Increased pitch velocity and workload are common risk factors for ulnar collateral ligament injury in baseball players: a systematic review

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ABSTRACT

Importance Ulnar collateral ligament (UCL) injuries commonly occur in baseball players. Strategies for injury prevention have long been accepted without clinical data informing which risk factors lead to serious injury.

Objective The objective of this study was to systematically review the impact of various pitching-related risk factors for UCL injury in baseball players from all levels of play.

Evidence review The electronic databases MEDLINE, EMBASE and PubMed were systematically searched until 4 March 2018, and pertinent data were abstracted by two independent reviewers. Search terms included 'ulnar collateral ligament', 'medial ulnar collateral ligament', 'Tommy John', 'risk' and 'association'. Inclusion criteria were English-language studies, level of evidence I–IV and studies reporting risk factors for UCL injury of the elbow in baseball players. Study quality was assessed using the methodological index for non-randomised studies (MINORS) criteria. The results are presented in a narrative summary.

Findings Pitching practices (workload and pitch characteristics) were reported in 9/15 studies. Specifically, three of four studies (n=1810) reported increased pitch workload as a risk factor for native UCL injury ($p<0.001$ to 0.02). The most common pitch characteristic reported was pitch velocity with four of five studies showing increased velocity being significantly associated with native UCL injury ($p<0.01$ to 0.02). Biomechanical risk factors reported were increased humeral retrotorsion (two studies; n=324), poor lower extremity and trunk balance (one study; n=42) and loss of total arc of shoulder motion (two studies; n=118), all significantly associated with UCL injury ($p<0.0001$ to 0.05). One of three studies assessing pitch workload as a risk factor for re-rupture of UCL reconstruction found a significant association ($p<0.01$).

Conclusions and relevance Pitching practices, reflected by increased pitch workload and velocity, were most commonly associated with UCL injury; however, the definition of workload (number of pitches per game, inning or season) was inconsistently reported. Biomechanical risk factors were less commonly reported and lack sufficient evidence to recommend preventative strategies. More quality data is needed to refine the current recommendations for injury prevention in baseball players.

Level of evidence III.

What is already known

- Ulnar collateral ligament (UCL) injuries commonly occur in baseball players.
- Strategies for injury prevention have long been accepted without clinical data informing which risk factors lead to serious injury.

What are the new findings

- Pitching practices, reflected by increased pitch workload and velocity, were most commonly associated with UCL injury.
- The definition of workload (number of pitches per game, inning or season) was inconsistently reported.
- Biomechanical risk factors were less commonly reported and lack sufficient evidence to recommend preventative strategies.

INTRODUCTION

Elbow overuse injuries are highly prevalent among baseball players, in particular pitchers.[1] Ulnar collateral ligament (UCL) tears represent one of the most common elbow injuries in baseball players. Evidence suggests that the rate of UCL injuries in baseball players has been rising dramatically in recent years.[2] Baseball pitchers put very high amounts of stress through their elbow when pitching. Biomechanical studies have shown that pitchers may exert, on average, over 90 n◦m of valgus torque through their elbow during the late cocking phase of pitching.[3] Although the dynamic (eg, flexor-pronator mass) and static (eg, coronoid, radiocapitellar joint and capsule) stabilisers protect the elbow from injury, cadaveric studies have shown that the UCL can only withstand an average varus torque of 32.1 n◦m before failing.[4] Thus, repetitive throwing can lead to attenuation and rupture of the UCL, which subsequently presents as medial elbow pain, poor pitch control, reduced velocity and decreased endurance of the throwing arm.[5]

UCL injuries were often career-ending injuries for competitive baseball players before the development of UCL reconstruction (UCLR), commonly known as Tommy John surgery in 1974.[6] While UCLR offers athletes return to sports rates of 80%–92%,[7 8] some studies have suggested that player in-game statistics may decline after

UCLR.[9 10] In addition, it can take athletes well over a year to be able to return to sport after UCLR.[7 11] Therefore, determining risk factors for UCL injury or failure of UCLR is of critical importance in order for physicians and trainers to advise athletes on steps that can be taken to minimise risk of injury. Studies have hypothesised that athlete workload,[12] pitching mechanics[13] and pitch type[13] may contribute to the development of UCL injuries. Furthermore, the rate of UCL injuries is shown to be highest among adolescent (15–19 years) pitchers.[2] Thus, many authors have recommended that leagues set strict pitch limits, allow athletes to only participate in one league at a time and prohibit curveballs or sliders in younger age demographics.[13] Furthermore, Little League Baseball replaced their inning limit rule with pitch count limits and added rules such as prohibiting participants from playing pitcher and catcher in the same game.[14] However, athlete and coach compliance with these restrictions has been an issue.[15] There are also many public misconceptions about UCL injuries and UCLR. One study showed that many athletes and coaches believe that UCLR may actually enhance players' performance.[16]

The objective of this study was to systematically review the impact of various pitching-related risk factors for UCL injury in baseball players from all levels of play. This review will provide evidence-based recommendations for which players, coaches and healthcare providers can use to assess and monitor potential risk factors in order to help tailor players' training and care accordingly.

METHODS

Search strategy and eligibility

Three online databases (PubMed, EMBASE, MEDLINE) were searched by one author (NH) for literature on risk factors for UCL injury and/or UCLR revision from database inception to 4 March 2018. Search terms included 'ulnar collateral ligament', 'Tommy John', 'risk', 'association' and similar phrases (online supplementary appendix table 1). The search terms were also entered into Google Scholar, a search engine for scholarly literature from various disciplines and sources (eg, articles, theses, books, etc), to help ensure that relevant articles were not missed. References of included studies were also screened using the same systematic approach. The research question and inclusion and exclusion criteria were established a priori. Inclusion criteria were (1) level of evidence I–IV; (2) male and female patients of all ages; (3) papers published in English; (4) studies on humans; (5) studies reporting on risk factors for UCL injury of the elbow; (6) baseball players; (7) all positions; (8) all levels of play; and (9) rupture of either the native or reconstructed UCL. The exclusion criteria were (1) studies reporting on non-baseball players and (2) when studies used overlapping patient populations, the study with the larger sample size was included.

Screening

Systematic screening in accordance with Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) was done in duplicate by two independent reviewers (RPC, YL) from title to full-text screening stages. Discrepancies at the title and abstract stages were resolved by automatic inclusion to ensure that all relevant papers were not excluded . Discrepancies at the full-text stage were resolved by consensus between the two reviewers. If a consensus could not be reached, the input of a third, senior reviewer (ORA) was used to determine the final eligibility of the study.

Data extraction

Two reviewers (RPC, YL) independently abstracted data from included studies and recorded the results onto an Excel Spreadsheet designed a priori. Recorded data included demographics (eg, author, year of publication and study design), reported risk factors and information required for quality assessment. No funding was received for this study. The Methodological Index for Non-Randomized Studies (MINORS) appraisal tool was used to assess the quality of the included, non-randomised studies (eg, case reports, case series, cohorts, etc) by two independent reviewers.[17] A score of 0, 1 or 2 was given for each of the 12 items on the MINORS checklist with a maximum score of 16 for non-comparative studies and 24 for comparative studies. A score of 0–8 or 0–12 was considered poor quality for non-comparative and comparative studies, respectively, while a score of 9–12 or 13–18 was considered fair quality, and a score of 13–16 or 19–24 was considered excellent quality.

Statistical analysis

Descriptive statistics such as mean, range and measures of variance (eg, SD, 95% CI) are presented where applicable. A kappa (κ) statistic was used to evaluate inter-reviewer agreement at all screening stages. An intra-class correlation coefficient (ICC) was calculated for the quality assessment using the MINORS criteria. Agreement was categorised a priori as follows: κ/ICC of 0.81–0.99 was considered as excellent agreement; κ/ICC of 0.61–0.80 was substantial agreement; κ/ICC of 0.41–0.60 was moderate agreement; κ/ICC of 0.21–0.40 fair agreement and a κ/ICC value of $\leq$0.20 was considered slight agreement.

RESULTS

Eligibility

The initial search yielded 1259 studies of which 15 full-text articles met the inclusion criteria. There were no additional studies identified from a manual search on Google Scholar or the references of included studies. There was substantial agreement between reviewers at the title (κ=0.71; 95% CI 0.68 to 0.73) and abstract (κ=0.69; 95% CI 0.63 to 0.75) screening stages. There was excellent agreement at the full-text (κ=0.90; 95% CI 0.83 to 0.97) screening stage.

Study characteristics

The included studies were conducted between 2009 and 2017. A total of 3702 patients were included in this review. All included patients were baseball players, of which 3489 (94.2%) were pitchers and 213 (5.8%) were position players. Among the pitchers, 317 (9.1%) were starters, 434 (12.4%) were relievers and 2738 (78.5%) had unspecified roles. There were 2614 (70.6%) Major League Baseball (MLB) players included in the study and others included were players from Little League, Minor League, high school and college (29.4%). Eight (53.3%) of the included studies used publicly available data. Three of the included studies (n=469) assessed risk factors for failure of UCLR, whereas the remainder of the studies focused on risk factors for native UCL injury. The mean total sample size per included study was 259.8 patients (range 19–1327). Of these included participants, 100% were male, with a mean age of 26.8. Mean follow-up across a reported five studies was 5.8 years (table 1).

Study quality

All studies in this systematic review were non-randomised in design. There were six cohort studies, eight case–control

Table 1 Study characteristics of included studies

Primary author	Year	Study design (level of evidence)	Total sample size	Study group sample size	Control group sample size	% male – UCLR	Mean age (range)±SD (years) – UCLR	Mean follow-up	Consensus MINORs score
Bushnell *et al*[24]	2010	Retrospective cohort study (III)	19	5	14	100	26.4 (20–30)±-2.9	3 seasons	15
Chalmers *et al**[20]	2016	Case–control (III)	1327	309	1018	100	28.1 (27.9–28.4)	8 seasons	16
DeFroda *et al**[26]	2016	Retrospective cohort study (III)	236	118	118	100	27.7 (± 3.92)	5 seasons	16
Dines *et al*[33]	2009	Case–control (III)	58	29	29	100	20.63±4.84	NR	17
Erickson *et al**[23]	2017	Retrospective cohort study (III)	67	64	3	N/A	(11–13)	NR	16
Erickson *et al**[18]	2016	Retrospective cohort study (III)	154	19	135	100	NR	>20 month	16
Garrison *et al*[40]	2013	Cross-sectional (III)	60	30	30	100	18.8± 1.5	NR	13
Han *et al*[45]	2009	Case–control (III)	490	160	330	100	(13–22)	5 years	11
Keller *et al**[46]	2016	Case– control (III)	166	83	83	100	28 (22–38)	2 years	16
Keller *et al**[19]	2017	Case– control (III)	150	29	121	100	26.44 (4.20)	1 season	13
Keller *et al**[12]	2017	Retrospective cohort study (III)	165	28	137	100	26.57 (3.10)	NR	14
Mayer *et al*[47]	2015	Prospective cohort study (II)	70	7	63	100	NR	NR	12
Meyer *et al*[32]	2016	Case– control (III)	112	56	56	100	17.8±2.5	18 months	13
Noonan *et al*[29]	2016	Case– control (III)	212	17	195	100	NR	5 years	16
Whiteside *et al**[48]	2016	Case– control (III)	416	208	208	100	28.1±3.49	NR	16

*Study used publicly available data.
NR, not reported; UCLR, ulnar collateral ligament reconstruction.

studies and one cross-sectional study. All of the included studies were of level III evidence except for one which was a level II study (table 1). There was a substantial level of agreement among quality assessment scores using the MINORS criteria (ICC=0.98; 95% CI 0.98 to 0.99). The mean MINORS score was 14.7±1.8 which indicates fair quality of evidence for non-randomised studies. Overall, most studies were comparative (14/15 studies) in nature and all had a clearly stated aim. Most studies had included consecutive patients, appropriate endpoints to the aim of the study, an adequate contemporary control group and good statistical analyses. However, studies lacked an unbiased assessment of study endpoint and prospective calculation of the study size due to most of the studies being retrospective (five studies) and case–control (eight studies) in nature.

Risk factors

Pitching workload (pitches per inning, game or season) and pitching characteristics (ie, pitching velocity, peak velocity, etc) were the most common risk factors reported for native UCL injury (six studies; n=2231) (table 2). Three (n=1810) of the four studies that looked at pitcher workload found that there was a significant relationship between increased pitcher workload and risk of UCL injury ($p<0.001$ to 0.02). Four (n=1998) of five studies found a significant increase in risk of UCL injury associated with increased pitch velocity ($p<0.001$ to 0.01). Two (n=1493) of three studies found a significant relationship between the percentage of fastballs thrown and risk of UCL injury ($p<0.001$ to 0.01).

Table 3 summarises the studies evaluating player biomechanics and the relationship with risk of UCL injury. Two studies (n=324) looked at the effect of humeral retrotorsion on risk of UCL injury. Both studies found that the elbow with the UCL injury had on average significantly ($p<0.003$ to 0.05) more humeral retrotorsion than the unaffected side. In addition, two studies found that total arc of shoulder range of motion (ROM) (dominant arm) was significantly decreased in players with UCL injury ($p<0.0273$ to 0.028). One study (n=60) found that athletes with a UCL injury had significantly poorer lower extremity and trunk balance as measured through the Y balance test ($p<0.001$). One study (n=42) found glenohumeral internal rotation deficit (GIRD) to be significantly $p<0.0001$) more likely in patients with UCL injury, whereas another study (n=60) did not find any significant difference ($p=0.453$).

Table 4 displays the risk factors summarised in the three studies that assessed risk factors for failure of UCLR. All three studies looked at the relationship between postoperative pitch workload and risk of re-rupture rate. One study (n=154) found no relationship between postoperative workload and risk of re-rupture.[18] Keller *et al* (n=150) had similar findings that there was no significant difference in innings or games pitched after UCLR and risk of re-rupture.[19] However, this study did find a significant difference ($p<0.001$) in the percentage of fastballs pitched and whether athletes experienced failure of UCLR.[19] One study (n=165) found that pitchers who later required revision UCLR increased their games pitched by 14.1% after primary reconstruction compared with the non-revision group that pitched 13.6% less games than they had before initial reconstruction ($P<0.01$).[12]

One study (n=70) looked at stress ultrasonography's ability to predict pitchers that were at risk for going on to experience a UCL injury. Pitchers that went on to have a UCL injury on average had higher initially measured gapped opening ($p=0.01$) on stress ultrasound and greater peak stiffness ($p=0.03$). One study (n=1327) found that players with higher body mass index (BMI) were significantly more likely to have a UCL injury, whereas one study (n=19) found no significant difference based off BMI.

Table 2 Pitcher workload and/or pitching characteristics and risk of ulnar collateral ligament (UCL) injury

Primary author, year	UCL injury	No UCL injury	Statistical significance (P values)
Bushnell *et al*[24] 2010	Games played: 114±54 Innings pitched: 210.1± 62.6 Total pitches: 3554.6± 1143.7 Pitches/game: 45.6± 35.8 Pitching velocity: 91.6± 5.4 MPH	Games played: 80± 66 Innings pitched: 224.8± 117.9 Total pitches: 3171.2± 2992.6 Pitches/game: 39.3± 24.7 Pitching velocity: 85.2± 3.2 MPH	Games played: p=0.28 Innings pitched: p=0.79 Total pitches: p=0.68 Pitches/game: p=0.66 Pitching velocity: p=0.004
Chalmers *et al*[20] 2016*	Peak velocity: 93.3 (95% CI 92.8 to 93.8) MPH Annual breaking ball pitch count: 53 (95% CI 40 to 66) Annual change up pitch count: 59 (95% CI 42 to 76) Annual fastball pitch count: 377 (95% CI 276 to 478) Annual pitch count: 589 (95% CI 440 to 737)	Peak velocity: 92.1 (95% CI 91.9 to 92.3) MPH Annual breaking ball pitch count: 48 (95% CI 39 to 57) Annual change up pitch count: 71 (95% CI 55 to 86) Annual fastball pitch count: 418 (95% CI 291 to 545) Annual pitch count: 673 (95% CI 472 to 873)	Peak velocity: p=0.001 Annual breaking ball pitch count: p=0.003 Annual change up pitch count: p=0.02 Annual fastball pitch count: p=0.001 Annual pitch count: p=0.002
DeFroda *et al*[26] 2016	Mean fastball velocity: 91.7± 2.4 MPH % fastball thrown: 65± 9.0% % breaking ball thrown: 24.1± -8.7%	Mean fastball velocity: 91.0± 2.5 MPH % fastball thrown: 64.0± 8.5% % breaking ball thrown: 24.3± 8.7%	Mean fastball velocity: p=0.01 % fastball thrown: p=0.29 % breaking ball thrown: p=0.85
Erickson *et al*[23] 2017†	Violated pitch count: 66.7% future UCL injury ERA: 2.6± 2.3	Violated pitch count: 3.4% future UCL injury ERA: 5.3± 1.5	Violated pitch count: p=0.009 ERA: p=0.04
Keller *et al*[46] 2016	Fastball velocity: 91.5± 3.0 MPH % fastball thrown: 46.8± 20.7%	Fastball velocity: 91.3± 2.7 MPH % fastball thrown: 39.7± 19.8%	Fastball velocity: p=0.69 % fastball thrown: p=0.03
Whiteside *et al*[48] 2016*	N/A	N/A	Mean days between games: p=0.002 Pitches per game: p=0.003 Mean pitch speed: p=0.005 Horizontal release location: p=0.025

*Only variables where the study found significance are shown. Other risk factors may have been analysed in the study which did not find significance that are not reported in the table for brevity.
†Pitchers from Little League World Series.
ERA, earned run average; MPH, miles per hour.

DISCUSSION

This systematic review identified several risk factors for UCL injury in baseball players. The majority of evidence supports that certain types of pitching practises, namely exposure to increased pitcher workload and pitch velocity, are risk factors for future UCL injury; however, the definition of pitch workload was inconsistently reported. Thus, the threshold of cumulative pitch volume (per inning, game or season) that puts an individual pitcher at risk remains unclear. Although many studies found statistical differences in pitcher workload and pitch velocity between pitchers experiencing UCL injury and those who did not, the absolute magnitude of difference between the two groups was often quite small. For instance, Chalmers *et al* found a significantly higher pitch velocity in pitchers who suffered a UCL injury compared with those who did not, but the absolute difference in pitch velocity between the two groups was only 0.8 miles per hour (MPH).[20] Lyman *et al* followed 298 youth baseball pitchers during two consecutive spring seasons.[21] The incidence of elbow pain increased with pitching with arm fatigue, and number of pitches thrown per season. USA baseball and the MLB have published 'Pitch Smart' guidelines which include age-appropriate pitching guidelines in order to help

Table 3 Player biomechanics and risk of ulnar collateral ligament (UCL) rupture

Primary author, year	UCL injury	No UCL injury	Statistical significance (P values)
Dines *et al*[33] 2009*	Dominant arm internal rotation: 29±13.16 Internal rotation deficit between dominant and non-dominant arm: 28.52± 10.65 Total shoulder range of motion: 133.45± 16.90	Dominant arm internal rotation: 38.34± 11.4 Internal rotation deficit between dominant and non-dominant arm: 12.69± 8.05 Total shoulder range of motion: 143.10± 13.60	Dominant arm internal rotation: p=0.0049 Internal rotation deficit between dominant and non-dominant arm: p<0.0001 Total shoulder range of motion: p=0.0273
Garrison *et al*[40] 2013	Y balance test (lead limb): 89.1± 6.7% Y balance test (stance limb): 88.2± 7.9% Total rotational motion‡ difference: -6.0± 9.6° Internal rotation deficit between dominant and non-dominant arm: −12.3± 8.9°	Y balance test† (lead limb): 95.8± 6.1% Y balance test† (stance limb): 95.4± 6.4% Total rotational motion‡ difference: −0.4± 9.6° Internal rotation deficit between dominant and non-dominant arm: −13.9± 7.0°	Y balance test† (lead limb): p<0.001 Y balance test† (stance limb): p<0.001 Total rotational motion‡ difference: p=0.028 Internal rotation deficit between dominant and non-dominant arm: p=0.453
Meyer *et al*[32] 2016	Side-to-side difference in humeral retrotorsion: −14.60± 6.88°	Side-to-side difference in humeral retrotorsion: −10.72± 6.88°	Side-to-side difference in humeral retrotorsion: p=0.003
Noonan *et al*[29] 2016	Side-to-side difference in humeral retrotorsion: 23.2°	Side-to-side difference in humeral retrotorsion: 14.8°	Side-to-side difference in humeral retrotorsion: p=0.05

*Dines *et al* also looked at the relationship between dominant arm external rotation (ER), non-dominant arm ER, non-dominant arm IR, dominant elbow total ROM, non-dominant elbow ROM, as well as non-dominant and dominant forearm pronation/supination and found no significant difference between the groups that had UCL injury and those that did not.
†A standardised measurement for trunk and lower extremity balance.
‡Defined as the side-to-side difference in the sum of shoulder external and internal rotation of the throwing arm in comparison to the non-throwing arm, with a negative value indicating lesser total rotational motion (TRM) on the throwing arm.

Table 4 – Risk factors for re-rupture of ulnar collateral ligament reconstruction (UCLR)

Primary author, year	UCLR failure	No UCLR failure (control)	Statistical significance (P values)
Erickson *et al*[18] 2016	Innings pitched: 90.2±58.6 Pitches thrown first season after UCLR: 1449.2± 904/1 Innings pitched: 399.3± 446.4 Pitches thrown in career after UCLR: 5674.7± 5755.4	Innings pitched: 79.4± 46.7 Pitches thrown first season after UCLR: 1233.2± 710.4 Innings pitched: 357.4± 312.0 Pitches thrown in career after UCLR: 5632.7± 4583.9	Innings pitched: p=0.901 Pitches thrown first season after UCLR: p=0.734 Innings pitched: p=0.695 Pitches thrown in career after UCLR: p=0.479
Keller *et al*[19] 2017*	Age at first UCLR: 27.3± 43 Years pitched in MLB before first UCLR: 5.0± 4.0 Total games pitched first season after UCLR: 37.4± 15.5 Total innings pitched first season after UCLR: 97.8± 54.1 Total pitches: 1413.6± 855.1 Average fast ball speed:-91.1 Percentage of fast balls pitched: 60.7%	Age at first UCLR: 22.9± 3.8 Years pitched in MLB before first UCLR: 1.5± 2.3 Total games pitched first season after UCLR: 37.9± 18.0 Total innings pitched first season after UCLR: 93.1± 36.6 Total pitches: 959.0± 652.7 Average fast ball speed: 91.6 Percentage of fast balls pitched: 69.5%	Age at first UCLR: p<0.001 Years pitched in MLB before first UCLR: p<0.001 Total games pitched first season after UCLR: p=0.999 Total innings pitched first season after UCLR: p=0.89 Total pitches: p=0.046 Average fast ball speed: p=0.559 Percentage of fast balls pitched: p<0.001
Keller *et al*[12] 2017	Relative games pitched: pitched 14.1% more games after surgery compared with before Relative inning workload: 9.8% reduction in innings pitched after surgery compared with before Relative pitch counts: 6.6% increase in pitches thrown after surgery	Relative games pitched: pitched an average of 13.6% fewer games after surgery compared with before Relative inning workload: 26% reduction in innings pitched after surgery compared with before Relative pitch counts: 19.6% reduction in pitches thrown after surgery	Relative workload: p<0.01 Relative inning workload: p=0.05 Relative pitch counts: p=0.08

*For all in game statistics (games pitched/innings pitched/pitches, average fast ball speed, percentage of fast balls pitched) refers to the first season pitched after UCLR.

prevent injury in young pitchers. Maximum pitch count recommendations have been made for skeletally immature patients in an effort to prevent overuse shoulder and elbow injuries.[22] One of the included studies found that pitchers in the Little League World Series that exceeded the recommended pitch counts were significantly more likely to require UCLR later in their careers.[23] A 10-year follow-up study of 481 youth pitchers found that pitching over 100 innings in a season resulted in 3.5 times the likelihood of subsequent injury (95% CI 1.16 to 10.44).[14]

Studies evaluating mean (or peak) pitch velocity fairly consistently found this to be a significant factor associated with UCL injury. Mechanistically, this is intuitive given there is a correlation between the joint reactive forces at the shoulder and elbow with velocity of the ball.[24 25] This risk factor is particularly worrisome due to an increasing trend of pitchers reaching even greater ball speeds.[26] In 2013, the *Wall Street Journal* reported that there were 62 pitchers that threw over 96 MPH in Major League baseball compared with 20 pitchers in 2003, and that this number is increasing every year.[27] As the performance standards for competitive pitching increase, the incidence of UCL injuries will continue to rise. Even with convincing evidence, the fact remains that putting a governor on maximum allowable ball speed is clearly not a viable solution. As such, pitching velocity is a non-modifiable risk factor at least with respect to game-type settings. Rather, emphasis should be placed on improving injury prevention programmes to determine optimal pitch counts, rest periods and understanding the potential harmful effects of early single-sport specialisation.[28]

According to Oyama *et al*, 'Previous studies suggest that increased humeral retrotorsion on the dominant limb is protective for shoulder injuries but increases the risk of elbow injuries in baseball pitchers at the college and professional levels.'[29–31] These findings are in agreement with this systematic review in that humeral retrotorsion in the dominant arm was found to be the most common biomechanical risk factor for UCL injury.[30 32] Noonan *et al* theorised that increased humeral retrotorsion prolongs the late-cocking and early-acceleration phases of throwing and exposes the UCL to higher stress while protecting the shoulder.[29] Alternations in shoulder ROM have long been thought to contribute to shoulder and elbow injuries, and thus focus has been placed on evaluating shoulder ROM characteristics by team physicians treating baseball players. Many studies have reported GIRD to be present in professional pitchers due to adaptive changes and contracture of the posteroinferior shoulder capsule.[33–39] This systematic review found only two contradictory studies which specifically investigated GIRD as a risk factor for UCL injury. While a case–control study by Dines *et al* found increased GIRD to be a significant risk factor, a cross-sectional study by Garrison *et al* did not find any significance.[33 40] Perhaps, only when GIRD exceeds external rotation gain (reflected by a loss of total arc of motion) do kinematics become deranged, and is what ultimately predisposes a pitcher to serious elbow injury.[33 40]

Strengths and limitations

This systematic review used robust research methodology with strict adherence to the PRISMA guidelines to present novel information on a clinically relevant topic. A broad search strategy was used to search multiple large databases and screening of studies was done in duplicate in order to ensure that all available literature on risk factors of UCL injury were captured accurately.

This systematic review identified risk factors associated with UCL injury but is unable to prove a cause and effect relationship. Many of the risk factors identified are related to overuse and could operate on the same causal pathways to UCL injury in baseball players. It is uncertain whether these trends are correlated with risk factors of UCL injury or individual pitcher's skillset.[24] For example, one study suggested that increased BMI was a predictor of subsequent UCL injury. It is plausible that bigger pitchers are able to generate more ball speed (which in itself is an independent risk factor for UCL), and thus play more games (ie, pitch workload). Furthermore, because some of the papers used UCL surgery as a surrogate for UCL injury, the prevalence of UCL injury might be higher. Although 15 studies identified risk factors for UCL injury in baseball players, a meta-analysis was not possible. Studies lacked consistent reporting of similar risk factors, and among those outcomes that were reported, there existed high heterogeneity (I^2 >50%). Specifically, there is limited number of studies examining player biomechanics as a risk factor for UCL injury. Given that this study included both adolescent and adult pitchers (mean age 26.8 years), it is difficult to directly address the current recommendations set forth by the USA Baseball Medical & Safety Advisory Committee as these were specifically developed with the youth pitcher in mind.[41] As pitchers reach skeletal maturity they generally adopt improved mechanics and pitching efficiency. For instance, older pitches are more likely to use mechanics such as maintaining their hand on top of the ball and keeping their shoulders closed at foot strike, both of which have important implications with regard to minimising stress on the shoulder and elbow.[42 43] However, actual injury prevention benefits of promoting proper mechanics in the young pitcher and during the late phases of Tommy John surgery rehabilitation remain to be seen. The curveball is believed to be a high-risk pitch, and current recommendations advise youth pitchers against throwing breaking balls until puberty.[24] However, according to Bushnell *et al*, a growing body of evidence is showing opposing current beliefs.[24] For example, a study by Fleisig *et al* revealed that joint reactive forces when throwing fastballs and curveballs did not differ significantly.[24 44] Although pitch velocity was the primary variable analysed by studies in this review, the influence of pitch selection on injury risk should be a focus of future research. Future studies should focus on establishing a consistent definition for pitcher workload (eg, pitches per season) across studies. Lastly, more research is needed to determine whether a certain level of exposure to any one risk factor is sufficient or rather a combination of factors is needed to predict incidence of UCL injury.

CONCLUSION

Pitching practices, reflected by increased pitch workload and velocity, were most commonly associated with UCL injury; however, the definition of workload (pitches per game, inning or season) was inconsistent. Biomechanical risk factors were less commonly reported and lack sufficient evidence to recommend preventative strategies. More quality data is needed to refine the current recommendations for injury prevention in baseball players.

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