Risk Stratification for Ulnar Collateral Ligament Injury in Major League Baseball Players

A Retrospective Study From 2007 to 2014

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Background: Ulnar collateral ligament (UCL) injury has become increasingly common in Major League Baseball (MLB) players in recent years.

Hypothesis: There is a significant difference in preinjury fastball velocity between MLB pitchers with tears and matched controls without UCL injury. Pitchers with injuries are throwing harder and getting injured earlier in their MLB careers.

Study Design: Cohort study; Level of evidence, 3.

Methods: From 2007 to 2014, a total of 170 documented UCL injuries (156 pitchers, 14 position players) occurred in MLB. Inclusion criteria for this study consisted of any player who tore his UCL in MLB during this time frame. There were 130 regular-season tears (April-September). From this group, 118 players who pitched more than 100 innings prior to tear were matched to subjects with no tear and were compared using a logistic regression analysis. A subgroup of "early tear" players who threw less than 100 career innings (n = 37) was also identified and compared with the larger tear group using a logistic regression analysis.

Results: Of the 130 tears that occurred during the regular season, a significantly larger number (62%) occurred in the first 3 months ($P = .011$). The rate of UCL tears per MLB player ($P = .001$) was statistically significant. In the group of 118 matched tears, the mean fastball velocity was greater in the tear group (91.7 mph) compared with the control group (91.0 mph; $P = .014$). Furthermore, relief pitchers made up a greater percentage of the early tear group (<100 innings) compared with the later tear group ($P = .011$). Sixteen of the 170 UCL tears (9.4%) were recurrent tears, with 5 of 16 experiencing both tear and retear within the past 4 years.

Conclusion: There is a statistically significant difference in the mean fastball velocity of pitchers who injure their UCL. Small increases in pitcher fastball velocity are a main contribution to the increased rate of tear in MLB. In addition, there has been an increased incidence of injury in the first 3 months of the season. Finally, early tears are more likely to occur in relief pitchers than starters.

Keywords: ulnar collateral ligament; baseball; throwing; velocity; elbow

The ulnar collateral ligament (UCL) is a major stabilizer to valgus stress during throwing and commonly injured in overhead athletes due to the magnitude of force generated during throwing.[16] UCL injury leads to medial elbow pain and instability and has been reported in numerous sports, but most commonly in baseball pitchers.[2,7,21] Prior to the advent of UCL reconstruction by Frank Jobe in 1974, UCL tear was considered a career-ending injury.[20] Numerous studies have documented the success of Tommy John surgery with regard to functional and biomechanical status as well as return to play.[8,9,11,16,30,32]

From 2000 to 2011, a mean 16 UCL tears per year occurred in Major League Baseball (MLB).[31] From 2011 to 2014, an above-average number of tears were noted, averaging 26 per season. The combination of increased UCL tears as well as the growth of sports media has

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consequently led to the concern of a "Tommy John epidemic."[17,31] Maximum throwing velocity has been identified as a risk factor for UCL tear, since throwing fastballs generates the greatest mean torque at the elbow compared with off-speed pitches.[10,14] In a cohort study of 23 professional pitchers, pitchers with the greatest fastball velocity (n = 3) all went on to tear and undergo subsequent reconstruction.[6] Conversely, earlier studies have not shown any difference in velocity between pitchers pre–UCL injury compared with matched controls.[19]

This study examined recent trends in UCL tears in MLB players to identify risk factors for UCL tear that, when present, could provide early warning to coaching staffs and pitchers. We hypothesized that a significant difference in fastball velocity and number of years of MLB experience for pitchers who tear their UCL exists compared with those who do not. Finally, we investigated our concern that as more pitchers tear their UCL and undergo subsequent repair, there are more recurrent tears among MLB pitchers compared with previously.

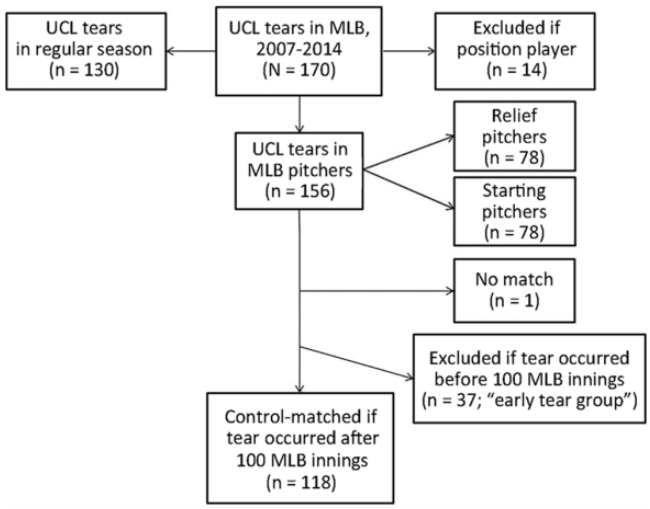

Figure 1. Flowchart of selection process for study inclusion. MLB, Major League Baseball; UCL, ulnar collateral ligament.

METHODS

Player Selection

MLB players with UCL tears diagnosed between 2007 and 2014 (8 seasons) were identified and examined through publically available Internet search results.[1] This method of data collection has been used in multiple prior studies on baseball and other sports.[2,7,11,14,19,24,30] An *MLB player* was defined as any player who recorded an inning of MLB experience during the regular season (April-September). Players who only participated in spring training or playoffs were excluded. "UCL tear" was defined as a UCL injury that caused a player to miss significant time by either being placed on the disabled list or undergoing surgical reconstruction.

An MLB database (www.baseball-reference.com) was cross-referenced for both biographic and UCL tear information.[4,5] In 2007, MLB began using the PITCHf/x system (Sportsvision Inc) to track pitches thrown in an official game. From these datasets, information was collected on age, height, pitching status (starting or relief), handedness (left or right), time during the season UCL injury occurred, number of seasons played, average fastball velocity, and percentage fastballs and breaking balls. Starting pitchers were defined as those pitchers who had >50% of their MLB appearances recorded as a "start" in official statistics. Fastballs included any 4-seam, 2-seam, or cut fastball. Breaking pitches were the sum of curveballs and sliders.[4]

Rate of Tear

During this 8-year time frame, 170 UCL tears were identified (Figure 1). Of these tears, 156 (92%) were pitchers and 14 (8%) were position players. Position players were used in the longitudinal analyses but excluded from the controlled aspect of the study. The 130 pitcher tears that occurred during the regular season (April-September) were divided into 2 categories: early season (April-June) and late season (July-September). Tears that occurred in the playoffs or offseason were excluded because not all teams were actively playing at this time. UCL tear rates were derived for each year by dividing the number of tears by the total number of MLB position players and pitchers.

Control Group

Matching was performed for pitchers using a similarity scores algorithm, which accounts for players' statistical metrics (earned run average [ERA], innings pitched, etc) as well as their length of time in MLB.[18,29] For a player to be appropriately matched, a minimum of 100 innings of MLB experience was required, leading to exclusion of 37 pitchers who were examined as a separate, uncontrolled "early tear" cohort. A paired *t* test was performed to assess pitchers with UCL tears compared with their matched controls. Age, pitching status, handedness, and number of participated MLB seasons were not analyzed, as the controls were matched on these factors in the similarity scores algorithm.

Early Tear Cohort

An independent Student *t* test and a Pearson chi-square test were used to compare the early tear and later tear cohorts for continuous and categorical variables, respectively. Multivariate analysis was performed using a logistic regression model. Multicollinearity was evaluated for all variables included and controlled for using interaction terms as appropriate. Data analysis was performed utilizing SPSS Version 22.0 (IBM Corp).

RESULTS

The average time to tear of the 170 players analyzed was 5.0 MLB seasons. Of 130 pitcher tears that occurred during

the regular season, 80 tears occurred during April-June ($P = .011$). Rate of UCL tears was examined for trends over time. An increase in tear rate from 2007 to 2014 (23 vs 37 UCL tears per MLB player × 1000) was identified ($P = .001$) (Figure 2). Likewise, 156 UCL tears in pitchers that occurred from 2007 to 2014 were further investigated to determine trends in average fastball velocity. Among pitchers with recurrent tears (n = 16), average velocity was 92.4 mph.

On assessing pitchers with UCL tears compared with their controls, certain trends emerged. Pitchers who tore their UCL threw greater velocity fastballs, averaging 91.7 mph (±2.4 mph) versus 91.0 mph (±2.5 mph) for controls ($P = .014$) (Table 1). Examining trends in velocity for tears versus controls over time, the control group threw with a similar velocity to the tear group from 2007 to 2010. However, in more recent seasons (2011-2014), the velocity gap widened (Figure 3). Although a greater difference in average fastball velocity occurred after 2010, this difference is only statistically significant for 2011 ($P = .005$). No significant difference was found in the amount of fastballs and off-speed pitches thrown between the 2 groups.

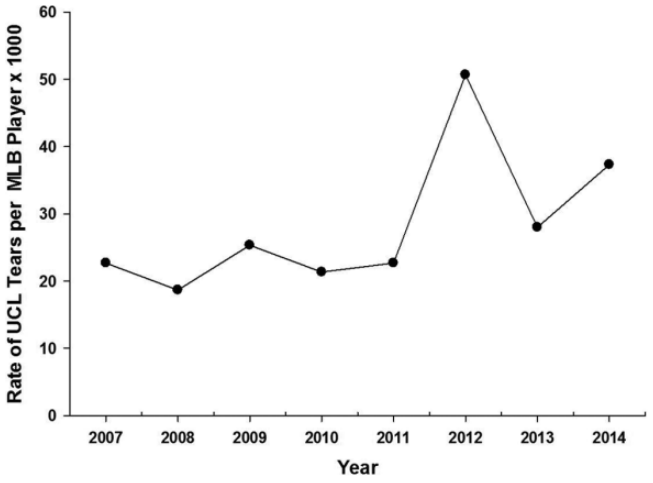

Figure 2. Rate of ulnar collateral ligament (UCL) tears each year in Major League Baseball (MLB) pitchers and positional players. Rate of UCL tears was calculated by dividing the number of UCL tears by the number of players in the MLB per year. *P* value was calculated using a logistic regression model ($P = .001$).

TABLE 1
Ulnar Collateral Ligament Tears Versus Controls[a]

Pitcher Characteristic	Cases (n = 118)	Controls (n = 118)	Mean Difference	95% CI of Mean Difference	*P* Value[b]
Height, in	74.6 ± 2.1	74.4 ± 2.2	0.2	−0.33 to 0.74	.46
Mean fastball velocity, mph	91.7 ± 2.4	91.0 ± 2.5	0.7	0.15 to 1.28	.014[c]
% Fastballs	65.0 ± 9.0	64.0 ± 8.5	1.0	−0.93 to 3.12	.29
% Breaking balls	24.1 ± 8.7	24.3 ± 8.7	−0.2	−2.54 to 2.09	.85

[a]Values are expressed as mean ± SD.
[b]Derived from a paired *t* test.
[c]Statistically significant.

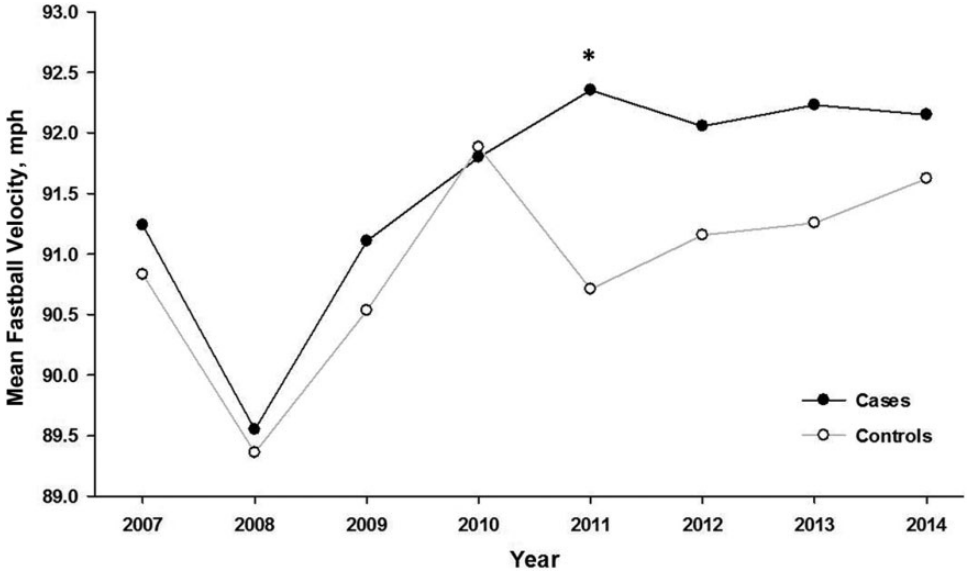

Figure 3. Mean fastball velocity of pitchers sustaining ulnar collateral ligament tear (cases) compared with the matched control group, 2007-2014. *P* values were calculated using a paired *t* test comparing cases with controls by year. *Statistically significant.

TABLE 2
Results of Early Versus Later UCL Tear Groups[a]

			Univariate			Multivariate		
	Early Tears (n = 37)[b]	Later Tears (n = 119)[b]	Mean Difference	95% CI of Mean Difference	*P* Value[c]	Exp (B)	95% CI for Exp (B)	*P* Value[d]
Age, y	24.6 ± 2.7	28.7 ± 4.3	−4.1	−5.3 to −3.0	<.001[e]	1.2	0.9 to 1.7	.14
Height, in	74.0 ± 1.9	74.6 ± 2.1	−0.6	−1.3 to 0.2	.15	1.1	0.9 to 1.3	.48
Pitching status			N/A	N/A	.011[e]	0.2	0.1 to 0.7	.011[e]
% Starting	12 (15)	67 (85)						
% Relief	25 (33)	52 (67)						
Handedness			N/A	N/A	.83		—	—
Left	9 (23)	31 (77)						
Right	28 (24)	88 (76)						
Time into season[f]			N/A	N/A	.58		—	—
Early (April-June)	21 (66)	59 (60)						
Late (July-September)	11 (34)	39 (40)						
MLB seasons	1.8 ± 1.1	5.9 ± 3.7	−4.1	−4.9 to −3.4	<.001[e]	19.3	4.3 to 86.4	<.001[e]
Mean fastball velocity, mph	92.1 ± 2.9	91.6 ± 2.6	0.5	−0.5 to 1.5	.34		—	—
% Fastballs	65.8 ± 7.1	65.0 ± 9.0	0.8	−2.4 to 4.0	.63		—	—
% Breaking balls	24.3 ± 10.2	24.0 ± 8.7	0.3	−3.1 to 3.6	.87		—	—

[a]Values are expressed as mean ± standard deviation. MLB, Major League Baseball; N/A, not applicable; UCL, ulnar collateral ligament.
[b]Early tears are defined as tears that occur before a player has played 100 innings, and later tears are any tear that occurs at or after 100 innings have been played.
[c]Derived from an independent *t* test or Pearson chi-square test as appropriate.
[d]Derived from a multivariable logistic regression analysis.
[e]Statistically significant.
[f]Not all tears are included because several occurred during spring training or playoffs.

Early tears comprised 24% of all pitcher tears. Univariate analysis of early tears demonstrated a difference in player age ($P < .001$) (Table 2), pitching status ($P = .011$), and MLB seasons ($P < .001$); however, multivariate analysis showed only pitching status ($P = .011$) and MLB seasons ($P < .001$) remained statistically significant. Consequently, we concluded that pitchers who tear before 100 innings likely tear with fewer MLB seasons (1.8 ± 1.1 vs 5.9 ± 3.7) and are more likely to be relievers (67% vs 44%). Furthermore, while there was a difference in average velocity of 92.1 mph in the early tear group compared with 91.6 mph in the group of 119 tears, this difference was not significant ($P = .34$).

DISCUSSION

Our study sought to evaluate possible predictive metrics for UCL tear in the MLB player[19] and to stratify UCL injury risk factors. We found that more tears (62%) occurred early (April-June) compared with later in the season (July-September). Possible explanations include the following: (1) conditioning level at the beginning of the season and the inherently competitive environment of securing an MLB roster spot than fatigue related to inning frequency and pitch counts, (2) preexisting UCL injury that has not yet been formally diagnosed or become symptomatic (eg, partial tear or UCL insufficiency), (3) variations in offseason pitching/throwing regimens (eg, winter baseball) may be too rigorous and need modification to reduce early-season tears, and (4) pitchers with medial elbow soreness and/or declining performance are often shut down in the later months of the season as a precaution to prevent further injury.

Our tear group threw at a harder fastball velocity than matched controls, with fastball velocity standing out as the only statistically significant difference between the 2 groups ($P = .014$), directly opposing an earlier study by Jiang and Leland[19] with fewer subjects that did not find a difference in fastball velocity when compared with a control-matched group. While this statistical difference was small and unlikely clinically significant, numerous biomechanical studies have examined alterations in force necessary to cause UCL sprain or tear. Morrey and An[25] showed that the UCL provides 55% (33 N·m) of the stability to valgus stress generated while throwing during a cadaveric study (64 N·m). A similar cadaveric study by Fleisig et al[13] showed that mean valgus torque generated by healthy pitching subjects was 67 N·m. Their follow-up study assessing valgus torque generated by various pitches (fastball, change up, curveball, and slider) showed values of 82, 71, 79, and 81 N·m, respectively.[14] When taking into account that mean torque on a pitch-to-pitch basis exceeds the torque to failure in cadaveric specimens by 248%, small changes in fastball velocity and pitch composition are potentially significant.

Because of the large amount of stress placed on the elbow joint during throwing and the repetitive nature of

baseball pitching, subtle differences in velocity and pitch composition could lead to a cumulative effect on the UCL. This finding may be best exemplified by our early tear cohort. Over the past 8 seasons, 37 players tore within their first 100 innings, with a mean time to tear of 1.8 professional seasons. This may indicate that not only are in-game innings an important predictor, but off-season workout regimens and experience prior to reaching MLB status may also play a role in injury. Furthermore, this group on average threw harder than the larger group of UCL tears, but the value was not statistically significant. Moreover, part of the attention garnered by UCL tears of late has been secondary to tears in young, high-profile pitching prospects.[22,23] Fascination with young, high-velocity pitchers by the media may be contributing to increased attention whenever a younger player experiences UCL tear. Over the past 8 years, 56% of players tore within the first 4 years of their MLB career, while over the past 4 seasons, 65% of players tore within their first 4 MLB seasons—a disturbing trend with regard to an increasing tear percentage at the beginning of a player's career. These figures are concerning due to the general trend in MLB toward harder-throwing pitchers. In 2013, there were 62 pitchers who threw at least 25% of their pitches >96 mph, compared with 20 pitchers in 2003.[3] As modern baseball pitchers become bigger, stronger, and faster, we predict the risk of UCL tear will inevitably continue to rise without the appropriate precautions.

Our study shows an increasing number of retears compared with prior studies. Overall, 16 of 170 (9.4%) tears were repeat injuries, while 6 of 16 (37.5%) experienced both tear and recurrence within the 8-year study period. Also, 13 of 16 (81.3%) retears were in the past 4 seasons (2011-2014). There was no difference in the average velocity of players with retear in our study. In contrast, Erickson et al[11] performed a study of 179 tears including outcome after surgery and found only a 3.9% revision rate. A potential difference in these figures could be due to a different time period in which the analysis took place, with the study by Erickson et al[11] only following patients through the beginning of the 2013 season.

While surgical outcomes can translate into successful return to play in major league athletes, there is increasing attention being directed toward the risk factors associated with UCL injuries and injury prevention strategies, especially in youth players. Young pitchers throwing more than 85 pitches/game for >8 months of the year may be at greater risk for future surgical intervention.[15,27] Olsen at al[26] demonstrated that the risk factor with the strongest correlation to elbow injury is pitching volume. Prospective studies performed by Fleisig et al[12] enrolling 9- to 14-year-old baseball players between 1999 and 2008 have shown that youth pitchers who pitch >100 innings/year were 3.5 times more likely to be injured, while other studies have demonstrated that it is not uncommon for youth pitchers to play $\geq$70 games per calendar year, often playing >8 consecutive months.[28] The current generation of MLB pitchers has spent their youth playing in an era where single-sport specialization among elite players is common, and pitching on multiple teams >8 months of the calendar year is the norm rather than the exception. Consequently, our study results demonstrating MLB pitchers with less experience throwing >92 mph may be at higher risk for tear is not surprising. Additionally, the current trend of MLB starting pitchers tearing at an increased rate compared with relievers since 2011 in our study lends further support to total pitching volume both during the season and spring training likely being the strongest correlation to elbow injury, as starting pitchers throw more pitches and innings over the course of an MLB season than relievers.

Our study must be considered in light of several limitations, including its retrospective nature. The advent of PITCHF/x in 2007 also limited our ability to match players to their "best match" according to the matching algorithm for baseball players. Similarly, for veteran players who were injured, velocity and pitch composition data were only available after 2007. We also excluded all pitching experience at the high school, college, and minor league level. With regard to UCL injury, there was no information available pertaining to the degree of injury (ie, sprain vs complete tear). Furthermore, we examined mean fastball velocity over a large cohort of MLB pitchers, which can be misleading due to an inherently wide range of average velocities. Setting an arbitrary cutoff of 92 mph, 73 of 156 (47%) tears were in pitchers throwing >92 mph. However, over the past 4 seasons (2011-2014), 52 of 99 (53%) pitchers who tore threw >92 mph, compared with only 21 of 57 (37%) pitchers from 2007 to 2011 ($P = .08$). These values were not statistically significant and were omitted from our results. Additionally, the 0.7-mph velocity difference may not be large enough to be considered clinically significant despite achieving statistical significance. Further studies are needed to fully evaluate the statistical and clinical significance of these trends, in addition to characteristics of current MLB pitchers' youth, high school, and collegiate experiences as potential risk factors for UCL tear. Additionally, as it is likely that intrinsic and extrinsic factors contribute to overall UCL tear rate, future studies should consider pitching biomechanics (eg, contralateral trunk tilt, stride length, etc) and weather and mound conditions as potential study design variables.

CONCLUSION

Time of year and average fastball velocity can be used as markers for pitchers at risk to tear their UCL. Mean time to tear of 170 players investigated was 5.0 MLB seasons (the average MLB career is 5.6 seasons[33]), with 56% of tears occurring in pitchers within the first 4 seasons of their MLB career. Our study identified that during the past 8 regular seasons of play, a significant number of pitcher UCL tears (62%) occurred in the first 3 months of the season ($P = .011$). Pitchers who tore within the first 100 innings of their career comprised 24% of pitcher tears and were also more likely to be relief pitchers ($P = .011$). Pitchers with UCL injury threw on average 0.7 mph harder than matched controls.

REFERENCES

1. All-time TJ surgery tracker 1974-2014 (30 updates). MLB Reports on WordPress.com. http://mlbreports.com/2014/08/26/all-time-tommy-john-tracker-1974-2014-29-updates/. Accessed November 26, 2014.
2. Azar FM, Andrews JR, Wilk KE, Groh D. Operative treatment of ulnar collateral ligament injuries of the elbow in athletes. *Am J Sports Med*. 2000;28:16-23.
3. Baseball 2013: Here come the flamethrowers. *Wall Street Journal*. http://www.wsj.com/news/articles/SB10001424127887323419104578376793663086624. Accessed December 16, 2014.
4. Baseball statistics and analysis. FanGraphs Baseball. http://www.fangraphs.com/. Accessed November 22, 2014.
5. Baseball-Reference.com. MLB stats, standings, scores, history. http://www.baseball-reference.com/. Accessed November 22, 2014.
6. Bushnell BD, Anz AW, Noonan TJ, Torry MR, Hawkins RJ. Association of maximum pitch velocity and elbow injury in professional baseball pitchers. *Am J Sports Med*. 2010;38:728-732.
7. Conway JE, Jobe FW, Glousman RE, Pink M. Medial instability of the elbow in throwing athletes. Treatment by repair or reconstruction of the ulnar collateral ligament. *J Bone Joint Surg Am*. 1992;74:67-83.
8. 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;35:2039-2044.
9. Dodson CC, Thomas A, Dines JS, Nho SJ, Williams RJ, Altchek DW. Medial ulnar collateral ligament reconstruction of the elbow in throwing athletes. *Am J Sports Med*. 2006;34:1926-1932.
10. Dun S, Loftice J, Fleisig GS, Kingsley D, Andrews JR. A biomechanical comparison of youth baseball pitches: is the curveball potentially harmful? *Am J Sports Med*. 2008;36:686-692.
11. Erickson BJ, Gupta AK, Harris JD, et al. Rate of return to pitching and performance after Tommy John surgery in Major League Baseball pitchers. *Am J Sports Med*. 2014;42:536-543.
12. Fleisig GS, Andrews JR, Cutter GR, et al. Risk of serious injury for young baseball pitchers: a 10-year prospective study. *Am J Sports Med*. 2011;39:253-257.
13. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med*. 1995;23:233-239.
14. Fleisig GS, Kingsley DS, Loftice JW, et al. Kinetic comparison among the fastball, curveball, change-up, and slider in collegiate baseball pitchers. *Am J Sports Med*. 2006;34:423-430.
15. Fleisig GS, Weber A, Hassell N, Andrews JR. Prevention of elbow injuries in youth baseball pitchers. *Curr Sports Med Rep*. 2009;8:250-254.
16. Gibson BW, Webner D, Huffman GR, Sennett BJ. Ulnar collateral ligament reconstruction in Major League Baseball pitchers. *Am J Sports Med*. 2007;35:575-581.
17. Is MLB in the midst of a Tommy John epidemic? ESPN. http://espn.go.com/mlb/story/_/id/10831700/is-mlb-midst-tommy-john-epidemic. Accessed February 9, 2015.
18. James B. *The Politics of Glory*. London, England: Macmillan; 1994.
19. Jiang JJ, Leland JM. Analysis of pitching velocity in Major League Baseball players before and after ulnar collateral ligament reconstruction. *Am J Sports Med*. 2014;42:880-885.
20. Jobe FW, Stark H, Lombardo SJ. Reconstruction of the ulnar collateral ligament in athletes. *J Bone Joint Surg Am*. 1986;68:1158-1163.
21. Kenter K, Behr CT, Warren RF, O'Brien SJ, Barnes R. Acute elbow injuries in the National Football League. *J Shoulder Elbow Surg*. 2000;9:1-5.
22. Masahiro Tanaka of New York Yankees has partially torn UCL. ESPN New York. http://espn.go.com/new-york/mlb/story/_/id/11201116/masahiro-tanaka-new-york-yankees-partially-torn-ucl. Accessed November 28, 2014.
23. Matt Harvey of New York Mets has partial tear in elbow. ESPN New York. http://espn.go.com/new-york/mlb/story/_/id/9602399/matt-harvey-new-york-mets-partial-tear-elbow. Accessed November 28, 2014.
24. Micieli R, Micieli JA. Factors influencing visor use among players in the National Hockey League (NHL). *Open Access J Sport Med*. 2014;5:43-46.
25. Morrey BF, An KN. Articular and ligamentous contributions to the stability of the elbow joint. *Am J Sports Med*. 1983;11:315-319.
26. Olsen SJ, Fleisig GS, Dun S, Loftice J, Andrews JR. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *Am J Sports Med*. 2006;34:905-912.
27. Popchak A, Burnett T, Weber N, Boninger M. Factors related to injury in youth and adolescent baseball pitching, with an eye toward prevention. *Am J Phys Med Rehabil*. 2015;94:395-409.
28. Register-Mihalik JK, Oyama S, Marshall SW, Mueller FO. Pitching practices and self-reported injuries among youth baseball pitchers: a descriptive study. *Athl Train Sports Health Care*. 2012;4:11-20.
29. Similarity scores. Baseball-Reference.com. http://www.baseball-reference.com/about/similarity.shtml. Accessed November 22, 2014.
30. Thompson WH, Jobe FW, Yocum LA, Pink MM. Ulnar collateral ligament reconstruction in athletes: muscle-splitting approach without transposition of the ulnar nerve. *J Shoulder Elbow Surg*. 2001;10:152-157.
31. Tommy John surgery now "an epidemic." http://www.usatoday.com/story/sports/mlb/2014/04/11/tommy-john-elbow-surgery-strasburg-parker-corbin/7583413/. Accessed December 7, 2014.
32. Vitale MA, Ahmad CS. The outcome of elbow ulnar collateral ligament reconstruction in overhead athletes: a systematic review. *Am J Sports Med*. 2008;36:1193-1205.
33. Witnauer WD, Rogers RG, Saint Onge JM. Major League Baseball career length in the twentieth century. *Popul Res Policy Rev*. 2007;26:371-386.