Fastball Pitch Velocity Helps Predict Ulnar Collateral Ligament Reconstruction in Major League Baseball Pitchers

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Background: Ulnar collateral ligament injury and its subsequent surgical reconstruction are some of the most common issues among Major League Baseball (MLB) players.

Purpose/Hypothesis: The purpose of this study was to determine factors predictive of ulnar collateral ligament reconstruction (UCLR) among MLB pitchers. The hypothesis was that pitchers who underwent UCLR would have higher preinjury peak fastball pitch velocity.

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

Methods: Data on pitch velocity, number, and type (fastball, curveball, etc) for every pitcher and game within MLB from April 2, 2007 to April 14, 2015 were gathered from the publically available PitchFx database. Pitcher demographic information was also recorded. Data from after 2012 were excluded to avoid lead-time bias. Using publically available information, the names and approximate dates of surgery for every MLB pitcher who ever underwent UCLR, including those before 2007 and after 2012, were collected. Each pitcher-game was then classified as ''control,'' ''preinjury,'' or ''postoperative.'' Control and preinjury pitchers were then compared to determine risk factors for UCLR.

Results: Overall, 1327 pitchers were included, of whom 309 (26.8%) had undergone UCLR. Of these, 145 had preinjury velocity data. Peak pitch velocity was significantly higher among preinjury pitchers than control pitchers (mean [95% CI], 93.3 mph [92.8-93.8] vs 92.1 mph [91.9-92.3]; $P < .001$), as was mean pitch velocity (87.8 mph [87.3-88.3] vs 86.9 mph [86.7-87.1]; $P = .001$). Both demonstrated a dose-response relationship. Although height did not differ ($P = .934$), weight was significantly higher for preinjury pitchers than controls ($P = .005$). Pitch counts per year were significantly lower for preinjury pitchers compared with control pitchers, although preinjury pitchers threw more breaking pitches ($P = .003$). On multivariate regression, peak pitch velocity was the primary independent predictor of whether a pitcher underwent UCLR ($P < .001$), with mean velocity ($P = .013$), body mass index ($P = .010$), and age ($P = .006$) being secondary predictors. However, a model constructed with these variables only explained 7% of the variance in UCLR rates. Pitch counts were not significant predictors.

Conclusion: Higher pitch velocity is the most predictive factor of UCLR in MLB pitchers, with higher weight and younger age being secondary predictors, although these factors only explained 7% of the variance in UCLR rates.

Keywords: baseball; overhand pitchers; ulnar collateral ligament reconstruction; velocity

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One or more of the authors has declared the following potential conflict of interest or source of funding: A.A.R. receives royalties from Arthrex and Saunders; is a paid consultant for Arthrex; receives other financial or material support from Arthrex and Saunders and SLACK Incorporated; is a paid speaker for Arthrex; and receives research support from Arthrex, DJO Surgical, Össur, and Smith & Nephew. N.N.V. receives research support from Arthrex, Arthrosurface, DJ Orthopaedics, Smith & Nephew, Athletico, Conmed Linvatec, Miomed, and Mitek; has stock or stock options in Cymedica, Minivasive, and Omeros; receives royalties from Smith & Nephew; and is a paid consultant for Smith & Nephew.

The American Journal of Sports Medicine, Vol. 44, No. 8
DOI: 10.1177/0363546516634305

The overhand baseball pitch is among the fastest and highest-stress athletic motions.[13,14,27] Consequently, pitching-related shoulder and elbow pain occur in up to 30% to 74% of baseball pitchers.[6,17] Injuries are also common, occurring in 23% to 31% of youth baseball players.[6,21] During the overhand pitch, the valgus stress experienced by the elbow routinely exceeds the load to failure of the ulnar collateral ligament (UCL).[18,25] UCL tears are thus among the most commonly encountered injuries and ulnar collateral ligament reconstruction (UCLR) is among the most frequently performed procedures among baseball pitchers, both youth and professional players in Major League Baseball (MLB). The prevalence of this procedure has increased to the point that many surgeons consider it an "epidemic."[5,8]

Risk factors of pitching-related injury remain incompletely understood. Fatigue is thought to be a risk factor.[12,17,28]

Various studies have defined fatigue as pitching for multiple teams, for more than 9 months a year, pitching more than 100 innings per year, and throwing more pitches per game, week, season, and year.[12,17,28] To prevent pitchers from throwing through fatigue, USA Baseball, Little League America, and MLB have put forth guidelines restricting pitch counts,[19,26] yet compliance remains an issue.

However, other studies have suggested that the torque placed through the arm during the pitch may be a primary risk factor for injury. In a prospective study of MLB players, elbow valgus torque correlated with subsequent elbow injury.[2] However, elbow valgus torque also correlates with pitch velocity.[11] In the same cohort, peak pitch velocity was found to be an even better predictor of subsequent injury.[4] These findings have been called into question because only 23 pitchers were included. A subsequent large-scale community study in youth pitchers demonstrated velocity to correlate with shoulder and elbow pain and a history of pitching-related injury.[6] These findings have been called into question because a history of injury was used as a primary correlate. As a result, it remains unknown whether velocity correlates with subsequent injury, specifically an injury to the UCL.

The purpose of this study was to determine UCLR-specific predictors among MLB pitchers. We hypothesized that pitch velocity would be a strong predictor of injury and subsequent need for UCLR.

METHODS

This was a retrospective case-control study. Because only publically available data were used in this study, no institutional review board approval was necessary. MLB pitchers who underwent UCLR were identified by cross-referencing a combination of Internet-based sources including team websites, injury reports, player profiles, biographies, press releases, and the MLB HITS database. Data collected from these sources were then cross-referenced with the publically available PitchFx database on the Baseball Heat Maps website (http://www.baseballheatmaps.com). This method of data collection has been used in multiple prior publications regarding this particular population.[9,20] The following data were collected for each player: name, date of surgery, and date of revision (if applicable).

Pitch velocity and type has been recorded and made publically available in the PitchFx database for every pitch thrown within the MLB since April 2, 2007. This database also contains pitcher height, weight, and age. Baseball Heat Maps provides data services for this database and produced mean and peak pitch velocity for each pitcher and each game. This search included only fastballs (including only fastballs, 4-seam fastballs, and 2-seam fastballs), because many breaking pitches have variably lower velocities. A secondary search was performed to generate pitch counts for each pitcher and each game, including total number of pitches thrown, total number of fastballs thrown (including 4-seam fastballs, 2-seam fastballs, cut fastballs, split-finger fastballs, forkballs, and sinks), total number of change-ups thrown, total number of breaking pitches thrown (including curveballs, knuckle curves, and screwballs), total number of sliders thrown, and total number of knuckleballs thrown. Pitches that could not be classified or were classified as Eephus (very low speed) pitches were excluded. All pitches between April 2, 2007 and April 14, 2015 were included. Data on year of entry into the MLB were also gathered for all pitchers from publically available data on the Baseball Prospectus website (http://www.baseballprospectus.com).

These data sources were then combined. Each pitcher-game was classified as an uninjured control, as a preinjured pitcher who subsequently underwent UCLR, or as a postoperative pitcher who had undergone previous UCLR by cross-referencing names and dates across databases. For each pitcher-game, the following data were available and calculated: date, peak velocity (in miles per hour), mean velocity (in miles per hour), height, weight, body mass index (BMI), age, years pitching in the MLB, total pitch count, fastball pitch count, change-up pitch count, breaking pitch count, slider pitch count, knuckleball pitch count, pitch count per year, fastball pitch count per year, change-up pitch count per year, breaking pitch count per year, slider pitch count per year, and knuckleball pitch count per year. Pitcher-games between primary and revision UCLR were excluded. In addition, to avoid a lead-time bias, all pitch data after the conclusion of the 2012 season (October 28, 2012) were excluded. This exclusion was performed based on the current understanding of the pathophysiology of UCL injuries as the chronic accumulation of microtrauma. Pitches within the 2013, 2014, and 2015 seasons potentially contribute to injuries that may not yet have undergone UCLR. These injuries would then be missed via a lead-time bias. Data from 2013 to 2015 were excluded to avoid this issue.

All data analysis was performed in Excel X (Microsoft Corp) and SPSS 22 (IBM Corp) software. Mean values were calculated for the above data for each pitcher within each classification (control, preinjury, and postoperative). Data were evaluated for normality using the Kolmogorov-Smirnov test. Both univariate and multivariate analyses were conducted. In the univariate analysis, control and preinjury data and control and postoperative data were compared using Mann-Whitney *U* tests. In the multivariate analysis, a stepwise logistic regression was performed to compare preinjury and control pitchers. From this model, correlation coefficients and R^2 values (via the Nagelkerke methodology[22]), as an estimation of percentage of variance in UCLR status explained by each variable, were determined. *P* values $< .05$ were considered significant.

RESULTS

In total, over 7 million pitches are included in the PitchFx database, with 143,128 pitcher-games. In this analysis, we included 1327 pitchers, with 1018 control pitchers and 309 pitchers (26.8%) who had undergone UCLR. Of these, 145 (46.9%) had preinjury velocity data, 208 (67.3%) had postoperative velocity data, and 44 (14.2%) had both pre- and postoperative velocity data. Of the included pitchers, 36

TABLE 1
Mean Pitch Velocity, Number, and Type Between Groups[a]

	Mean (95% CI)			*P* Value	
Variable	Control	Pre-UCLR	Post-UCLR	Control vs Pre	Control vs Post
Peak velocity	92.1 (91.9 to 92.3)	93.3 (92.8 to 93.8)	92.6 (92.2 to 93)	<.001	.051
Mean velocity	86.9 (86.7 to 87.1)	87.8 (87.3 to 88.3)	87.4 (87 to 87.8)	.001	.178
Height	1.89 (1.89 to 1.89)	1.89 (1.88 to 1.9)	1.89 (1.88 to 1.9)	.934	.633
Weight	96.1 (95.5 to 96.7)	98.2 (96.7 to 99.6)	98.1 (96.8 to 99.3)	.005	.002
Body mass index	26.8 (26.7 to 27)	27.4 (27.1 to 27.8)	27.4 (27.1 to 27.8)	.002	<.001
Age	28.1 (27.9 to 28.4)	26.7 (26 to 27.3)	30 (29.4 to 30.7)	<.001	<.001
Years in the league	7.5 (7.2 to 7.7)	6.2 (5.6 to 6.8)	9.4 (8.8 to 10.1)	.001	<.001
Pitch count	2823 (2581 to 3065)	2804 (2233 to 3374)	2459 (2040 to 2877)	.083	.599
Fastball count	1764 (1611 to 1918)	1772 (1405 to 2139)	1533 (1273 to 1793)	.062	.538
Change-up count	327 (291 to 363)	290 (221 to 360)	269 (207 to 331)	.188	.365
Breaking pitch count	262 (229 to 294)	302 (209 to 396)	254 (184 to 325)	.012	.265
Slider count	435 (393 to 477)	415 (319 to 511)	386 (300 to 473)	.796	.600
Knuckleball count	18 (–7 to 43)	6 (–4 to 17)	0 (0 to 0)	.999	.087
Annual pitch count	673 (472 to 873)	589 (440 to 737)	318 (250 to 385)	.002	.045
Annual fastball count	418 (291 to 545)	377 (276 to 478)	196 (155 to 238)	.001	.063
Annual change-up count	71 (55 to 86)	59 (42 to 76)	33 (24 to 42)	.017	.006
Annual breaking pitch count	48 (39 to 57)	53 (40 to 66)	37 (25 to 50)	.003	.806
Annual slider count	129 (70 to 189)	95 (65 to 125)	49 (37 to 60)	.212	.025
Annual knuckleball count	1 (0 to 3)	1 (–1 to 2)	0 (0 to 0)	.919	.100

[a]UCLR, ulnar collateral ligament reconstruction.

(11.7%) had undergone a known UCLR revision and 1 had undergone 2 revisions.

Univariate Analysis

Peak pitch velocity was significantly higher among preinjury pitchers than control pitchers (mean [95% CI], 93.3 mph [92.8-93.8] vs 92.1 mph [91.9-92.3]; $P < .001$) (Figure 1 and Table 1). Likelihood of subsequent UCLR increased sequentially with peak pitch velocity, with 20% of pitchers with a peak pitch velocity of >95.7 mph requiring subsequent UCLR, whereas only 7.8% of those with a peak pitch velocity <86.9 mph required subsequent UCLR. Mean pitch velocity was also significantly higher among preinjury pitchers than control pitchers (87.8 mph [87.3-88.3] vs 86.9 mph [86.7-87.1]; $P = .001$) (Figure 2 and Table 1). Likelihood of subsequent UCLR increased sequentially with mean pitch velocity. Of those pitchers with a mean pitch velocity below 81.4 mph, only 7.8% required subsequent UCLR; of those pitchers with a mean pitch velocity higher than 91.0 mph, 18.3% required subsequent UCLR.

When demographics were compared between preinjury and control pitchers, preinjury pitchers had significantly higher weight ($P = .005$) (Figure 3), higher BMI ($P = .002$), younger age ($P < .001$) (Figure 4), and fewer years in the league ($P = .001$) (Table 1).

When total pitch counts were compared between control and preoperative pitchers, there were no significant differences in the overall number of pitches, the number of fastballs, the number of change-ups, the number of sliders, or the number of knuckleballs ($P > .062$ in all cases) (Table 1). Preinjury pitchers had thrown significantly more breaking

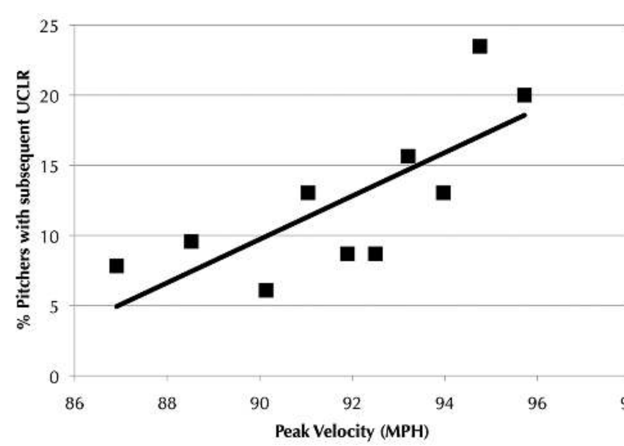

Figure 1. Percentage of pitchers requiring subsequent ulnar collateral ligament reconstruction (UCLR) versus peak pitch velocity. Data are summarized in deciles.

pitches (262 [229-294] vs 302 [209-396]; $P = .012$) (Table 1). When pitch counts were normalized by year, control pitchers threw significantly more pitches per year, fastballs per year, and change-ups per year than preinjury pitchers ($P < .017$ in all cases) but fewer breaking pitches ($P = .003$) (Table 1).

Multivariate Analysis

On multivariate regression, peak pitch velocity was the primary independent predictor of whether a pitcher subsequently underwent UCLR ($P < .001$, $R^2 = 0.036$) (Table 2).

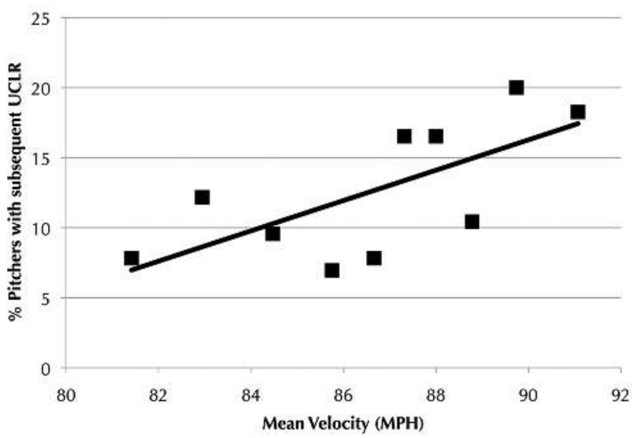

Figure 2. Percentage of pitchers requiring subsequent ulnar collateral ligament reconstruction (UCLR) versus mean velocity. Data are summarized in deciles.

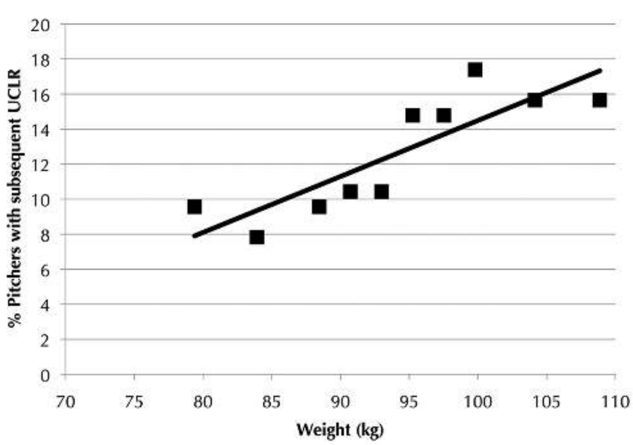

Figure 3. Percentage of pitchers requiring subsequent ulnar collateral ligament reconstruction (UCLR) versus pitcher weight. Data are summarized in deciles.

After accounting for correlation owing to peak pitch velocity, mean pitch velocity negatively correlated with likelihood of UCLR (P = .013, R^2 = 0.013). BMI was positively correlated with likelihood of UCLR (P = .010, R^2 = 0.009), and age (P = .006, R^2 = 0.01) was negatively correlated with UCLR.

DISCUSSION

Previous studies have identified fatigue and pitch counts as primary risk factors for injury in baseball pitchers,[17] leading to the current guidelines regarding pitch counts.[26] The purpose of this study was to determine UCLR-specific predictors among MLB pitchers. We found peak pitch velocity to be the strongest predictor of subsequent UCLR. Although the absolute difference in peak pitch velocity between uninjured controls and preinjury pitchers was only 1.2 mph,

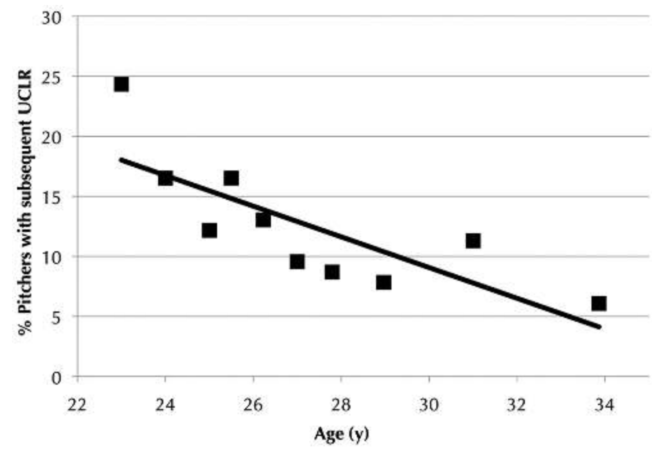

Figure 4. Percentage of pitchers requiring subsequent ulnar collateral ligament reconstruction (UCLR) versus pitcher age. Data are summarized in deciles.

a clear dose-response relationship can be observed when peak pitch velocity and likelihood of subsequent UCLR are compared. Likelihood of subsequent UCLR increased sequentially with peak pitch velocity, with 20% of pitchers with a peak pitch velocity of >95.7 mph requiring subsequent UCLR, whereas only 7.8% of those with a peak pitch velocity <86.9 mph required subsequent UCLR—a 2.6-fold reduction in risk. In addition, higher BMI and younger age also independently correlated with injury, and in combination, these factors create an injury risk profile within pitcher body habitus, pitcher experience, and pitch type. Our results suggest that the UCLR-at-risk pitcher is young, heavy, and hard throwing. However, a model constructed with these variables only explained 7% of the variance in UCLR rates.

The findings of the current study suggest that pitch counts may need to be considered in concert with velocity to best prevent injury. Several studies have clearly demonstrated the rising number of UCLRs in MLB pitchers, but no definitive explanation for this recent increase has been offered.[9,20] Mean pitch velocity has steadily increased in professional baseball over the past decade, which may offer an explanation.[3] Further, large-scale prospective studies will be necessary to determine the interaction between velocity, pitch counts, and pitching through fatigue so that guidelines can be optimized to best prevent injury. Based on the results of our study as well as 2 previous studies identifying velocity as a risk factor for injury,[4,6] high velocity pitchers may be optimal targets for injury prevention. In particular, high velocity pitchers may need lower pitch counts or a greater focus on mechanics than low velocity pitchers. The role of breaking pitches in the risk for injury remains unclear. Although initial epidemiologic studies suggested breaking pitches to predict arm pain in youth pitchers,[17] biomechanical studies have failed to demonstrate any increase in torque with breaking pitches compared with fastballs[8,15,23] and further clinical studies have also failed to confirm this relationship.[6,12,24] Within our results, although breaking pitches were identified as a risk factor on univariate analyses, they were not

TABLE 2
Parameters of Stepwise Logistic Regression Comparing Preinjury Players With Uninjured Controls

Variable	*P* Value	Beta Coefficient	Standard Error	R^2
Peak velocity	.001	0.271	0.079	0.036
Mean velocity	.013	–0.166	0.067	0.013
Body mass index	.010	0.106	0.041	0.009
Age	.006	–0.081	0.03	0.01

a risk factor on multivariate analyses once peak velocity, age, and weight were accounted for and are thus not an independent risk factor. Within our data set, breaking pitches thus only predict injury because they correlate with velocity, weight, and age, which are independent risk factors. Previous studies may have identified breaking pitches as risk factors for injury because velocity was not measured within these studies and not because breaking pitches contribute to injury.

Within the current study, mean pitch velocity is positively correlated with subsequent UCLR on univariate analysis. However, on multivariate analysis, after accounting for peak pitch velocity, mean pitch velocity is negatively correlated with subsequent UCLR. This change suggests that the findings of the univariate analysis are driven by the high correlation between mean and peak velocity (Pearson correlation coefficient = 0.919, $P <$ .001). Multivariate analysis thus suggests that UCLR risk is driven by higher peak and not higher mean velocity. A negative relationship between mean velocity and injury has not been previously described. Although the precise reason for this negative relationship is unclear, it is possible that once the variance in injury attributable to high peak velocity has been explained, higher mean pitch velocity may correlate with pitcher experience and efficiency in the kinematic chain and may thus be protective. Overall, these findings suggest that the current pathobiomechanical model for UCLR of cumulative repetitive microtrauma, as measured by mean pitch velocity, may be less important for tear creation than the peak stresses encountered by the ligament, as measured by peak pitch velocity.

Within the current study, both weight and BMI were found to correlate with injury on univariate analysis, and BMI was found to correlate with injury in multivariate analysis. To the best of the authors' knowledge, no previous study has identified weight as a predictor for injury. Multiple potential explanations exist for this finding. Heavier pitchers may have a higher muscle mass that could then translate into higher shoulder and elbow torques. Alternatively, heavier pitchers may have a mild degree of the metabolic syndrome, which could lead to microvascular changes inhibiting reparative processes, similar to as observed in Achilles tendinosis.[16] Flexibility or deficiencies in the kinetic chain specific for heavier pitchers may also play a role. In addition, height was not significantly different between preinjury and control pitchers. Previous studies have suggested that forces and torque should be normalized for subject height, because taller individuals can exert more force and torque through the upper extremity as a result of the overall longer lever arm.[1,7] Previous studies have suggested height to correlate with a history of injury among youth pitchers.[6] It remains unclear why height did not act as a predictor within this cohort, although MLB pitchers are highly selected compared with youth pitchers and may simply display less variance within height.

Within the current study, preinjury pitchers were significantly younger than control pitchers. This may be because older pitchers may be more likely to retire and less likely to undergo UCLR when they sustain a UCL tear. Youth and adolescent pitchers appear to be undergoing UCLR at increasing frequencies and this difference may reflect this overarching trend toward UCLR at younger ages.[5,10] Alternatively, if a pitcher undergoes UCLR, then only those pitches from before the UCLR are counted toward mean age, which by definition leads to a lower mean age.

Multivariate analysis allowed the estimation of the percentage of variance in UCLR rates explained by each included variable. The overall model explained only 6.8% of UCLR variance, with peak pitch velocity accounting for 3.6% of variance, mean pitch velocity accounting for 1.3%, BMI accounting for 0.9%, and age accounting for 1.0%. Factors not included in this analysis therefore accounted for the majority (93.2%) of the variance in UCLR rates. The variables included in this analysis were relatively weak predictors. However, many of these factors have been identified as the best injury predictors in past analyses[4,12,17,28] and have been codified into recommendations.[19,26] Our analysis thus indicates that further research is warranted to identify more strongly predictive injury risk factors.

Strengths of the study include the size of the cohort and the comparative design. Limitations include the use of publically available data, which may be incomplete or inaccurate. This methodology has been used on numerous previous occasions for this particular population.[9,20] Because only publically available data were used, numerous variables are not included in this study, such as hand dominance, pitch counts in noncompetition settings, medical history, concomitant injuries, other procedures, other injuries, technique used for UCLR, rehabilitation program, and so forth. These factors can certainly influence both preinjury and postoperative data. Data within the PitchFx database are collected using a variety of radar guns, which vary in accuracy and reliability, as well as using human observers to assign pitch type, which also vary in accuracy in reliability. This limitation applies to both the study and control groups. Our findings will need to be confirmed in a prospective cohort study. In addition, not all pitchers who sustain UCL tears undergo subsequent UCLR. Some players within the control group could thus have sustained UCL tears and could have decided to retire or could have managed their injuries nonoperatively instead of opting for UCLR; thus, the current conclusions apply only to subsequent UCLR and not necessarily UCL tears. Pitchers who retired as a result of injury may have had lower preinjury velocities, which could have contributed to the differences observed between groups. Pitchers who underwent UCLR before entering the MLB could be inappropriately counted as controls instead of as postoperative pitchers. The last limitation is the possibility of a lead-time bias. Some of the pitchers considered uninjured controls within this study could subsequently go on to have a subsequent UCLR. To mitigate against lead-time bias, no pitch data subsequent to 2012 were analyzed. In combination, these limitations prevent the current findings from altering guidelines. However, given that these findings are concordant with prior studies examining the connection between velocity and injury,[4,6] future prospective studies should account for this variable. Our analysis analyzed only UCLR and not other upper extremity or lower extremity pitching injuries and thus may not apply to other pitching injuries. These other injuries may be the subject of future similar analyses. Future analyses within this database could also incorporate release point statistics, which were not considered in this analysis.

CONCLUSION

Higher pitch velocity is the most predictive factor of UCLR in MLB pitchers, with higher weight and younger age being secondary predictors, although these factors only explained 7% of the variance in UCLR rates.

ACKNOWLEDGMENT

The authors thank Jeffrey Zimmerman and Darrell Zimdar for assistance with data procurement.

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