitchers

A blinded, randomized, age-matched control group of MLB pitchers was identified so that the MUCL reconstruction pitchers' performance could be compared with a representative level of MLB pitching performance during a similar period. Our method for selection of a control cohort was similar to that of previous literature.[6,11,15,24] The median year of surgery for the MUCL reconstruction pitchers was 2004.4, so we began the process of selecting the cohort of control pitchers by identifying each MLB team's opening day roster of pitchers for the 2004 and 2005 seasons. Two seasons of pitchers (2004 and 2005) were necessary to identify an adequate number of aged-matched control pitchers. For selection of the control pitchers, every fifth player was selected from the complete roster of all opening day pitchers for the 2004 and 2005 seasons and age matched with a corresponding MUCL reconstruction pitcher. This process of identifying the fifth name from the complete roster of pitchers continued until 178 age-matched controls had been selected. This process required just more than 7 cycles through the 2004 and 2005 rosters. Pitchers with a known history of MUCL reconstruction were excluded from being part of the control cohort. No other exclusion criteria were used for the control pitchers.

For the control pitchers, we recorded age, MLB experience, height, weight, BMI, pitching arm, and pitching role (starting pitcher vs relief pitcher) in their index year, that is, the roster year (2004 or 2005) from which they were selected. Pitching performance was then determined for each control pitcher with only major league data 3 years before the index year and 3 years after the index year.

Statistical analysis

We analyzed both pre-index and post-index performance measures of each MLB pitcher in the reconstructed and control groups by paired analysis. Continuous variables were checked for normality

with skewness, kurtosis, Shapiro-Wilk tests, and stem-and-leaf plots. When normality assumptions were violated, univariate Wilcoxon 2-sample tests were used; otherwise, 2-group t tests were used to compare groups. χ^2 tests were used to compare categorical variables between groups. Univariate paired analyses were done with the Wilcoxon signed rank test. Game outcomes were compared across time points by repeated-measures mixed models to account for the lack of independence in taking multiple observations from the same subject. A generalized estimating equation (GEE) model with the link function and logistic distribution was used to identify risk factors for MUCL reconstruction. GEE was used because repeated-measures data from the 3 presurgery time points were included as possible risk factors. The initial model included age, pitching role (starting pitcher vs relief pitcher), presurgery ERA, presurgery WHIP, presurgery innings pitched, and presurgery winning percentage. Variables were reduced by backward selection. When pair-wise comparisons were done, a Tukey-Kramer adjustment was made to control the type I error rate (also known as α, or error of the first kind). The risk of this error increases with multiple comparisons, and so an adjustment was requested within the SAS code of the GEE models. To assess the relationship between age at surgery and innings pitched, a nonparametric Spearman correlation coefficient was used. Spearman correlation was used because of the non-normal distribution of age and the ordinal nature of innings pitched. Data were generated by SAS software (SAS Institute Inc, Cary, NC, USA).

Results

Player characteristics

Table I reports the characteristics of the MUCL reconstruction pitchers and the control pitchers. Player weight between the cohorts was found to be significantly different and consequently so was BMI; the average weight and BMI of the MUCL reconstruction pitchers were 94.1 kg (range, 72.6-136.1 kg) and 26.3 (range, 20.3-31.9), respectively, compared with 91.8 kg (range, 68.0-122.8 kg) and 25.6 (range, 20.6-36.5) for the controls ($P = .007$ and .012, respectively). MUCL reconstruction pitchers also had a higher percentage of starters, 63.7%, compared with 35.4% of controls ($P < .001$). Similar to the controls, 232 major league pitchers (38%) were listed as starting pitchers in 2005.[13] The reconstructed pitchers had an average of 6.2 years (range, 1-26 years) of MLB pitching experience before surgery, whereas the control pitchers had an average of 3.9 years (range, 1-20 years) of MLB experience ($P = .001$). No statistically significant differences were detected between the MUCL reconstruction pitchers and the control pitchers in terms of age (cases, 26.3 years [range, 17-48]; controls, 26.2 years [range, 19-43]; $P = .648$), height (cases, 1.9 meters [range, 1.8-2.1]; controls, 1.9 meters [range, 1.8-2.1]; $P = .216$), or percentage of right-handed pitchers (cases, 73.8%; controls, 72%; $P = .652$).

Return to MLB pitching

Of the MUCL reconstruction pitchers, 87% returned to MLB pitching.

Table I Means (standard deviations) and comparisons of characteristics between the MUCL reconstruction pitchers and the control pitchers

Variable	Control pitchers	MUCL reconstruction pitchers	*P* value
Age (years)	26.1 (4.4)	26.3 (4.8)	.648
Height (m)	1.9 (0.1)	1.9 (0.1)	.216
Weight (kg)	94.1 (10)	91.8 (9.4)	.007
BMI	26.3 (2.4)	25.7 (2.1)	.012
Right handed (%)	73.6	71.4	.652
Starting pitcher (%)	35.4	63.7	<.001
MLB experience (years)	3.9 (3.8)	6.2 (4.5)	.001

MUCL, medial ulnar collateral ligament; *BMI*, body mass index; *MLB*, Major League Baseball.

Table II Means (standard error) and comparisons of pitching performance before and after MUCL reconstruction

Variable	Before surgery	After surgery	*P* value
ERA	4.15 (0.13)	4.74 (0.14)	.001
WHIP	1.40 (0.03)	1.48 (0.03)	.011
Innings pitched	59.81 (4.61)	50.28 (3.92)	.026
Winning percentage	45 (2)	42 (2)	.145

MUCL, medial ulnar collateral ligament; *ERA*, earned run average; *WHIP*, walks and hits per inning pitched.

Presurgery vs postsurgery pitching performance

Compared with presurgical data, pitching performance declined after MUCL reconstruction (Table II). Specifically, worse pitching performance was reported after surgery in terms of ERA (before surgery, 4.15; after surgery, 4.74; $P = .001$), WHIP (before surgery, 1.40; after surgery, 1.48; $P = .011$), and innings pitched (before surgery, 59.81; after surgery, 50.28; $P = .026$). Winning percentage also decreased from 45% before MUCL reconstruction to 42% after reconstruction, but this change was not found to be statistically significant ($P = .145$). Interestingly, salary increased from $1.9 million per year before MUCL reconstruction to $2.0 million per year after reconstruction, but this change was also not found to be statistically significant ($P = .837$).

Presurgery pitching performance

There were significant changes in the reconstructed group's pitching performance in the year leading up to MUCL reconstructive surgery compared with the 2 previous years (Table III and Table IV). The year before surgery, pitchers' ERA, WHIP, innings pitched, and winning percentage were

Table III Means (standard error) and comparisons of pitching performance between the MUCL reconstruction pitchers (MUCL) and control pitchers (CTL) from the 3 years before the surgery/index year to the 3 years after the surgery/index year

Year	Cohort	ERA	WHIP	Innings pitched	Winning percentage
3 years before	MUCL	4.00 (0.21)*	1.36 (0.03)*	109.66 (8.97)*	48 (3)*
	CTL	4.94 (0.42)	1.45 (0.05)	90.94 (9.23)	54 (3)
	P value	.112	.155	.029	.153
2 years before	MUCL	3.91 (0.20)*	1.36 (0.03)*	103.71 (8.00)*	49 (3)*
	CTL	4.95 (0.27)	1.52 (0.04)	66.04 (7.88)	51 (3)
	P value	.006	.006	<.001	.761
1 year before	MUCL	5.14 (0.41)	1.62 (0.10)	60.11 (5.27)	37 (3)
	CTL	5.10 (0.42)	1.49 (0.08)	74.11 (5.65)	51 (3)
	P value	.942	.258	.080	<.001
Surgery year (MUCL pitchers) or index year (CTL pitchers)					
1 year after	MUCL	4.77 (0.28)	1.47 (0.05)	48.35 (4.24)	39 (3)
	CTL	5.69 (0.33)	1.60 (0.05)	78.80 (5.18)	47 (3)
	P value	.050	.077	<.001	.025
2 years after	MUCL	4.83 (0.21)	1.49 (0.04)	78.61 (5.91)†	43 (2)
	CTL	4.95 (0.22)	1.50 (0.04)	79.65 (5.89)	46 (2)
	P value	.723	.855	.903	.361
3 years after	MUCL	4.57 (0.22)	1.44 (0.03)	82.88 (6.99)†	44 (3)
	CTL	5.04 (0.27)	1.52 (0.04)	83.60 (6.60)	52 (2)
	P value	.186	.123	.374	.043

ERA, earned run average; *WHIP*, walks and hits per inning pitched.
* Significantly different from 1 year before surgery ($P < .05$).
† Significantly different from 1 year after surgery ($P < .05$).

Table IV Means (standard error) and comparison of statistics of the reconstructed players based on years before surgery

	Means (SE)	Comparison	*P* value
ERA			
1 year before	5.14 (0.41)	1 vs 2	**.010**
2 years before	3.91 (0.20)	1 vs 3	**.037**
3 years before	4.00 (0.21)	2 vs 3	.946
WHIP			
1 year before	1.62 (0.10)	1 vs 2	**.028**
2 years before	1.36 (0.03)	1 vs 3	.055
3 years before	1.36 (0.03)	2 vs 3	.994
Innings			
1 year before	60.11 (5.27)	1 vs 2	**<.001**
2 years before	103.71 (8.00)	1 vs 3	**<.001**
3 years before	109.66 (8.97)	2 vs 3	.366
Win %			
1 year before	0.37 (0.03)	1 vs 2	**.009**
2 years before	0.49 (0.03)	1 vs 3	**.024**
3 years before	0.48 (0.03)	2 vs 3	.996
Salary			
1 year before	2,648,404 (368,964)	1 vs 2	.132
2 years before	2,225,711 (334,835)	1 vs 3	**<.001**
3 years before	1,621,637 (328,970)	2 vs 3	**<.001**

SE, standard error; *ERA*, earned run average; *WHIP*, walks and hits per inning pitched.
Bolded values indicate statistically significant values (i.e., $P < .05$).

all significantly worse than in the previous 2 seasons. In contrast, salary increased over the 3 seasons before surgery ($P < .001$).

Postsurgery pitching performance

The study failed to detect any changes in ERA ($P = .635$), WHIP ($P = .363$), or winning percentage ($P = .355$) in the 3 years after MUCL reconstruction (Table III). However, the number of innings pitched in the second and third years after surgery was significantly greater than in the first year after surgery ($P < .001$; Table III). Salary increased significantly from the second to the third year after MUCL reconstruction ($P = .046$).

MUCL reconstruction pitchers vs control pitchers

Before MUCL reconstruction, the MUCL reconstruction pitchers had better pitching performance than the control pitchers at 3 years and 2 years before surgery (Table III). Specifically, the MUCL reconstruction pitchers demonstrated significantly lower ERA at 2 years before surgery ($P = .006$; Fig. 1), lower WHIP at 2 years before surgery ($P = .006$; Fig. 2), and more innings pitched at 3 years ($P = .029$) and 2 years ($P < .001$) before surgery (Fig. 3). However, the control pitchers had a higher winning percentage than the MUCL reconstruction pitchers at 2 years before surgery ($P < .001$).

After MUCL reconstruction, the MUCL reconstruction pitchers had a lower ERA than that of the control pitchers in the first year after surgery ($P = .05$; Table III and Fig. 1). However, the control pitchers had a

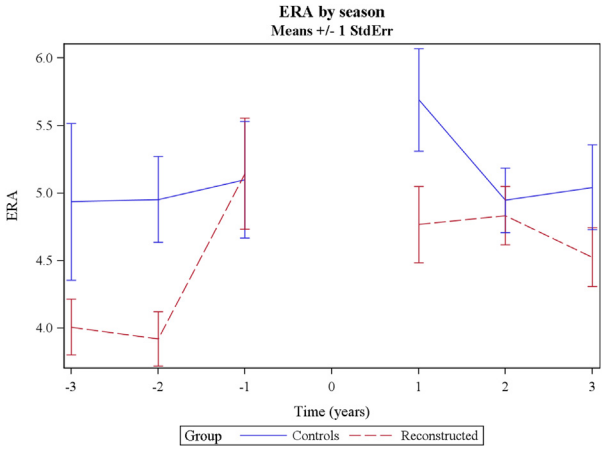

Figure 1 The MUCL reconstruction pitchers' average earned run average (ERA) in the 3 years after surgery (4.74 ± 0.14) was significantly higher than their average ERA in the 3 years before surgery (4.15 ± 0.13; $P = .001$). *Statistically significant difference between MUCL reconstruction pitchers and control pitchers ($P < .05$).

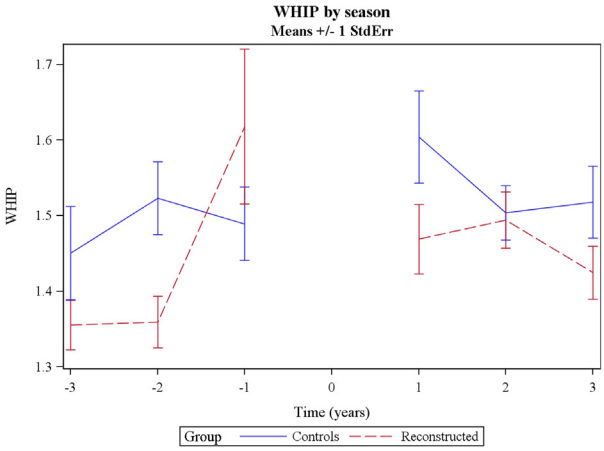

Figure 2 The MUCL reconstruction pitchers' average walks and hits per inning pitched (WHIP) in the 3 years after surgery (1.48 ± 0.03) was significantly higher than their average WHIP in the 3 years before surgery (1.40 ± 0.03; $P = .011$). *Statistically significant difference between MUCL reconstruction pitchers and control pitchers ($P < .05$).

significantly higher number of innings pitched ($P < .001$) and a higher winning percentage ($P = .025$) than the MUCL reconstruction pitchers (Table III and Fig. 3). The study failed to detect any differences between the 2 pitching cohorts in the second year after surgery (Table III). In the third year after surgery, the control pitchers had a significantly higher winning percentage than the MUCL reconstruction pitchers did ($P = .043$; Table III and Fig. 3). The study failed to detect any significant difference in salary between the MUCL reconstruction pitchers and the control pitchers at any presurgical or postsurgical time point.

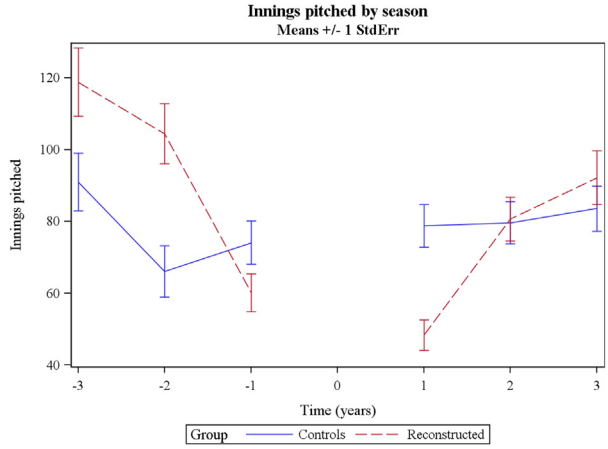

Figure 3 The MUCL reconstruction pitchers' average number of innings pitched in the 3 years after surgery (50.28 ± 3.92) was significantly lower than their average number of innings pitched before surgery (59.81 ± 4.61; $P = .011$). *Statistically significant difference between MUCL reconstruction pitchers and control pitchers ($P < .05$).

Table V Predictors of MUCL reconstruction surgery

Variable	Odds ratio	95% CL	Z	*P* value
ERA	0.96	0.92, 0.99	−2.28	.023
WHIP	1.17	1.04, 1.32	2.57	.010
Winning percentage	0.65	0.49, 0.86	−2.96	.003
MLB experience (years)	1.16	1.07, 1.25	3.66	<.001
Starting pitcher	1.89	1.22, 2.94	2.88	.004

MUCL, medial ulnar collateral ligament; *CL*, confidence limits; *ERA*, earned run average; *WHIP*, walks and hits per inning pitched; *MLB*, Major League Baseball.

Indicators for MUCL reconstruction

The odds of surgical MUCL reconstruction increased with higher WHIP (odds ratio [OR], 1.17; 95% confidence interval [CI], 1.04-1.32; $P = .010$), decreased with increased win percentage (OR, 0.65; 95% CI, 0.49-0.86; $P = .003$), increased with increased MLB years (OR, 1.16; 95% CI, 1.07-1.25; $P < .0001$), and increased for starting pitchers (OR, 1.89; 95% CI, 1.22-2.94; $P = .004$). Interestingly, the odds of surgery reconstruction decreased with increased ERA (OR, 0.96; 95% CI, 0.92-0.99; $P = .023$).

An important predictor of surgery was that of MLB experience (Table V). Approximately 60% of pitchers requiring Tommy John surgery had the surgery within the first 5 years of their career (Fig. 4). Compared with age-matched controls, the reconstructed pitchers had more major league innings pitched at 3 years ($P = .029$) and 2 years ($P < .001$) before surgery (Table III) and more years of pitching in MLB at the same age ($P = .001$; Table I).

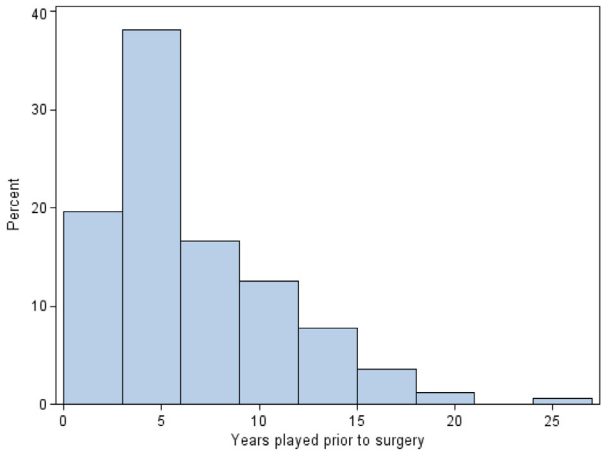

Figure 4 Years played in the major leagues before surgery.

Discussion

A variety of studies have shown that a very high percentage of players return to their sport, at the same level of competition, after MUCL reconstruction. Cain et al published the results of a series of 743 baseball players, levels high school through professional, who underwent MUCL reconstruction.[5] In this series, 83 players were professional pitchers. They had at least a 2-year follow-up and found that 83% of players returned to the same level or higher in their sport. Similarly, Koh et al published a cohort of 20 professional and collegiate baseball players with a mean follow-up of 41.9 months. They found that 94% returned to the same level of competition with limited adverse effects.[17] Dodson et al presented a series of 100 overhead throwing athletes; 96 of the 100 athletes were baseball players and 91 were pitchers. With a 36-month follow-up, they found a 90% return to the previous level or a higher level of sport.[10] Three previous reviews have dealt exclusively with MLB pitchers.[11,15,19] These studies reported a rate of return to professional pitching after MUCL reconstruction of 80% to 83%. Interestingly, Erickson et al reported 97.2% of pitchers making it back to the major or minor leagues.[11] Similar to these studies, this current study is consistent with previous findings in reporting that 87% of the MUCL reconstruction pitchers returned to MLB pitching.

An interesting finding in this study is that reconstructed pitchers' statistical performance declined significantly in the year before they underwent reconstructive surgery. Specifically, in the year before surgery, the pitchers had a higher ERA, higher WHIP, lower number of innings pitched, and lower winning percentage than in the 2 and 3 years before surgery (Table IV). These findings make intuitive sense as these pitchers most likely damage or injure the arm in the season before reconstructive surgery. Cain et al found that the diagnosis of MUCL injury in their cohort took approximately 6.4 months from onset of symptoms, with surgery performed 7.1 months after symptoms began.[5] These data suggest that a clinician should suspect MUCL injury if a pitcher begins to have declining statistics with medial elbow pain.

There have been 3 previously published studies that have reported objective pitching data both before and after MUCL reconstructive surgery.[11,15,19] In the study by Gibson et al, data were analyzed from a cohort of 56 MLB pitchers.[15] Similar to the current study, they analyzed the pitching data of 3 years before and 3 years after MUCL reconstruction and compared this group with a control group of other MLB pitchers. They found that pitchers who successfully returned to major league play after MUCL reconstruction experienced no significant decline from pre-index performance. More recently, Erickson et al and Makhni et al published cohorts of 178 pitchers and 147 pitchers, respectively.[11,19] In contrast to this study, Erickson's group found improvements in many statistical performance markers after reconstruction. Compared with this current study, their cohort was slightly larger and the average age at reconstruction was 2.2 years older (28.6 years vs 26.4 years), and they did not evaluate performance 3 years before and 3 years after surgery. Beyond methodologic differences, a potential reason for differences in results may be due to our finding that reconstructed pitchers may have decreased statistical performance in the year before surgery. If pre-reconstruction statistics are taken only from the year before reconstructive surgery and compared with post-surgical performance statistics, there could potentially be confounding to the trend of increased performance after reconstruction. Similar to our results, Makhni et al evaluated 147 MLB pitchers who underwent MUCL reconstruction and found a decrease in statistical performance after reconstruction, including ERA and WHIP.[19]

Our results suggest that the MUCL reconstruction pitchers had statistically significant worse ERA, WHIP, and innings pitched than presurgical statistics (Table II). In addition, the data also suggested a trend toward a lower winning percentage, although this decrease after surgery was not statistically significant ($P = .145$). The decline in pitching performance of the MUCL reconstruction pitchers could also be observed in comparison with the control pitchers. The MUCL reconstruction pitchers were statistically better than the controls in regard to ERA, WHIP, innings pitched, and win percentage in the 3 years and 2 years before surgery (Table III). However, after surgery, the control pitchers were superior to the MUCL reconstruction pitchers or no difference was detected between the pitching cohorts in almost every measure of pitching performance (Table III). The lone exception to these findings is that the MUCL reconstruction pitchers had a significantly lower ERA than that of the controls in the first year after surgery ($P = .050$; Table III). Taken together, these findings indicate that pitching performance declines after MUCL reconstruction and does not return to preinjury levels. Although there is a very high level of return to play (87%), this study presents evidence that suggests pitchers never

make it back to their same level of pitching performance after MUCL reconstruction.

Public perception of MUCL reconstruction is extremely positive. For example, Ahmad et al reported a study in 2012 that directly assessed the public perception of MUCL reconstruction.[1] They surveyed 260 participants that included 53 youth players, 53 high-school players, 83 collegiate players, 15 coaches, and 36 parents. They found that 42% of high-school athletes, 19% of collegiate athletes, 20% of coaches, and 35% of parents believed that MUCL reconstruction would result in an overall increase in pitching performance beyond that of the preinjury level. The current study presents data contradicting the public perception that MUCL reconstruction will allow players to perform at an even higher level.

The mechanism of MUCL injury is not fully understood, but it is generally believed that this injury is the result of overuse (e.g., number of pitches, number of games pitched, insufficient recovery) or excessive valgus stresses on the elbow due, perhaps, to pitching velocity or changes in glenohumeral joint motion.[3,7,12,13,18,25,26] Gibson et al reported that the risk of MUCL reconstruction was associated with better pitching performance (specifically, lower ERA and lower WHIP), suggesting that higher levels of pitching performance may be associated with greater functional demands on the MUCL.[15] Consistent with the findings reported by Gibson et al, the current study indicates that lower ERA (i.e., better pitching performance) was associated with an increased risk of MUCL reconstruction (Table V). However, a peculiar finding of this study was that a higher WHIP and lower winning percentage (i.e., worse pitching performance) were also associated with an increased risk of MUCL reconstruction (Table V). These contradictory findings make it unclear whether better or worse measures of pitching performance are risk factors for MUCL reconstruction. One potential explanation is that better pitchers (i.e., those with a lower ERA) place higher functional demands on the elbow, which, when coupled with overuse, may lead to the gradual onset of injury, lower measures of performance (i.e., higher WHIP and lower winning percentage), and the eventual need for MUCL reconstruction. This hypothesis is certainly speculative and not directly supported by the findings of this study. However, reconciling these seemingly contradictory findings regarding risk factors for MUCL reconstruction is difficult because the specific mechanism of MUCL injury is not fully understood and the extent to which measures of pitching performance (i.e., ERA, WHIP, winning percentage) are associated was not assessed in this study.

Sixty percent of pitchers in our cohort required surgery within their first 5 years in the MLB. In addition, the reconstructed pitchers had more major league innings pitched at 3 years ($P = .029$) and 2 years ($P < .001$) before surgery (Table III) and more years of MLB pitching compared with age-matched control pitchers ($P = .001$; Table I). These data suggest that pitchers who begin performing at the major league level at a younger age have an increased risk for MUCL reconstruction surgery ($P < .001$; Table V).

As with any observational study such as this, there is the potential for confounding and bias. Potential areas of bias include the information bias from potential missing data as we used an internet-based review method for evaluation of player statistics. There is confounding bias in assessing for associated risk factors. This could lead to incorrect and misguided postulation regarding potential risks. Randomized, prospective trials would be necessary to better assess these risks. Another potential limitation of this study was the use of an age-matched control group. It may have been ideal to select the control group on the basis of years of professional experience and pitching role, but selection of a randomized and blinded control group on the basis of age was necessary to generate the appropriate sample size and to minimize selection bias. Also, the temporal length of our cohort, 19 years, although similar to previously published data, may be limited as operative technique and rehabilitation protocols have changed and evolved with time.[5,11,19] Future studies evaluating statistical performance markers from different time periods would be beneficial. In addition, there is a large number of pitching performance statistical markers that could have been selected to evaluate pitching performance that we did not use in this study. It is possible that performance markers other than those used in this study may better evaluate pitchers' performances.

Conclusions

This study presents data from a large cohort of MLB pitchers who have undergone MUCL reconstruction. The results of this study suggest that MUCL reconstruction allows most MLB pitchers to return to pitching at the major league level. There appears to be a statistically significant decline in pitching performance with respect to certain pitching metrics in the year before reconstructive surgery. After MUCL reconstruction, there seems to be a statistically significant decline in pitching performance that improves in the second and third postoperative years but does not fully return with respect to certain pitching metrics. There may be an increased risk of MUCL injury requiring reconstruction for pitchers who begin performing at the major league level at a younger age.

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