Incidence and risk factors for musculoskeletal disorders of the elbow in baseball pitchers: a systematic review of the literature

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Objective: To determine the incidence and risk factors of musculoskeletal disorders of the elbow in baseball pitchers.

Design: Systematic review.

Data Sources: Medline, CINAHL, Cochrane, PubMed and SportDiscus from onset to July 7, 2018.

Eligibility Criteria: Eligible studies included randomized controlled trials, cohort studies and case-control studies. Independent pairs of reviewers screened titles and abstracts for eligibility. Relevant articles were critically appraised for internal validity using the SIGN criteria. We included low risk of bias studies in our best evidence synthesis.

Objectif : Établir l’incidence et facteurs de risque de troubles musculosquelettiques du coude chez le lanceur de baseball.

Méthodologie : Revue exhaustive.

Sources des données : Medline, CINAHL, Cochrane, PubMed et SportDiscus depuis le début jusqu’au 7 juillet 2018.

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Results: We retrieved 4502 articles, 39 were critically appraised and nine had a low risk of bias. These were included in the evidence synthesis. The incidence of musculoskeletal disorders of the elbow ranges from 2.3% in adolescent pitchers to 40.6% in youth pitchers. Evidence suggests that pitch characteristics, inadequate rest, biomechanical and anthropometric factors may be risk factors of UCL tears.

Summary/Conclusion: Baseball pitchers develop musculoskeletal disorders of the elbow. There is little high-quality evidence to understand the etiology. Preliminary evidence suggests the risk factors are multifactorial.

PROSPERO Trial Registration Number: CRD42018092081

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KEY WORDS: baseball, elbow, epidemiology, injury

Introduction
Musculoskeletal disorders of the elbow are a considerable source of disability in baseball pitchers.1 In high school pitchers, the elbow is the second most commonly injured area (18.9%) after the shoulder (34.2%).2 Musculoskeletal disorders of the elbow affect 12.4% of professional baseball pitchers every season and these pitchers are more likely to require surgery, or to be placed on the disabled list compared to other players.1,3 In Major League Baseball, 90.3% of medial ulnar collateral ligament (UCL) reconstruction surgeries are performed on pitchers, requiring an average of 17.8 months on the disabled list.4 Several risk factors for musculoskeletal disorders of the elbow in baseball pitchers have been proposed including overuse5,6, pitch velocity6, pitch types5,7, changes in glenohumeral rotation8–10, humeral torsion11, and poor throwing biomechanics12. Despite methodological limitations related to study design, population at risk, case definition, and measurement of exposure, guidelines have been developed in an attempt to reduce injury rates in pitchers.5,6,9,13–18 A few systematic reviews have been published recently on the topic of arm injuries in baseball players.19–21 Norton et al.20 examined the risk factors for shoulder and elbow injuries in adolescent baseball pitchers and found age, height, playing for multiple teams, pitch velocity and arm fatigue to be independent risk factors for throwing arm injuries. However, no risk factors specific to elbow injuries were identified in this review. Agresta et al.21 investigated prospective cohort studies and randomized controlled trials looking at both youth and professional baseball players and identified that pitching greater than 100 innings per year, being aged nine to 11 years, being a pitcher or a catcher, training greater than 16 hours per week and having a history of elbow pain were significant risk factors for elbow injury among youth baseball players. Through a systematic review and meta-analysis Salamh et al.19 identified that the only statistically significant risk factor for adolescent baseball pitchers was pitching with arm fatigue. A systematic review of the available evidence is needed to determine the incidence and risk factors specific to musculoskeletal disorders of the elbow in baseball pitchers across all age groups. The purpose of
our systematic review is to synthesize the best available evidence on the incidence and risk factors for musculoskeletal disorders of the elbow in baseball pitchers of all ages and levels of play. Incidence refers to the number of new cases of a disorder in a population initially free of the condition (those without the disorder of interest at the beginning of the study). Risk factors are characteristics associated with an increased or decreased incidence of developing a disorder.

Methods

Registration and reporting
We registered the review with the International Prospective Register of Systematic Reviews (PROSPERO) on March 24, 2018 (CRD42018092081). Our systematic review complies with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.

Eligibility criteria

Population: Our review targeted baseball pitchers of all age groups and levels of play that sustained an elbow musculoskeletal disorder.

Outcomes: The outcome of interest was musculoskeletal disorders of the elbow, defined as any physical complaint sustained by a player that results from a baseball game or baseball training, irrespective of the need for medical attention or time-loss from baseball activities.

We included all reported elbow musculoskeletal disorders affecting the bones (humerus, radius, ulna), joints (elbow joint, proximal radioulnar joint) and soft tissues (muscles, tendons, ligaments, connective tissue, nerves and blood supply). Eligible articles reported on at least one type of musculoskeletal disorder of the elbow: 1) physical complaint (i.e. elbow pain); 2) disorder requiring assessment of a player’s complaint by a qualified medical practitioner; 3) time-loss (inability to participate in practice or a game); or 4) UCL tear requiring surgical repair.

Study characteristics: Eligible articles met the following criteria: 1) English language; 2) published in peer-reviewed journals; 3) randomized controlled trials, cohort studies and case-control studies; 4) study population including baseball pitchers of any age or level of play; and 5) measured the incidence or risk factor(s) for musculoskeletal disorders of the elbow. We excluded the following articles: 1) letters, editorials, commentaries, unpublished manuscripts, dissertations, government reports, books and book chapters, conference proceedings, meeting abstracts, lectures and addresses, and consensus development statements; 2) cross-sectional studies, pilot studies, case reports, case series, qualitative studies, literature reviews, clinical practice guidelines, laboratory studies and studies without methodology; 3) cadaveric or animal studies; 4) studies solely analyzing softball pitching; and 5) studies that do not differentiate between injury rates of pitchers and positional players.

Data sources and searches
We developed our search strategy with a health sciences librarian (Appendix A). A second librarian reviewed the search strategy for completeness and accuracy using the Peer Review of Electronic Search Strategies (PRESS) Checklist. We searched MEDLINE, CINAHL, Cochran, PubMed and SportDiscus from the beginning of the database to July 7, 2018.

We developed the search strategy in MEDLINE, which was subsequently adapted to the other bibliographic databases. The search terms included subject headings specific to each database (e.g. MeSH in MEDLINE) and free text words relevant to baseball injury epidemiology. We downloaded the search results into a database created using EndNote x6 (Thompson Reuters Corp, New York, New York).

Study selection
We used a two-phase screening process. In phase one, pairs of independent reviewers (from a pool of six reviewers) screened citation titles and abstracts to determine eligibility. In phase two, the same pairs of reviewers independently reviewed the full text of possibly relevant articles to make a final determination of eligibility. Reviewers met to resolve disagreements. If consensus could not be reached, a third reviewer was used.

Quality assessment and data extraction
Two independent reviewers (from a pool of seven reviewers) critically appraised each eligible article. We assessed the internal validity of articles using the Scottish Intercollegiate Guidelines Network (SIGN) criteria. The SIGN criteria were used to qualitatively evaluate the impact of selection bias, information bias and confounding
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on study results. We did not use a quantitative score, or a cut-off point to determine the internal validity of studies. All reviewers were trained to critically appraise studies using the SIGN criteria. Consensus between the reviewers in each pair was reached through discussion, with the involvement of an independent third reviewer if necessary. We contacted authors when we needed additional information for the critical appraisal to be accurate and valid.

Data extraction
Only articles with a low risk of bias were included in our synthesis. The lead author (CG) extracted data from articles with a low risk of bias and built evidence tables. A second reviewer (TT) independently checked the extracted data. Disagreements were resolved through discussion.

Data synthesis and analysis
We conducted a qualitative best-evidence synthesis due to the heterogeneity of study populations.27 The evidence was stratified according to level of play (youth, adolescent and high school, and professional) and type of elbow disorder (physical complaint, musculoskeletal disorder requiring medical attention, time-loss musculoskeletal disorder and UCL tear requiring surgical repair).

We computed reviewer agreement for the screening of titles and abstracts and reported kappa statistics with 95% confidence intervals (95% CIs).28 The percentage of agreement for critical appraisal of articles was calculated for the studies with high and low risk of bias.

Role of the funding source
No funding was provided for this systematic review.

Results

Article selection
We retrieved 4502 articles, removed 1157 duplicates, and screened 3345 papers for eligibility (Figure 1). Of those, 39 articles were critically appraised and nine had a low risk of bias. The inter-rater agreement for phase one screening of articles was $k = 0.71$ (95% CI = 0.65-0.76). The inter-rater agreement for phase two screening of articles was $k = 0.62$ (95% CI = 0.43-0.80). The inter-rater agreement for critical appraisal of articles was $k= 0.68$ (95% CI = 0.44-0.91).

Article characteristics
Of the nine articles with a low risk of bias, six were cohort studies and three were case-control studies.10,29-36 All six of the cohort studies reported on incidence.10,29-33 The three case-control studies reported on risk factors.34-36 Three cohort studies investigated professional baseball pitchers29,31,32, two studied adolescent and high school pitchers (age 13-19 years)10,33, and two studied youth (less than 13 years) pitchers.10,30 Five articles reported on the incidence of time-loss associated with musculoskeletal
disorder of the elbow. One article reported on
the incidence of elbow physical complaints and disorders re-
quiring medical attention. Five articles followed players
for one baseball season and the other article fol-
lowed players for one year.

Three low risk of bias case-control studies investigated
risk factors in professional pitchers, and one in high
school pitchers. The studies of professional pitchers in-
vestigated risk factors for UCL tears requiring surgical re-
construction. These four articles investigated the following
risk factors: pitch velocity, pitch selection, playing
catcher as a secondary position, days between games pitched,
standing height, horizontal release location, and the number of pitches per game.

Risk of bias
All low risk of bias cohort studies had a clear research
question, their outcomes were clearly defined and all in-
cluded clearly defined populations at risk (pitchers had
no restrictions in throwing or baseball participation at
the time of enrolment). All cohort studies had a fol-
low-up rate of at least 95%. All case-control studies
(3/3) clearly defined cases and controls and the exposure
was measured in a standard, valid and reliable way. The
cases and controls were taken from comparable
populations in 100% (3/3) of the case-control studies.
Potential confounders (age, height, weight, position, ma-
.jor league experience, innings pitched) were identified
and controlled for in all case-control studies.

Twenty-five cohort studies had a high risk of bias. The limitations of these cohort studies included
lack of blinding of outcome assessment (15/25) and lack of evidence to demonstrate the outcome
assessment was valid and reliable (15/25). Eight of the cohort studies had a high risk of bias
because they failed to report whether the pitchers were
injury-free at the onset of the study. Five high-risk of bias case-control studies had important
limitations including lack of an appropriate control group, pre-injury exposure data available for less than
half of the eligible participants, and lack of consider-
ation for potential confounding variables.

Incidence of musculoskeletal disorders of the elbow in baseball pitchers

Youth baseball pitchers
The incidence of musculoskeletal disorders of the elbow varies depending on case definition (Table 1). In youth
baseball pitchers (between the ages of 6-12 years old),
the incidence of musculoskeletal disorders of the elbow
requiring medical attention was 2.2 disorders per 1000
athletic-exposures (95% CI: 1.5-3.2). This equates to
40.6% (95% CI: 29.8-52.4) of the pitchers sustaining an
elbow disorder requiring medical attention per year. The
case definition for medical attention was as one athlete partici-
pating in one practice or game during which a player was
injury-free at the onset of the study. As expected, musculoskel-
etal disorders of the elbow requiring medical attention are
more common than those requiring time-loss in youth
baseball pitchers.

Adolescent and high school baseball pitchers
The reported incidence of time-loss musculoskeletal disor-
ders of the elbow, per season, is lower in adolescents
than in youth or professional baseball pitchers. Hibberd et al. reported that 2.3% (95% CI: 1.2-4.4) of high school
baseball pitchers (between the ages of 14-19 years) sus-
tained a time-loss musculoskeletal disorder of the elbow
over the course of a season. Shanley et al. documented a
higher incidence of 11.8% (95% CI: 6.1-21.5) of adoles-
cent baseball pitchers (between the ages of 13-18 years)
sustaining a time-loss musculoskeletal disorder of the
elbow over a season.

Professional baseball pitchers
The reported incidence of elbow musculoskeletal disor-
ders requiring time-loss in professional baseball pitchers
ranges from 13.5% (95% CI: 9.5-18.9%) to 21.7% (95% CI:
15.5-29.6%). The definitions used for time-loss musculoskeletal disorders of the elbow were: (1) any

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## Table 1.
Elbow injury incidence in baseball pitchers. Abbreviations: AE = athletic-exposure; CI = confidence interval.

<table>
<thead>
<tr>
<th>Author(s), year</th>
<th>Study design</th>
<th>Subjects and setting</th>
<th>Follow-up period</th>
<th>Case definition</th>
<th>Incidence (95% CI)</th>
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<tbody>
<tr>
<td><strong>Youth injuries</strong></td>
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</table>
| Sakata et al., 2016 | Cohort study | 69 junior baseball pitchers (ages 6-12 years) with no history of elbow pain | 12 months | **Physical complaint (elbow pain):**  
• Elbow pain lasting greater than 2 weeks, elbow pain that caused them not to play in a game or practice, or recurrent elbow pain  
**Elbow injury requiring medical attention:**  
• Medial elbow pain during throwing with either an abnormal sonography finding or the presence of pain during a clinical assessment | Elbow pain incidence density: 2.5/1000 AEs (1.8-3.5/1000 AEs)  
Elbow injury requiring medical attention incidence density: 2.2/1000 AEs (1.5-3.2/1000 AEs)  
Elbow injury requiring medical attention annual incidence: 40.6% (29.8-52.4) |
| Shanley et al., 2015 | Cohort study | 47 asymptomatic youth (8-12 years old) | One baseball season | **Time-loss elbow injury:**  
• An injury to any muscle, joint tendon, ligament, bone or nerve of the elbow requiring the pitcher to miss at least one game or practice | Time-loss elbow injury incidence per season: 21.3% (12.0-34.9) |
| **High school and adolescent injuries** | | | | | |
| Shanley et al., 2015 | Cohort study | 68 adolescent (13-18 years old) pitchers | One baseball season | **Time-loss elbow injury:**  
• An injury to any muscle, joint tendon, ligament, bone or nerve of the elbow requiring the pitcher to miss at least one game or practice | Time-loss elbow injury incidence per season: 11.8% (6.1-21.5) |
| Hibberd et al., 2018 | Cohort study | 384 high school baseball pitchers (age 14-19 years) | One spring baseball season | **Time-loss elbow injury:**  
• An injury to the elbow that occurred as a result of baseball throwing that resulted in at least one missed athletic-exposure. | Time-loss elbow injury incidence per season: 2.3% (1.2-4.4) |
| **Professional injuries** | | | | | |
| Byram et al., 2010 | Cohort study | 207 pitcher-seasons from 144 Major and Minor League Baseball pitchers | One season | **Time-loss elbow injury:**  
• An injury to the elbow that resulted in placement on the disabled list and/or missing at least one game  
**Non-operative time-loss elbow injury:**  
• An elbow injury that did not require surgery  
**Operative time-loss elbow injury:**  
• An elbow injury that did require surgery | Time-loss elbow injury incidence per season: 13.5% (9.5-18.9)  
Non-operative time-loss elbow injury incidence per season: 5.8% (3.4-9.9)  
Operative time-loss elbow injury incidence per season: 7.7% (4.8-12.2) |
| Camp et al., 2018 | Cohort study | 129 pitcher-seasons from pitchers invited to Major League Baseball Spring Training for a single professional baseball organization | One baseball season | **Time-loss elbow injury:**  
• A musculoskeletal injury to the elbow that resulted in at least one day out of play | Time-loss elbow injury incidence per season: 21.7% (15.5-29.6) |
| Camp et al., 2017 | Cohort study | 132 pitcher-seasons from 81 pitchers invited to Major League Baseball Spring Training for a single professional baseball organization | One baseball season | **Time-loss elbow injury:**  
• An injury to the elbow that resulted in at least one day out of play | Time-loss elbow injury incidence per season: 21.2% (15.1-29.0) |
elbow condition resulting in the pitcher’s placement onto the disabled list and/or missing at least one game because of the condition; or (2) any elbow injury that resulted in at least one day out of play. These articles included all pitchers invited to the Major League Baseball Spring Training for a single professional baseball organization, who were willing to participate in the preseason assessment, were not currently injured, and did not have a recent surgery which would limit their ability to fully participate in baseball-related activities without restrictions.

Risk factors for musculoskeletal disorders of the elbow

High school baseball pitchers
Data from Hibberd et al. indicate that playing catcher as a secondary position may have a higher incidence than those who do not play catcher as a secondary position (RR=3.14; 95% CI: 0.68-14.50; p=0.14). However, the precision of this estimate is low as there is a non-significant p-value and a wide 95% confidence interval.

Professional baseball pitchers

Pitch velocity
The evidence suggests that pitch velocity is positively associated with UCL tears requiring reconstructive surgery in professional baseball pitchers (Table 2). According to Whiteside et al., the odds of undergoing UCL reconstruction surgery increased by 38% for every unit (meters/second) increase in mean pitch speed (OR=1.38; 95% CI: 1.10-1.73; p=0.005). Similarly, Prodromo et al. identified that a greater average fastball velocity (OR=1.15; 95% CI: 1.06-1.24; p=0.001), slider velocity (OR=1.10; 95% CI: 1.02-1.20; p=0.02), curveball velocity (OR=1.11; 95% CI: 1.03-1.20; p=0.009), and changeup velocity (OR=1.09; 95% CI: 1.02-1.18; p=0.016) was associated with an increased odds of an UCL tear requiring surgical reconstruction in professional baseball pitchers. However, an increase of one-mile per hour to the mean pitch velocity of the cut fastball (OR=1.01; 95% CI: 0.94-1.08; p=0.85) or split-fingered fastball (OR=1.13; 95% CI: 0.94-1.34; p=0.191) did not increase the odds of UCL tears requiring surgical repair in professional baseball pitchers.

Pitch selection
The evidence suggests that throwing a greater percentage of fastballs is associated with an increased risk of an UCL tear requiring surgical reconstruction, while throwing a greater variety of unique pitch types may reduce the risk of sustaining an UCL tear requiring surgical reconstruction. Keller et al. reported a 2% increase in the odds of UCL tears for every 1% increase in the percentage of fastballs thrown over the course of a season (OR=1.02; 95% CI: 1.00-1.03; p=0.035). However, a greater percentage of sliders (OR=0.98; 95% CI: 0.96-1.00; p=0.11), curveballs (OR=1.00; 95% CI: 0.97-1.03; p=0.88), and changeups (OR=1.03; 95% CI: 0.99-1.07; p=0.13) thrown were not associated with an increased risk of UCL injury. Whiteside et al. reported that having a greater number of unique pitch types was associated with a decreased odds of UCL tears requiring surgical reconstruction (OR=0.67; 95% CI: 0.49-0.92; p=0.012). Unique pitch types can be defined as the number of different pitches that pitcher throws regularly. For example, a pitcher that throws a fastball, curveball and sinker would have three unique pitch types. After controlling for confounders, a pitcher’s odds of undergoing UCL reconstruction surgery decreased by 33% for each unique pitch type that he possessed in his repertoire.

Pitcher workload
Limited evidence suggests that a greater number of pitches thrown per game is associated with an increased risk of sustaining an UCL tear requiring surgical reconstruction. A greater amount of days between games pitched is associated with a decreased risk of sustaining an UCL tear requiring surgical reconstruction. Whiteside et al. reported that the odds of undergoing UCL reconstruction surgery increased by 2% over the course of a season for every one-pitch increase to the mean number of pitches per game (OR=1.02; 95% CI = 1.01-1.03; p=0.003). Increasing the number of days between games pitched was associated with a reduction in UCL tears requiring surgical reconstruction in professional baseball pitchers. After controlling for confounders, a pitcher’s odds of undergoing UCL reconstruction surgery decreased by 31% (OR=0.69; 95% CI: 0.54-0.87; p=0.002) for each additional day between consecutive games pitched.
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Anthropometric and biomechanical factors
We found limited evidence suggesting that being taller and having a greater horizontal release location are associated with decreased odds of sustaining an UCL tear requiring surgical reconstruction in professional baseball pitchers. Whiteside et al.\textsuperscript{35} reported that for every unit (cm) increase in standing height, the odds of undergoing UCL reconstruction surgery decreased by 6% (OR=0.94; 95% CI: 0.90-0.99; p=0.013). They also reported that a greater horizontal release location (normalized to standing height) may be associated with a reduced odds of undergoing UCL reconstruction surgery (OR=0.03; 95% CI: 0.001-0.64; p=0.025).

Discussion
Our review included nine articles with a low risk of bias,
six of which assessed the incidence of musculoskeletal disorders of the elbow in baseball pitchers, three that evaluated risk factors, and one article that assessed for both incidence and risk factors. We found that the incidence of time-loss musculoskeletal disorders of the elbow may be lower in adolescent and high school baseball pitchers (13-19 years), than in youth (less than 13 years) and professional baseball pitchers.10,29,31–33

We used a novel approach to synthesize the evidence by relying on musculoskeletal disorder severity: (1) physical complaint, (2) musculoskeletal disorder requiring medical attention, and (3) time-loss musculoskeletal disorders. This provides a novel approach for comparing incidence rates.24 Using this classification allowed us to compare incidence within and between different types of musculoskeletal disorders of the elbow (Table 3). The available evidence suggests that musculoskeletal disorders of the elbow requiring medical attention are more common than time-loss musculoskeletal disorders of the elbow in youth baseball pitchers.10,30 However, there is insufficient evidence to compare the incidence of physical complaints, musculoskeletal disorders requiring medical attention and time-loss musculoskeletal disorders of the elbow across youth, adolescent, high school and professional baseball pitchers. Future research should aim to investigate the incidence of physical complaints and musculoskeletal disorders of the elbow requiring medical attention in adolescent, high school and professional baseball pitchers.

We investigated the risk factors for elbow injuries in baseball pitchers of all levels of play. The available evidence demonstrates that the risk factors for UCL tears requiring surgical repair in professional baseball pitchers are multifactorial in nature.34–36 Variables related to pitch velocity, pitch selection, pitcher workload, anthropometric data and pitching biomechanics appear to affect the rate of UCL tears in professional baseball pitchers.34–36

The available evidence indicates that mean pitch velocity, number of unique pitch types thrown and number of days between consecutive games pitched may have the largest impact on the risk of professional baseball pitchers sustaining an UCL tear requiring surgical reconstruction.

The UCL is believed to tear as a result of the valgus stress being placed on the elbow joint during the pitching motion, resulting in a tissue load that exceeds tissue capacity.61 Most of the available evidence supports this paradigm. A greater mean pitch velocity and a greater pitch velocity of the fastball, slider, curveball and changeup were associated with a greater risk of sustaining an UCL requiring surgical repair in professional baseball pitchers.35,36 A greater pitch velocity is likely to place a greater valgus load on the elbow, thus increasing the strain on the UCL.62–64 However, greater pitch velocity is often a desired performance metric that pitchers seek to attain, as a greater pitch velocity decreases the batter’s decision time of whether to strike the ball, thus increasing the pitcher’s chance at success.65,66

We found that certain pitch types may increase the risk of elbow injuries in baseball pitchers.7 The pitch type that

Table 3.

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<thead>
<tr>
<th></th>
<th>Youth pitchers</th>
<th>Adolescents and high school pitchers</th>
<th>Professional pitchers</th>
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<tbody>
<tr>
<td><strong>Physical complaints of the elbow</strong></td>
<td><strong>Incidence Density:</strong> 2.5 (1.8-3.5) physical complaints per 1000 athletic-exposures30</td>
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</tr>
<tr>
<td><strong>Musculoskeletal disorders of the elbow requiring medical attention</strong></td>
<td><strong>Incidence:</strong> 40.6% (29.8-52.4) of pitchers per year30</td>
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<tr>
<td></td>
<td><strong>Incidence Density:</strong> 2.2 (1.5-3.2) injuries per 1000 athletic-exposures30</td>
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<tr>
<td><strong>Time-loss musculoskeletal disorders of the elbow</strong></td>
<td><strong>Incidence:</strong> 21.3% (12.0-34.9) of pitchers per season10</td>
<td><strong>Incidence:</strong> 2.3% (1.2-4.4) to 11.8% (6.1-21.5) of pitchers per season10,33</td>
<td><strong>Incidence:</strong> 13.5% (9.5-18.9) to 21.7% (15.5-29.6) of pitchers per season29,31,32</td>
</tr>
</tbody>
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has received the greatest amount of scrutiny is the curveball. This is demonstrated in previous guidelines produced by the USA Baseball Medical and Safety Advisory Committee which states that, youth pitchers should avoid throwing breaking pitches in order to reduce the risk of future overuse injuries. However, Grantham et al. reported no increased risk of elbow injury associated with the curveball. Escamilla et al. reported that fastballs create the greatest amount of valgus stress on the medial elbow before ball release. The results of our systematic review support these findings. The evidence suggests that a greater percentage of fastballs thrown is associated with an increased risk of sustaining an UCL tear requiring surgical reconstruction in professional baseball pitchers, while the percentage of sliders, curveballs and change-ups do not appear to have an effect on the risk of injury. Despite the consistency of the results of our systematic review with previous studies for professional baseball pitchers, careful consideration of the level of evidence and best practices are necessary when considering design and implementation of pitching guidelines for all levels of play.

Having a greater repertoire of pitch types may be associated with a decreased risk of surgical reconstruction for a torn UCL in professional baseball pitchers. Overuse injuries are thought to be the result of repetitive microtrauma to tissue. It is hypothesized that throwing a variety of unique pitch types decreases the rate of UCL tears as a result of avoiding repetitive, uniform loading of the UCL due to the biomechanical difference of each pitch type.

Our synthesis suggests that pitcher workload may be associated with the rate of UCL tears requiring surgical repair in professional baseball pitchers. Throwing a greater number of pitches per game and having fewer days between consecutive games pitched are associated with an increased risk of sustaining an UCL tear in professional baseball pitchers. These risk factors highlight the importance of load management in professional baseball pitchers. However, a specific cut-off point beyond which a greater load will result in an increased risk of injury remains poorly defined.

Looking solely at load management and prescribing mandated pitch counts or minimum rest intervals for pitchers is likely an oversimplification of the multifactorial nature of UCL tears in professional baseball pitchers. Baseball experts often tout that pitching biomechanics variables (i.e. open lead foot angle, open foot position, insufficient or excessive shoulder rotation, excessive horizontal shoulder adduction during arm cocking, etc.) are a risk factors for elbow musculoskeletal disorders in baseball pitchers. There is evidence suggesting a relationship between pitching biomechanics and stresses placed on the shoulder and elbow. However, other than the association between greater normalized horizontal release location and decreased risk of sustaining an UCL tear, there is a lack of high quality epidemiological evidence demonstrating the relationship between pitching biomechanics and elbow injuries in baseball pitchers. Future epidemiological research is required to determine the relationship between pitching biomechanics and musculoskeletal disorders of the elbow in baseball pitchers.

Most of the low risk of bias articles assessed risk factors for UCL tears requiring surgical repair in professional baseball pitchers. This leaves a gap in the literature for risk factors in pitchers at the youth, adolescent, high school and collegiate levels. These risk factors must be considered with caution, as there is no evidence demonstrating the identified risk factors are applicable for populations other than professional pitchers.

High quality cohort studies are urgently needed to understand the etiology of elbow disorders in baseball pitchers. Many studies that were identified through our search strategy were not included in the systematic review because they could not ensure that the pitchers did not have a musculoskeletal disorder of the elbow at the onset of the study. Cohort studies must focus on enrolling samples of pitchers at risk of developing a musculoskeletal disorder of the elbow (incident cases) and avoid the enrollment of pitchers who may already have a musculoskeletal disorder of the elbow (prevalent cases). This is necessary to prevent prevalence-incidence bias. Moreover, the independence of the risk factors must be tested through well-planned studies to control for confounding.

Some limitations exist for this review. We limited our search to English-language articles. Some articles have reported incidence density based on athletic-exposures. However, using athletic-exposure as a measure of exposure, requires the assumption that each athletic-exposure has the same potential for injury. This may not be true as time engaged in throwing, throwing effort or differences in throwing mechanics may alter the risk for injury. The
studies identified in this review that assess risk factors for musculoskeletal disorders of the elbow in baseball pitchers focus largely on UCL tears in professional baseball pitchers. This may leave a gap in the literature for youth, adolescent, high school and collegiate players that may sustain UCL tears or other musculoskeletal disorders of the elbow. There are also several strengths to the current review. We included studies that only assessed the incidence or risk factors for musculoskeletal disorders of the elbow in baseball pitchers. This allowed for us to thoroughly examine a concise and important topic in baseball. We were broad in our inclusion of multiple age ranges and level of play. Although the evidence is limited at this point it does allow for some comparison of the incidence of musculoskeletal disorders of the elbow in baseball pitchers across different age groups. This review also used a novel approach to synthesize the evidence by classifying the musculoskeletal disorders of the elbow based on disorder severity. This allowed for unique comparison of incidence of musculoskeletal disorders of the elbow of varying severity.

Conclusions
Elbow musculoskeletal disorders are common in baseball pitchers. The available evidence suggests that an increased pitch count, a greater percentage of fastballs thrown, a greater mean pitch velocity and greater fastball, slider, curveball and changeup velocity are associated with an increased risk of sustaining a tear of the UCL requiring surgical reconstruction in professional baseball pitchers. More days between games pitched, having a greater repertoire of unique pitch types, being of greater height and having greater normalized horizontal release location have been associated with a decreased risk of sustaining a tear of the UCL requiring surgical reconstruction in professional baseball pitchers. Overall, the epidemiological studies regarding elbow injuries in baseball pitchers are of low quality and future high-quality evidence is needed to confirm these findings before adequate guidelines and prevention strategies can be developed.

Key Points
What is already known:
• Baseball pitchers are at risk for musculoskeletal disorders of the elbow.
• Pitching biomechanics and overuse are hypothesized to be risk factors for these conditions in baseball pitchers.

What are the new findings:
• The etiology of musculoskeletal disorders of the elbow is multi-faceted and includes biomechanical, anthropometric and pitch selection variables.
• The overall quality of the evidence is weak and well-designed epidemiological studies are needed to inform the development of effective prevention strategies.

References:


64. Nissen CW, Westwell M, Öunpuu S, Patel M, Solomito M,


Appendix 1.

PubMed search strategy.

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