

Prevalence of Ulnar Collateral Ligament Surgery in Professional Baseball Players

Stan A. Conte,^{*†} PT, DPT, ATC, Glenn S. Fleisig,[‡] PhD, Joshua S. Dines,[§] MD, Kevin E. Wilk,^{‡||} PT, DPT, Kyle T. Aune,[‡] MPH, Nancy Patterson-Flynn,[†] MS, ATC, and Neal ElAttrache,^{†¶} MD

Investigation performed at the Los Angeles Dodgers, Los Angeles, California, USA

Background: While the high rate of ulnar collateral ligament (UCL) injuries in professional baseball is widely discussed in the media and medical literature, the actual prevalence of UCL reconstruction has not been documented.

Hypothesis: The prevalence of UCL reconstruction will be higher among pitchers than nonpitchers, and Major League Baseball (MLB) pitchers will have a higher prevalence than will minor league pitchers.

Study Design: Descriptive epidemiology study.

Methods: An online questionnaire was distributed to all 30 MLB organizations. Certified athletic trainers from each team administered the questionnaire to all players in the organization, including major league players and 6 levels of minor league players. Demographic data were compared between major and minor league players. Continuous variables (age, years of professional baseball, country of origin, etc) were compared with Student *t* tests ($P < .05$). Categorical variables (level, position, etc) were compared using chi-square analysis ($P < .05$).

Results: A total of 5088 professional baseball players (722 major league and 4366 minor league) participated in the survey. Pitchers represented 53% of all players, and 497 players reported at least 1 UCL reconstruction, demonstrating a prevalence rate of 10% (497 of 5088). Pitchers reported a significantly higher prevalence of UCL reconstruction (16%; 437 of 2706) than nonpitchers (3%; 60 of 2382; $P < .001$). Among major league pitchers, 25% (96 of 382) had a history of UCL reconstruction, while minor league pitchers showed a 15% (341 of 2324) prevalence ($P < .001$). Major league pitchers were also significantly older (28.8 ± 3.9 years) than minor league pitchers (22.8 ± 3.0 ; $P < .001$). The majority of major leaguers (86%) had their UCL reconstruction as professional pitchers, whereas the majority of minor league pitchers (61%) underwent their UCL reconstruction during high school and college ($P < .001$). The rates of UCL revision, prior elbow surgery, prior shoulder surgery, and types of UCL graft were similar between the major league and minor league pitchers. No difference in prevalence was shown between pitchers born in the United States versus Latin American countries.

Conclusion: Pitchers have a high prevalence of UCL reconstruction in professional baseball, with 25% of major league pitchers and 15% of minor league pitchers having a history of the surgery.

Keywords: UCL; ulnar collateral ligament revision; Tommy John surgery; pitchers; Major League Baseball

Throwing elbow injuries are common at all levels of baseball, and recent reports suggest that these injuries may even be on the rise.^{4,11,14} Studies utilizing the Major League Baseball (MLB) disabled list have shown that elbow injuries represent

between 16% and 22% of all MLB injuries.^{5,19} These injuries have been shown to result in an average of 4451 lost days per MLB season.⁵ Ulnar collateral ligament (UCL) injuries are a common problem in the throwing athlete and account for a large percentage of days lost because of elbow injury. By far, baseball exhibits the highest incidence of UCL injuries requiring surgical reconstruction.^{4,12} Throwing is particularly stressful on the UCL, placing large amounts of valgus torque across the medial elbow.^{3,8,10,11,18} This opening stress of the medial elbow peaks near the instant of maximum shoulder external rotation and the arm's acceleration phase of throwing.^{3,8,10,11,18} This stress appears to be the greatest in professional baseball pitchers.^{11,13}

Numerous studies have documented successful outcomes in both the short term and the long term after UCL reconstruction in baseball players and other athletes, with return-to-play rates approaching as high as 90%.^{2,4,6,7,9,14,15,17} A recent study by Makhni et al¹⁷

*Address correspondence to Stan A. Conte, PT, DPT, ATC, Los Angeles Dodgers, 1000 Elysian Park, Los Angeles, CA 90045, USA (email: sconcept@aol.com).

[†]Los Angeles Dodgers Baseball Organization, Los Angeles, California, USA.

[‡]American Sports Medicine Institute, Birmingham, Alabama, USA.

[§]Hospital for Special Surgery, New York, New York, USA.

^{||}Champion Sports Medicine, Birmingham, Alabama, USA.

[¶]Kerlan-Jobe Orthopaedic Clinic, Los Angeles, California, USA.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

reported that among MLB players, performance declines after UCL reconstruction similar to the typical decline over time of a cohort of age-matched healthy pitchers. Pitchers with a history of UCL reconstruction also exhibit an increased risk of future time on the disabled list for elbow injury. Controversy exists among baseball players, baseball organizations, the medical community, mass media, and the general public about the actual prevalence of UCL reconstruction in baseball, how the numbers have increased in recent years, why so many players (particularly pitchers) are injuring their elbows and tearing their UCLs, and whether pitchers are too anxious to have a UCL reconstruction. Surprisingly, the prevalence of UCL reconstructive surgery in baseball has not been documented.

Therefore, the purpose of this study was to document the prevalence of UCL reconstructions in professional baseball players. It was hypothesized that the prevalence would be much higher among pitchers when compared with nonpitchers. Data were also analyzed with respect to playing level, age, and country of origin. These findings can improve our understanding of UCL injuries in professional baseball, including the subgroups particularly affected, as well as serve as a baseline to assess whether the prevalence of UCL reconstructions decreases or increases in the future.

METHODS

This study was conducted after it was reviewed and approved by MLB and the Major League Baseball Players Association. An online questionnaire for minor league players not on the 40-man roster was distributed to all 30 MLB organizations during July and August of the 2012 baseball season. A similar online questionnaire was also sent to all 30 MLB organizations in April and May of 2013 for the players on the 40-man roster. Certified athletic trainers from each team administered the questionnaire to all players in the organization, including the major league players and 6 levels of minor league players: AAA, AA, High A, Low A, High Rookie, and Low Rookie. The questionnaire consisted of 8 to 26 questions based on whether the player had no history of UCL reconstruction (8 questions), a single UCL reconstruction (20 questions), or multiple UCL reconstructions (26 questions). Two versions of the questionnaire were available per the player's preferred language, English or Spanish. For inclusion in the study analysis, players were required to answer all applicable questions pertinent to their subgroup.

Statistical analyses were performed with JMP 10 (SAS Institute Inc). Demographic data were compared between major league and minor league players. Preliminary analysis confirmed that pitchers were much more likely to have undergone previous UCL reconstruction ($P < .001$), and for this reason UCL reconstruction prevalence was further analyzed among only pitchers. Variables were also compared between major league and minor league pitchers. Continuous variables (age, years of professional baseball, etc) were compared with Student t tests ($P < .05$). All categorical variables (level, position, etc) were compared using a chi-square analysis ($P < .05$).

TABLE 1
Demographics of All Players^a

	Major League Players (n = 722)	Minor League Players (n = 4366)	P
Age, y	28.8 ± 3.9	22.8 ± 3.0	<.001
Professional baseball, y	8.8 ± 4.0	3.9 ± 2.9	<.001
Current age, y			<.001
<21	<1 (3)	20 (858)	
21-25	18 (128)	65 (2858)	
26-30	54 (387)	13 (548)	
31-35	22 (157)	2 (86)	
>35	7 (47)	0 (16)	
Position			.87
Pitcher	53 (382)	53 (2324)	
Nonpitcher	47 (340)	47 (2042)	
Country of origin			.14
United States	73 (526)	71 (3119)	
Dominican Republic	10 (72)	13 (533)	
Venezuela	8 (57)	7 (286)	
Other	9 (67)	9 (407)	

^aValues are presented as mean ± SD or % (n).

RESULTS

Demographics of the participants in this investigation are shown in Table 1. There were 5088 professional baseball players, including 722 major league players and 4366 minor league players. An estimated 5700 players were offered to complete the survey, thus resulting in an 89% response rate. The minor league population consisted of 643 AAA, 673 AA, 1739 A, and 1311 Rookie players. The major league players were significantly older and had more professional baseball experience than did the minor league players. Pitchers represented 53% of all players. The majority of players were from the United States (US), with a significant minority of players from the Dominican Republic and Venezuela.

Among the 5088 respondents, 497 had undergone at least 1 UCL reconstruction. Thus, the prevalence of professional baseball players including pitchers and position players who had UCL surgery was 10% (497 of 5088). The prevalence of UCL reconstruction was much higher in pitchers (16%) than in nonpitchers (3%). Among pitchers, the prevalence of UCL reconstruction was higher in major league pitchers, older pitchers, and current relief pitchers (Table 2). There was no difference in prevalence between left- and right-handed pitchers nor between US-born and international pitchers. When the subgroups of international pitchers born in the Dominican Republic or all Latin American countries were compared with pitchers from the US, there was still no difference in UCL reconstruction prevalence.

As shown in Table 3, there were several differences between the major league and minor league pitchers with a history of UCL reconstruction. The major league pitchers were significantly older ($P < .001$) with more years of professional baseball experience. The average age for first UCL reconstruction was also higher in major league

TABLE 2
Prevalence of Ulnar Collateral Ligament
Reconstruction Among Pitchers

	Prevalence, % (n)	P
Current level		<.001
Major league	25 (96 of 382)	
Minor league	15 (341 of 2324)	
Current age, y		<.001
21-25	14 (235 of 1698)	
26-30	27 (132 of 484)	
31-35	36 (39 of 108)	
Current role		.002
Starting pitcher	14 (161 of 1176)	
Relief pitcher	18 (276 of 1530)	
Throwing hand		.26
Right-handed	17 (328 of 1969)	
Left-handed	15 (109 of 737)	
Country of origin		
United States	16 (322 of 2007)	
Not United States	16 (115 of 699)	.81 ^a
Latin America	16 (91 of 577)	.87 ^a
Dominican Republic	16 (54 of 343)	.89 ^a

^aP value based on comparison with "United States."

pitchers. The majority of major leaguers (86%) had their UCL reconstruction as professional pitchers, whereas the majority of minor league pitchers (61%) underwent their UCL reconstruction during high school. The rates of UCL revision, prior elbow surgery, prior shoulder surgery, and types of UCL graft were similar between the major league and minor league pitchers. Ulnar nerve transposition was performed in a majority of pitchers who underwent UCL reconstruction (71%). Other commonly performed concomitant procedures were bone spur removal (33% of all pitchers) and loose body removal (14%).

The outcome results portion of the questionnaire for pitchers who underwent UCL reconstruction are shown in Table 4. All players in the UCL reconstruction group were asked about their perception regarding their current throwing velocity. Because previous studies suggested that it takes 12 to 18 months for players to return to their previous levels of play after UCL reconstruction, responses were excluded for this question among players who had undergone their primary UCL reconstruction during the past 12 months. When asked, "If you had to, would you have Tommy John surgery again?" 72% of the players in the UCL reconstruction group responded that they would, 17% said that they would not, and 11% were unsure. Minor league pitchers were more likely than major league pitchers to have self-reported higher throwing velocity after their surgery but were less likely to state that they would undergo UCL reconstruction again.

DISCUSSION

Despite an increasing body of literature being written on the topic of UCL reconstructions in baseball players, there

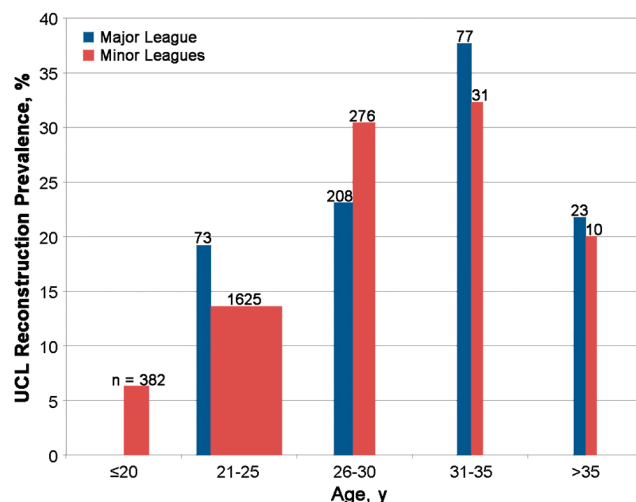


Figure 1. Prevalence of ulnar collateral ligament (UCL) reconstruction for various age groups and levels. The height of each column represents the prevalence of UCL reconstruction among pitchers in each league within each age group, and the width of each column is representative of the total number of pitchers in each league within each age group. UCL prevalence increased with age group (21-25 vs 26-30 vs 31-35 years), with no interaction between levels (major vs minor leagues) within each age group.

has not been a study documenting the prevalence of UCL reconstructive surgery among professional baseball players. Single-center studies have done an excellent job in reporting their follow-up findings, with Cain et al⁴ reporting on the largest number of athletes after UCL reconstruction to date.^{2,4,6,7,16,17} However, even the Cain et al study did not elucidate the number of players in professional baseball who had undergone reconstruction of their UCLs. In the current investigation, the overall prevalence of UCL reconstruction among professional baseball players was 10%. Not surprisingly, the majority of the UCL surgeries (88%) were performed on pitchers. In analyzing only pitchers, 16% had UCL reconstruction surgery. During the time of this study, the prevalence was 14% (161 of 1176) among starting pitchers and 18% (276 of 1530) among relief pitchers. These group percentages were surprisingly similar given that there is so much debate over which type of pitcher is at higher risk to incur a tear of his UCL. Although the prevalence of UCL reconstruction was higher among active relief pitchers when compared with active starting pitchers, 51% (220 of 433) of the pitchers with a history of UCL reconstruction were starters at the time of injury. Sixty-one current relief pitchers were starting pitchers at the time that they sustained their UCL injuries, while only 1 current starting pitcher was a relief pitcher at the time of his UCL injury.

Whereas the overall prevalence of UCL reconstructions among pitchers was 16%, the rates were higher among major league pitchers and among older pitchers. Since major leaguers were older in general, a worthwhile question is whether the higher prevalence among major league

TABLE 3
Comparison of Major and Minor League Pitchers With a History of UCL Reconstruction^a

	Major League Pitchers	Minor League Pitchers	P
Current age, y	28.7 ± 3.8	22.8 ± 2.7	<.001
Professional experience, y	8.4 ± 4.0	3.8 ± 2.7	<.001
At time of first UCL reconstruction			
Age, y	24.0 ± 4.1	21.0 ± 2.8	<.001
Level			<.001
High school	6 (6 of 96)	61 (205 of 338)	
College	7 (7 of 96)	30 (103 of 338)	
Professional	86 (83 of 96)	9 (30 of 338)	
Position			.064
Starting pitcher	59 (57 of 96)	48 (163 of 337)	
Relief pitcher	41 (39 of 96)	52 (174 of 337)	
No. of UCL reconstructions			.71
1	97 (93 of 96)	98 (333 of 341)	
2	3 (3 of 96)	2 (8 of 341)	
Graft (first UCL reconstruction)			.60
Forearm-throwing arm	59 (55 of 94)	60 (198 of 330)	
Forearm-nonthrowing arm	14 (13 of 94)	13 (44 of 330)	
Leg	27 (25 of 94)	22 (74 of 330)	
Other/don't know	1 (1 of 94)	4 (14 of 330)	
Surgery before first UCL reconstruction			
Elbow	11 (11 of 96)	7 (25 of 338)	.21
Shoulder	9 (8 of 94)	4 (15 of 335)	.13

^aValues are presented as mean ± SD or % (n). UCL, ulnar collateral ligament.

TABLE 4
Outcomes for Pitchers With UCL Reconstruction^a

	Major League Pitchers	Minor League Pitchers	P
Surgery since primary UCL reconstruction			
Shoulder	11 (10 of 94)	5 (17 of 335)	.057
Elbow	9 (9 of 96)	11 (36 of 335)	.85
Current velocity vs that before primary UCL reconstruction			.004
Faster	26 (20 of 77)	46 (111 of 239)	
Same	1 (1 of 77)	1 (3 of 239)	
Slower	51 (39 of 77)	42 (101 of 239)	
Don't know	22 (17 of 77)	10 (24 of 239)	
If had to, would have UCL reconstruction again ^b			.047
Yes	86 (65 of 76)	72 (171 of 239)	
No	9 (7 of 76)	16 (39 of 239)	
Don't know	5 (4 of 76)	12 (29 of 239)	

^aValues are presented as % (n). UCL, ulnar collateral ligament.

^bIncludes only responses from players with primary UCL reconstruction at least 12 months before survey.

pitchers can be attributed solely to age. Figure 1 shows UCL prevalence for various age groups of major and minor league pitchers. A Cochran-Mantel-Haenszel stratification by age group (21-25 vs 26-30 vs 31-35 years) of UCL reconstruction prevalence revealed no significant differences between major and minor league pitchers ($P = .55$). However, the question of age and UCL injury certainly requires further examination.

A topic receiving attention in the media is the apparently increasing number of younger athletes requiring UCL reconstruction. Much of this media commentary is

based on the work of Fleisig and Andrews,¹¹ who reported a significant increase in UCL reconstruction surgery in youth baseball players during the past 15 years. In the current investigation, the overall prevalence of UCL reconstructions in baseball players younger than 20 years was 5%. When we look at the minor league players in isolation (which is statistically a younger aged population), the current study demonstrated that 30% of minor league players underwent UCL reconstruction before the age of 20 years (including one who was 14 and one who was 15 years old), echoing the results of Fleisig and Andrews. While

this highlights the fact that UCL reconstructive surgeries are being done on younger patients, it also indicates that the surgery is often successful enough to allow these athletes to excel to the highest level of baseball even after a major surgical reconstruction. To this point, Osbahr et al¹⁸ evaluated the outcomes after UCL reconstruction in competitive baseball players at a minimum 10-year follow-up. They found that 83% of athletes (90% of pitchers) were able to return to baseball in <1 year and that after surgery, the average baseball career was 3.6 years. More to our point, professional baseball players returned for longer than college or high school athletes. What remains unknown is how many teenage baseball players undergo UCL reconstruction and are subsequently unable to reach the level of professional participation or even return to their prior levels of function. A large multisite prospective study would be needed to determine the long-term clinical outcomes of UCL reconstruction in teenage athletes.

Another issue that is frequently discussed in the media is whether UCL reconstruction is a problem preferentially affecting US-born athletes.²⁰ Despite news articles stating this to be the case, the results of the current study clearly show this to be false and that the prevalence of UCL reconstruction is equal between US and Latin American players. One difference that was noted to be statistically significant ($P < .001$) was that there was a much larger percentage of Dominican Republic pitchers who underwent their first UCL reconstruction at the professional level when compared with pitchers from the US (96% vs 56%). However, there was no difference between the average ages of the first UCL reconstructive surgery between these 2 groups (21 years of age). This was also true when pitchers from all Latin American countries were compared with the pitchers from the US.

When a pitcher returns to throwing after shoulder surgery, there is often concern about potential elbow injury owing to altered throwing mechanics and incomplete rehabilitation. This survey indicated that only 9% of the UCL reconstruction group had any previous elbow surgery and only 5% had previous shoulder surgery. Given the limitations of the study, we do not have details regarding any prior surgeries. However, the players who had undergone previous surgeries represent a very small number of the study population, so on the basis of these data, it appears that previous elbow or shoulder surgery is not a significant risk factor for subsequent UCL reconstruction.

Of the players who had a UCL reconstruction, 10% had an additional elbow procedure later in their careers, and only 6% underwent a shoulder surgery. These are encouragingly low values that represent a minimal risk of additional injury after a return to throwing after UCL reconstruction. Cain et al⁴ reported that 7% of their patients with UCL reconstruction underwent a subsequent elbow procedure, with the most common one being the removal of an olecranon osteophyte. They also reported a 3% incidence of a shoulder surgery after the UCL reconstruction. The most likely reason for these findings can be attributed to adequate and complete rehabilitation after UCL reconstruction. While our study looked at the risk of future surgery after UCL reconstruction, it is important

to note that this underestimates the risk of future injury after UCL reconstruction. The study by Makhni et al¹⁷ revealed that 57% of pitchers undergoing UCL reconstruction returned to the disabled list after surgery because of injury to their throwing arms.

A major concern regarding players undergoing UCL reconstruction is whether their performance will be reduced after the surgery. Along these lines, Makhni et al¹⁷ reviewed 147 cases of MLB pitchers who underwent UCL reconstruction and returned to MLB. Eighty percent returned to pitch at least 1 MLB game. However, only 67% returned to their prior levels of competition, and even more discouraging was the fact that 57% returned to the disabled list after the surgery because of injury to their throwing arms. Additionally, in contrast to other reports, performance declined after surgery.¹⁷

In our current survey, we did query about throwing velocity. Admittedly, this was based solely on the athlete's own perception, which may be inaccurate. We included the results because physicians treating these athletes are often asked if the athlete will throw harder after surgery, and a significant proportion of athletes and coaches believe that performance is enhanced by the procedure.¹ In fact, 41% of the players who underwent UCL reconstruction reported throwing faster after surgery, while 44% reported throwing slower after surgery. However, this study does not include players who were unable to return to professional baseball after UCL reconstruction. If this group of players were to be included, it is likely that the percentage (41%) of respondents reporting that they were able to throw faster after UCL reconstruction would be lower.

There exist several limitations to this study. It is vital to recognize that this study reported the prevalence, not the incidence, of UCL reconstruction in professional baseball. Professional baseball players who had UCL reconstruction but are no longer in professional baseball were not included. Results from this study—particularly, the outcomes reported in Table 4—could be different if players who did not return and stay in professional baseball were included. A prospective longitudinal study is needed to quantify the incidence of UCL injuries and outcomes after all UCL reconstructions. Furthermore, the prevalence of UCL reconstruction was determined by self-report, which may have introduced misclassification bias. Ideally, we would have compared participants' responses with their medical records. Unfortunately, this was not possible. It is our belief, however, that because Tommy John surgery is so common among baseball players and requires such a long, unique rehabilitation protocol, professional baseball players' recollections of what elbow surgery they underwent are unlikely to be too disparate from their medical records. Players were given the option of an English or Spanish version of the questionnaire, and a small number of players in the study were from countries that did not speak either language fluently. The survey was administered by the given player's certified athletic trainer, who was able to ensure understanding and completion of every question. Players who were not able to understand or complete every question were excluded.

Clearly, the strength of this study is that it reported on a homogeneous group of >5000 professional baseball players,

with an estimated 89% of eligible players completing the survey. A perceived increased frequency of UCL reconstruction in professional baseball has drawn much attention from the medical community, press media, and general public, but the current study is the first to report the true prevalence of UCL reconstruction in professional baseball. Since any past prevalence is unknown, a historical rise in UCL reconstruction rates cannot be confirmed. However, this study showed a current prevalence of 16% among professional pitchers and 3% among nonpitchers. These numbers provide a perspective of the effect that UCL reconstructions have on professional baseball today and so can serve as a baseline for assessing future increases or decreases in UCL surgery rates.

ACKNOWLEDGMENT

The authors thank K. C. Cord for her assistance in the survey design, as well as Major League Baseball and the athletic trainers of the Professional Baseball Athletic Trainers Society for the collection of the data. A special thanks to Michael Weiner, executive director of the Major League Baseball Players Association. Without the advice and support of the late Dr Lewis Yocum, this article would not have been possible.

REFERENCES

1. Ahmad CS, Grantham WJ, Greiwe RM. Public perception of Tommy John surgery. *Phys Sportsmed*. 2012;40(2):64-72.
2. Bowers AL, Dines JS, Dines DM, Altchek DW. Elbow medial ulnar collateral ligament reconstruction: clinical relevance and the docking technique. *J Shoulder Elbow Surg*. 2010;19(2)(suppl):110-117.
3. 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(4):728-732.
4. Cain EL Jr, Andrews JR, Dugas JR, et al. Outcome of ulnar collateral ligament reconstruction of the elbow in 1281 athletes: results in 743 athletes with minimum 2-year follow-up. *Am J Sports Med*. 2010;38(12):2426-2434.
5. Conte S, Requa RK, Garrick JG. Disability days in Major League Baseball. *Am J Sports Med*. 2001;29(4):431-436.
6. Dines JS, ElAttrache NS, Conway JE, Smith W, Ahmad CS. Clinical outcomes of the DANE TJ technique to treat ulnar collateral ligament insufficiency of the elbow. *Am J Sports Med*. 2007;35(12):2039-2044.
7. Dines JS, Jones KJ, Kahlenberg C, Rosenbaum A, Osbahr DC, Altchek DW. Elbow ulnar collateral ligament reconstruction in javelin throwers at a minimum 2-year follow-up. *Am J Sports Med*. 2012;40(1):148-151.
8. Dun S, Kingsley D, Fleisig GS, Loftice J, Andrews JR. Biomechanical comparison of the fastball from wind-up and the fastball from stretch in professional baseball pitchers. *Am J Sports Med*. 2008;36(1):137-141.
9. Erickson BJ, Gupta AK, Harris JD, et al. Rate of return to pitching and performance after Tommy John surgery in Major League Baseball. *Am J Sports Med*. 2014;42(3):536-543.
10. Escamilla RF, Barrentine SW, Fleisig GS, et al. Pitching biomechanics as a pitcher approaches muscular fatigue during a simulated baseball game. *Am J Sports Med*. 2007;35(1):23-33.
11. Fleisig GS, Andrews JR. Prevention of elbow injuries in youth baseball pitchers. *Sports Health*. 2012;4(5):419-424.
12. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med*. 1995;23(2):233-239.
13. Fleisig GS, Barrentine SW, Zheng N, Escamilla RF, Andrews JR. Kinematic and kinetic comparison of baseball pitching among various levels of development. *J Biomech*. 1999;32(12):1371-1375.
14. Fortenbaugh D, Fleisig GS, Andrews JR. Baseball pitching biomechanics in relation to injury risk and performance. *Sports Health*. 2009;1(4):314-320.
15. Jiang JJ, Leland JM. Analysis of pitching velocity in major league players before and after ulnar collateral ligament reconstruction. *Am J Sports Med*. 2014;42(4):880-885.
16. Jones KJ, Osbahr DC, Schrupf MA, Dines JS, Altchek DW. Ulnar collateral ligament reconstruction in throwing athletes: a review of current concepts. AAOS exhibit selection. *J Bone Joint Surg Am*. 2012;94(8):e49.
17. Makhni EC, Lee RW, Morrow ZS, Gaultieri AP, Gorroochurn PA, Ahmad CS. Performance, return to competition, and reinjury after Tommy John surgery in Major League Baseball pitchers: a review of 147 cases. *Am J Sports Med*. 2014;42(6):1323-1332.
18. Osbahr DC, Swaminathan SS, Allen AA, Dines JS, Coleman SH, Altchek DW. Combined flexor-pronator mass and ulnar collateral ligament injuries in the elbows of older baseball players. *Am J Sports Med*. 2010;38(4):733-739.
19. Posner M, Cameron KL, Wolf JM, Belmont PJ Jr, Owens BD. Epidemiology of Major League Baseball injuries. *Am J Sports Med*. 2011;39(8):1676-1680.
20. Verducci T. Overuse of young pitchers fueling MLB's Tommy John surgery problem. <http://www.si.com/mlb/2014/04/15/tommy-john-surgery-high-school-pitchers-jameson-taillon>. Accessed March 2015.