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How many innings can we throw: does workload influence injury risk in Major League Baseball? An analysis of professional starting pitchers between 2010 and 2015

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Background: There has been increasing interest regarding the association between pitch counts, as well as total workload per season, and the risk of injury among Major League Baseball (MLB) starting pitchers.
Methods: We used publicly available databases to identify all MLB starting pitchers eligible for play who made at least 5 starts in seasons between 2010 and 2015. For all included pitchers, annual pitching statistics (number of starts, total season pitch counts, total season inning counts, and average pitch count per game started) and annual disabled list (DL) information (time on DL for any reason and time on DL related to upper extremity, lower extremity, or axial body injury) were collected. A multiple logistic regression analyzed games started, pitch counts, innings pitched, and pitches per start during all previous seasons as a risk factor for injury in the current season, controlling for previous injury.
Results: A total of 161 starting MLB pitchers met the inclusion criteria. With the exception of total innings pitched from 2010-2011 being significantly associated with DL placement in 2012 (no DL, 310.5 ± 97.5 innings; DL, 344.7 ± 85.9 innings; $P = .040$), no other finding for starts, pitch counts, innings, or pitches per start in the cumulative years from 2010-2014 had a significant association with pitcher placement on the DL for any musculoskeletal reason or for an upper extremity reason between 2011 and 2015.
Conclusions: In this study, we demonstrate that there is no association between preceding years of cumulative pitches, starts, innings pitched, or average pitches per start and being placed on the DL for any musculoskeletal reason.

Institutional review board or ethics committee approval was not applicable as all information was gathered from publicly available databases.

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Level of evidence: Level II; Retrospective Design; Prognostic Study
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Keywords: Major League Baseball (MLB); pitcher; pitches; disabled list; injury; innings pitched

Conservative estimates have found that the sport of baseball accounts for greater than 50,000 injuries per year, with documented rates ranging from 2 in 100 players at the Little League level[15] to 58 in 100 players at the Major League Baseball (MLB) level.[14] From the 2002 MLB season through the 2008 season, an average of 438.9 players per year were placed on the disabled list (DL), yielding a rate of 3.61 per 1000 athlete exposures. An important finding was that a significant 37% increase in injuries was also noted between 2005 and 2008.[23] Over this study period, pitchers had a 34% higher incidence rate of injury when compared with fielders, as well as a significantly greater proportion of injuries to the upper extremity. Pitchers also had a greater proportion of days on the DL when compared with fielders. From 1998-2015, a total of 8357 DL designations were recorded (mean of 464 annually) among all MLB players. As in other sports, there is widespread concern about the incidence, epidemiology, and associated costs of injuries in these professional athletes.

Pitchers are at particular risk of injuries to the upper extremity given the biomechanics of the overhead throwing motion, in which shoulder internal rotation velocities and elbow extension velocities are high and activation of the accelerator muscles (subscapularis, latissimus dorsi, and pectoralis major) is unparalleled.[20] In addition, the strenuous training and season schedule may fatigue pitchers. The starting pitcher plays a prominent role in a club's success. Injuries in pitchers may be more significant than those in position players with greater numbers of days missed, particularly from injury to the elbow, in which injury leads pitchers to 27 times and 34 times the rate of days missed compared with position players and all players, respectively.[20]

While the aforementioned epidemiologic studies have identified rising trends in injuries, they have not provided clear reasons or predictive factors for them. Observed injury patterns in baseball are multifactorial, and studies that identify a causal relationship between pitching variables and injury patterns in MLB pitchers are lacking. For instance, there has been increasing attention in the media regarding the association between pitch counts and the risk of injury among MLB starting pitchers, yet at present, there are no data linking pitch counts to injury risk. Limits on pitch counts for professional pitchers have been decided arbitrarily or nonscientifically but have led to a drastic decline in the maximum number of pitches thrown per game over the past 30 years.[2]

The ability to predict which pitchers are more susceptible to injury and need for time on the DL would provide invaluable information to the team medical staff, players, and management, as these injuries greatly affect the athlete's income, performance, and career longevity and the baseball organization's success.[19] Conversely, the ability to suggest which factors do not increase a pitcher's risk of injury could help to select which variables of a pitcher's game should be modified. The primary purpose of this study was to determine whether there was an association between average pitch count per game, cumulative pitch counts, cumulative innings pitched, or cumulative number of starts over a multi-year period and the subsequent risk of injury requiring time on the DL. Our hypothesis was that there would be no correlation between the aforementioned pitching metrics and the ensuing risk of any injury requiring DL time.

Methods

We used publicly available databases to retrospectively identify all MLB starting pitchers eligible for play who made at least 5 starts in seasons between 2010 and 2015. Players were excluded from the analysis if they underwent a previous surgical procedure during the period of interest, had an injury in a current year from trauma or a medical reason, or began a season on the DL because of an injury that carried over from the previous year; if they were injured during spring training and began the season on the DL, they were included in the analysis for that year. Trauma was defined as any injury due to an impact or/blunt trauma such as a fracture, laceration, contusion, or concussion. Annual pitching statistics (number of starts, total season pitch counts, total season inning counts, and average pitch count per game started) and annual DL information (time on DL for any reason and time on DL related to upper extremity, lower extremity, or axial body injury) were collected for all included pitchers from 2010 through 2015. Information on player statistics was obtained from the publicly available Baseball-Reference.com and Fangraphs.com websites, as has been used before in studies of this genre.[12] Data on player injuries and the DL were identified through prior studies, MLB team websites, and publicly available Internet-based injury reports.[13]

The DL is a mandated part of MLB that defines, in a single database, the injuries of all professionals and the time lost from participation. To be placed on the DL, a player is certified as unable to play, with a specific diagnosis made by the head team physician; the player remains on the DL for a minimum of 15 days but remains longer if necessary to be ready for return to play.[7]

Statistical analysis

Descriptive statistics were determined and reported as means and standard deviations for continuous variables. Time on the DL was a binary variable (any time vs no time on the DL). We performed a multiple logistic regression analyzing games started, pitch counts, innings pitched, and pitches per start during all previous seasons as a risk factor for any musculoskeletal injury in the current season, controlling for previous injury. We performed an additional analysis looking only at players with upper extremity injuries versus uninjured players using the same analysis, as well as a comparison

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between the 3 injury types. Statistical significance was defined as $P < .05$ (2-sided α of .05). Analyses were conducted using STATA software (version 13.1; StataCorp, College Station, TX, USA).

Results

A total of 161 starting MLB pitchers met the criteria to be included in our study. In each year from 2011 through 2015, upper extremity injury was responsible for more DL occurrences and total DL days than lower extremity or axial body injury, and in each year except 2013 (axial injury, 87 ± 74 days/pitcher; upper extremity injury, 54 ± 43 days/pitchers), upper extremity injury also accounted for higher average days spent per player on the DL than the other injury locations (Table I).

With the exception of total innings pitched from 2010-2011 being significantly associated with DL placement in 2012 (no DL, 310 ± 97 innings; DL, 344 ± 85 innings; $P = .04$), no other finding for starts, pitch counts, innings, or pitches per start in the cumulative years from 2010-2014 had a significant association with pitcher placement on the DL for any musculoskeletal reason between 2011 and 2015 (Tables II and III). In addition, we found no significant differences in starts, pitch counts, innings, or pitches per start in any year when comparing upper extremity, lower extremity, and axial injuries.

Discussion

No study to this point has demonstrated a definitive correlation between cumulative work (number of total pitches thrown, games pitched, total innings pitched per game, pitches thrown per game) and injury in MLB pitchers, although studies have found this correlation in youth pitchers.[11] Thus, although limitations being imposed on MLB starting pitchers are ubiquitous, the efficacy of injury prediction from such cumulative work metrics as pitches per game or total starts has remained in question. Our study aimed to definitively determine whether an association exists between average pitch count per game, cumulative pitch counts, cumulative innings pitched, or cumulative number of starts over a multi-year period and the risk of injury requiring time on the DL for starting pitchers in MLB. Our hypothesis was confirmed, as there was no association of these pitching metrics between 2010 and 2015 with the subsequent odds thereafter of being placed on the DL for any reason—any musculoskeletal injury or upper extremity injury.

In 2001, Conte et al[7] reported that from 1989 to 1999, the number of players and player days on the DL gradually and consistently increased. In particular, the frequency with which pitchers were placed on the DL was increasing, as was the proportion of DL days. This finding seems contrary to conventional wisdom that would suggest that better diagnostic methods, improvements in conditioning and training, and superior therapeutic strategies would reduce the number of MLB players sustaining injury and time on the DL.

The most recent data suggest that overall injury rates and DL assignments in MLB continue to rise and represent a significant source of lost revenue.[6] Pitcher metrics quantifying one's workload can include games pitched, innings pitched, and number of pitches thrown.[16] Consideration of the number of pitches thrown is a potential concern given the high rate and magnitude of biomechanical loading on the tissues during the pitching motion, as well as fatigue-related pathology.[16] Baseball pitchers subject the shoulder and elbow in particular to extreme repetitive stresses. Even asymptomatic pitchers have been demonstrated to show shoulder and elbow abnormalities on radiographic and advanced imaging and dynamic ultrasonography.[18,19,22,26] Hence, the maximum number of pitches thrown in an MLB game

Table I Year-by-year breakdown of injuries

	Overall	UE	LE	Axial
Injury year 2011				
No. of injuries (days on DL)	54 (4040)	34 (3005)	7 (337)	13 (698)
Average days/pitcher	81 ± 108	94 ± 127	56 ± 43	58 ± 49
Injury year 2012				
No. of injuries (days on DL)	44 (3460)	29 (2793)	7 (405)	8 (262)
Average days/pitcher	91 ± 120	121 ± 139	58 ± 92	33 ± 20
Injury year 2013				
No. of injuries (days on DL)	40 (1902)	28 (1255)	7 (211)	5 (436)
Average days/pitcher	54 ± 47	55 ± 44	30 ± 18	87 ± 74
Injury year 2014				
No. of injuries (days on DL)	29 (2105)	16 (1359)	10 (617)	3 (28)
Average days/pitcher	75 ± 96	91 ± 123	62 ± 57	43 ± 19
Injury year 2015				
No. of injuries (days on DL)	22 (1318)	14 (1019)	6 (237)	2 (62)
Average days/pitcher	60 ± 49	73 ± 55	40 ± 32	31 ± 9

UE, upper extremity; *LE*, lower extremity; *DL*, disabled list.

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Table II Year-by-year comparison of workload for injured and uninjured players*

	Overall	No DL	DL	*P* value*
Injury year 2011	n = 161	n = 107	n = 54	
Starts (2010)	25 ± 9	25 ± 9	26 ± 7	.401
Count (2010)	2537 ± 845	2525 ± 908	2561 ± 710	.555
Innings (2010)	154.4 ± 54.2	154.4 ± 58.2	154.4 ± 45.6	.719
Pitches per start (2010)	103 ± 18	103 ± 20	101 ± 11	.331
Injury year 2012	n = 134	n = 90	n = 44	
Starts (2010-2011)	52 ± 14	51 ± 14	55 ± 12	.072
Count (2010-2011)	5244 ± 1473	5083 ± 1529	5573 ± 1307	.057
Innings (2010-2011)	321.7 ± 94.9	310.5 ± 97.5	344.7 ± 85.9	.040†
Pitches per start (2010-2011)	100 ± 7	100 ± 7	101 ± 6	.311
Injury year 2013	n = 93	n = 54	n = 39	
Starts (2010-2012)	81 ± 16	83 ± 15	77 ± 17	.118
Count (2010-2012)	8056 ± 1835	8341 ± 1736	7660 ± 1917	.117
Innings (2010-2012)	494.0 ± 118.6	511.2 ± 114.2	470.3 ± 122.0	.150
Pitches per start (2010-2012)	99 ± 6	100 ± 5	98 ± 6	.240
Injury year 2014	n = 68	n = 39	n = 29	
Starts (2010-2013)	112 ± 19	110 ± 22	113 ± 16	.523
Count (2010-2013)	11,275 ± 2183	11,001 ± 2547	11,345 ± 1867	.486
Innings (2010-2013)	693.3 ± 142.2	675.6 ± 164.0	698.7 ± 122.4	.458
Pitches per start (2010-2013)	100 ± 4	100 ± 5	100 ± 4	.509
Injury year 2015	n = 54	n = 33	n = 21	
Starts (2010-2014)	143 ± 19	143 ± 20	142 ± 19	.861
Count (2010-2014)	14,399 ± 2211	14,414 ± 2281	14,215 ± 2217	.832
Innings (2010-2014)	882.9 ± 145.1	887.8 ± 155.6	865.3 ± 133.6	.663
Pitches per start (2010-2014)	101 ± 4	101 ± 4	100 ± 4	.764

DL, disabled list.
* Calculated using multiple logistic regression controlling for previous injury.
† Statistically significant with α of .05.

has declined from the 1980s and 1990s (highs in the 160s or 170s) to the 2000s (highs in the 130s).[2]

High-level pitchers clearly exhibit adaptive changes in their biomechanics in response to increased exertion and physiological fatigue as pitch counts increase over the course of a game.[8,21] Whiteside et al[25] evaluated changes in pitching performance characteristics across innings in MLB games. They reported a significant decrease in pitch speed and proportion of hard pitches thrown as the game progressed, with the largest differences between the first inning and the late innings (seventh-ninth). These data revealed that several aspects of a starting pitcher's performance change from baseline as early as the second or third inning of an MLB game, although they did not correlate these performance declines with relevance to injury occurrence or patterns. Bradbury and Forman[2] examined the performances of 1058 MLB starting pitchers from 1988-2009 by use of fractional polynomial multiple regression to estimate the impact of pitches thrown on performance. They found that each pitch thrown in the preceding game increased the earned run average (ERA) by 0.007 in the following game, when controlling for other factors that likely affect pitcher effectiveness. In addition, each pitch averaged in the preceding 5 and 10 games increased the ERA by 0.014 and 0.022, respectively. Thus, the authors concluded that a negative linear relationship exists between past pitches thrown and future performance and that this pitching load is cumulative—but they cautioned that this magnitude is small.

Karakolis et al[16] evaluated the cumulative work for pitchers during the 2002-2007 seasons and injury days and, through regression analyses, found that no cumulative work metric was a significant predictor of future injury. It is interesting to note that they reported that a negative correlation existed between pitching more than 220 innings in a season and the injury rate. They also found a threshold of 3300 pitches in a season, after which the injury rate for an MLB pitcher actually decreased. The authors believed that those pitchers who have the ability to throw such high numbers of pitches may have unique pitching mechanics or tissue tolerances that would allow them to do so. However, they did note an increasing trend toward injury with pitches per appearance, starting from the cohort throwing 41-50 pitches to the cohort throwing 91-100 pitches. Ultimately, the authors suggested that management of a pitcher's playing schedule based on these metrics alone would be ineffective in preventing injury. Studies have since demonstrated that higher pitch counts are associated with lower future performance levels, with each pitch averaged in the preceding 5 games and 10 games leading to an increased ERA of 0.014 and 0.022, respectively.[12] However, no study exists that has correlated pitch count and the risk of future injuries.[20]

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Table III Year-by-year comparison of workload for players with upper extremity injuries and uninjured players

	Overall	No DL	UE DL	*P* value*
Injury year 2011	n = 141	n = 107	n = 34	
Starts (2010)	25 ± 9	25 ± 9	26 ± 7	.403
Count (2010)	2535 ± 870	2525 ± 908	2564 ± 749	.642
Innings (2010)	154.8 ± 55.6	154.4 ± 58.2	155.9 ± 47.0	.691
Pitches per start (2010)	102 ± 18	103 ± 20	99 ± 5	.204
Injury year 2012	n = 119	n = 90	n = 29	
Starts (2010-2011)	52 ± 14	51 ± 14	54 ± 12	.260
Count (2010-2011)	5163 ± 1461	5083 ± 1529	5414 ± 1219	.251
Innings (2010-2011)	316.1 ± 93.1	310.5 ± 97.5	333.4 ± 76.7	.209
Pitches per start (2010-2011)	100 ± 7	100 ± 7	101 ± 6	.500
Injury year 2013	n = 82	n = 54	n = 28	
Starts (2010-2012)	81 ± 16	83 ± 15	77 ± 18	.144
Count (2010-2012)	8072 ± 1862	8341 ± 1736	7552 ± 2014	.139
Innings (2010-2012)	495.5 ± 119.8	511.2 ± 114.2	465.3 ± 126.5	.191
Pitches per start (2010-2012)	99 ± 5	100 ± 5	98 ± 5	.184
Injury year 2014	n = 55	n = 39	n = 16	
Starts (2010-2013)	110 ± 21	110 ± 22	112 ± 18	.618
Count (2010-2013)	11,057 ± 2404	11,001 ± 2547	11,194 ± 2086	.628
Innings (2010-2013)	682.9 ± 157.1	675.6 ± 164.0	700.6 ± 142.4	.446
Pitches per start (2010-2013)	100 ± 5	100 ± 5	100 ± 4	.762
Injury year 2015	n = 47	n = 33	n = 14	
Starts (2010-2014)	142 ± 20	143 ± 20	139 ± 21	.684
Count (2010-2014)	14,273 ± 2337	14,414 ± 2281	13,940 ± 2520	.728
Innings (2010-2014)	876.1 ± 153.8	887.8 ± 155.6	848.7 ± 151.3	.634
Pitches per start (2010-2014)	101 ± 4	101 ± 4	100 ± 4	.948

DL, disabled list; *UE*, upper extremity.

* Calculated using multiple logistic regression controlling for previous injury, with statistical significance defined as α of .05.

Many studies have evaluated how different variables and parameters of MLB pitchers predict ulnar collateral ligament (UCL) injury and reconstruction needs in particular. Chalmers et al[4] determined that higher pitch velocity is the most predictive factor of ulnar collateral ligament reconstruction (UCLR) in MLB pitchers, with higher weight and younger age being secondary predictors. Whiteside et al[24] found that fewer days between consecutive games, a smaller repertoire of pitches, smaller stature, a less pronounced horizontal release location, a greater mean pitch speed, and greater mean pitch counts per game were all significant predictors of UCLR in MLB pitchers. Keller et al[17] found conflicting results, suggesting that MLB pitchers requiring UCLR did not pitch at higher velocities than matched controls and that pitch velocity was not a risk factor for UCLR. They did, however, report that pitchers who pitched a high percentage of fastballs may be at increased risk. The contribution of fastball velocity to UCL injury risk was identified by DeFroda et al[10] as well.

However, few studies have evaluated the risks of other injuries in starting MLB pitchers. This is despite the fact that injuries to the hip and groin of professional baseball players (including labral tears, chondral defects, athletic pubalgia, muscle strains, and avulsions), as well as the knee joint (including contusions or hematomas, sprains, ligament injuries, tendinopathy or bursitis, and meniscal or cartilage injuries) and core or lumbar spine, continue to be on the rise as well and lead to a substantial number of days on the DL.[3,5,9] Hamstring injuries in the 2011 MLB season, for instance, occurred at an injury rate of 0.7 per 1000 athlete exposures and resulted in a mean of 24 days of play missed.[1]

Thus, our study provides additional valuable and up-to-date insight into the absence of correlation between pitch count, innings pitched, and game appearances and the risk of injury in starting MLB pitchers. This study uses cumulative pitcher data from 5 consecutive seasons of pitching to determine the associations with injury and thereby intends to reduce the effect of confounding variables from individual seasons on the overall aggregate findings. In addition, while most of the aforementioned studies have focused on shoulder and elbow injuries including UCL rupture (which remain most prevalent in pitchers), our data confirm that the collective pitching variables of interest over the 2010-2015 period additionally do not increase the odds of any musculoskeletal injury, including upper extremity, lower extremity, or axial body injury.

Of note, the total range of (number of) pitches per start for all pitchers—and when comparing those with and without DL time—demonstrates a relatively narrow range for pitch count. This highlights the current trend in MLB where teams are more closely following pitch counts for starting pitchers given the pervasive belief from previous years that this would reduce overuse injury. This narrow pitch count range also limits our ability to understand through data analysis whether a wider

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range of pitch counts—or, more specifically, a higher upper range—would correlate with DL time and occurrence.

Postinjury as well as preventive protocols have been suggested for various pathologies to decrease a player's risk of injury or reinjury. An integrated approach to injury prevention for starting pitchers in MLB is imperative. For instance, consideration of scheduled musculoskeletal examinations at regular intervals during the MLB season and/or off-season may be worth further discussion. In addition, future data collection that could be of value in predicting injury or assisting prevention should be performed; this could include more situation-specific data that can be tested for significance in reducing DL time, such as number of pitches with runners on base or in scoring position, or situation-specific pitch counts after 0, 1, or 2 outs. Multidimensional factors such as interviews, questionnaires, stress examinations, ultrasound, and magnetic resonance imaging are additionally imperative to evaluating stresses and overuse activity in the shoulder and elbow of MLB pitchers who did not meet the threshold for DL occurrence and thus documented injury. Future study would be necessary to conduct to determine whether adherence to suggested guidelines actually effectively prevents injury in the MLB starting pitcher, as well as to further define and understand what variables actually lead to injury and DL time in pitchers.

Limitations

Our study has limitations. As our information on player statistics was obtained from records in a publicly available database, we are limited to the accuracy with which these records were kept. Our analysis does not capture those injuries that occurred in MLB but were not sufficient to require the player to be placed on the DL; thus, we cannot comment on less severe injuries and their effect on MLB pitchers. As a result, reported injury rates are likely underestimated. Since we excluded pitchers who did not pitch at least 5 games in a season, this could have introduced an element of selection bias, although we believed this strengthened uniformity within our cohort selection. Because some players were included in 1 season (via starting ≥5 games) but not another season if they played fewer than 5 games, our study does not definitively include longitudinal data to analyze trends in injuries with time. However, implementing this criterion, we ensure that each season is comparing players who were eligible for a similar number of games and is not confounded by players who may not have been in the league in earlier seasons. We were also unable to track off-season injuries in these players unless such injuries caused them to be placed on the DL at the beginning of the season of interest. In addition, we limited our analysis to starting pitchers only; thus, our data do not suggest the association between average pitch count per game and risk of injury requiring time on the DL for relief pitchers or for position players. Also important to note is that, as this study focuses its analysis on an "in-game" cumulative work statistic,[16] namely pitch count, it is limited in suggesting how the "between-game" or off-season cumulative work statistics (including pitches thrown during an off-day bullpen session, strength training, and days of rest between starts) affect the injury patterns.

Furthermore, we did not analyze treatment of injuries and factors that affect return to play, including differences between individual players and variability in rehabilitation or medical support between affiliated MLB teams. These data are also limited to professional MLB players and thus are not necessarily generalizable to Minor League or amateur baseball players or participants in other sports. Moreover, as the numbers of pitchers who went on the DL each year and/or required surgical intervention for their injury designation were relatively small, our study was underpowered to more closely analyze specific statistical data for these injured players to generate further results.

Finally, the data (ie, starts, pitch counts, and innings pitched) over the period from 2010-2015 are limited overall by current pitching volume limits or recommendations imposed on the pitchers by particular coaches and/or teams. Thus, the findings of our study do not promote the safety of unlimited or unregulated throwing. Rather, our results suggest that, within the current scope of pitching norms from the past half decade, we are unable to identify pitching volume as an independent risk factor for injury.

Conclusion

In this study, we demonstrate that there is no association between preceding years of cumulative pitches, starts, innings pitched, or average pitches per start and being placed on the DL for any musculoskeletal reason.

Disclaimer

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