ISSN 0008-3194 (p)/ISSN 1715-6181 (e)/2020/165–179/$2.00/©JCCA 2020

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

Chris Grant, BSc, DC, FRCCSS(C)[1]
Taylor Tuff, BSc, DC, FRCCSS(C)[1]
Melissa Corso, BSc, MSc, DC, FRCCSS(C)[1,2,4]
James J. Young, DC, MSc, FCCS(C)[1]
Paula J. Stern, BSc, DC, FCCS(C)[1]
Elie Côté, MD[3]
Pierre Côté, DC, PhD[2,4]

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.*

Critères d'admissibilité : *Les études admissibles étaient des essais comparatifs à répartition aléatoire, des études de cohortes et des études de cas-témoins. Des pairs examinateurs indépendants ont trié des titres et des résumés satisfaisant les critères d'admissibilité. On a évalué la validité interne des articles pertinents en utilisant les critères SIGN. On a tenu compte d'un faible risque d'études faussées dans notre meilleure synthèse de preuves.*

[1] Division of Graduate Studies, Canadian Memorial Chiropractic College, Toronto, Canada
[2] Faculty of Health Sciences, Ontario Tech University, Oshawa, Canada
[3] Department of Ophthalmology & Vision Sciences, University of Toronto, Toronto, Canada
[4] Centre for Disability Prevention and Rehabilitation at Ontario Tech University and CMCC

Corresponding author:
Chris Grant, Canadian Memorial Chiropractic College, 6100 Leslie Street, Toronto, ON M2H 3J1
E-mail: chris.grant016@gmail.com
Tel: 647-967-2443.


The authors have no disclaimers, competing interests, or sources of support or funding to report in the preparation of this manuscript.

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

(JCCA. 2020;64(3):165-179)

KEY WORDS: baseball, elbow, epidemiology, injury

Résultats : Sur les *4 502 articles retenus, 39 ont été évalués d'une façon critique; neuf présentaient un risque de parti pris. Ceux-ci ont été inclus dans la synthèse de preuves. L'incidence des troubles musculosquelettiques du coude variait de 2,3 % chez les lanceurs adolescents à 40,6 % chez les jeunes lanceurs. Les données semblent indiquer que les caractéristiques du lancer, un repos insuffisant, des facteurs biomécaniques et anthropométriques pourraient être des facteurs de risque de déchirure du ligament collatéral de l'ulna (LCU).*

Résumé/conclusion : *Les lanceurs de baseball développent des troubles musculosquelettiques au coude. Il existe peu de preuves de grande qualité permettant de comprendre l'étiologie de ces troubles. Les données préliminaires semblent indiquer que les causes sont multifactorielles.*

Numéro d'enregistrement d'essai PROSPERO : CRD42018092081

(JCCA. 2020;64(3) : 165-179)

MOTS CLÉS : baseball, coude, épidémiologie, blessure

## 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 overuse[5,6], pitch velocity[6], pitch types[5,7], changes in glenohumeral rotation[8–10], humeral torsion[11], and poor throwing biomechanics[12]. 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).[22] Risk factors are characteristics associated with an increased or decreased incidence of developing a disorder.[22]

## 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.[23]

### *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.[24] 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[24]; 3) time-loss (inability to participate in practice or a game[24]); 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.[25] We searched MEDLINE, CINAHL, Cochrane, 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.[26] The SIGN criteria were used to qualitatively evaluate the impact of selection bias, information bias and confounding

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 popualtions.[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).

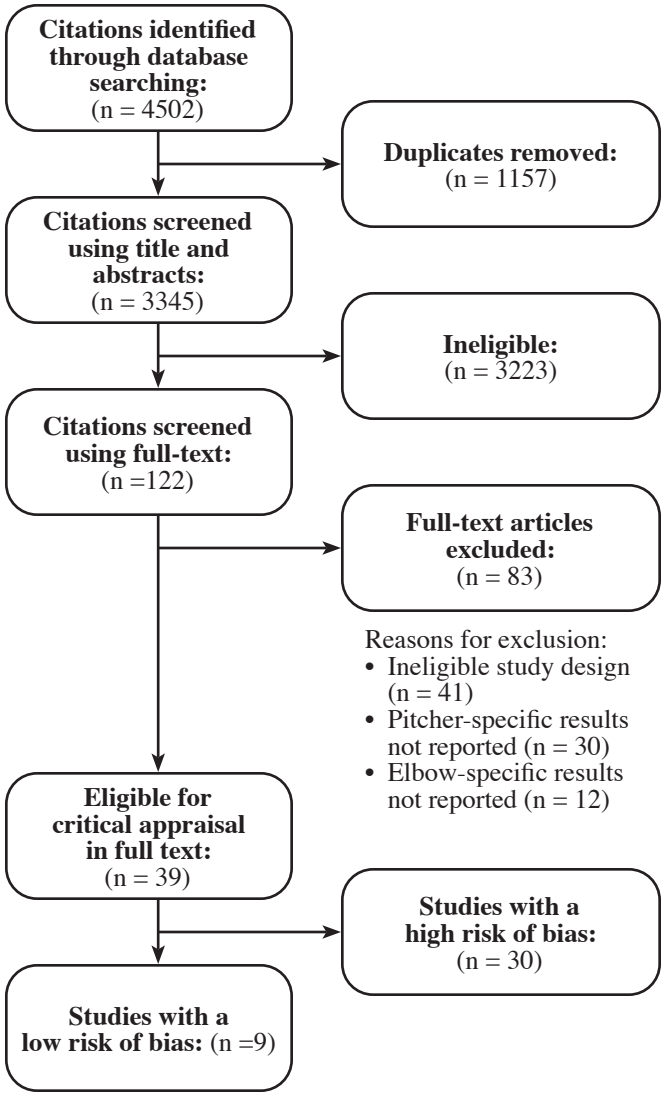


Figure 1.
*PRISMA flowchart*.

### *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 pitchers[29,31,32], 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.[10,29,31–33] One article reported on the incidence of elbow physical complaints and disorders requiring medical attention.[30] Five articles followed players for one baseball season[10,29,31–33] and the other article followed players for one year[30].

Three low risk of bias case-control studies investigated risk factors in professional pitchers[34–36], and one in high school pitchers[33]. The studies of professional pitchers investigated risk factors for UCL tears requiring surgical reconstruction.[34–36] The study of high school pitchers studied risk factors for time-loss musculoskeletal disorders of the elbow.[33] These four articles investigated the following risk factors: pitch velocity[36], pitch selection[34], playing catcher as a secondary position[33], days between games pitched[35], standing height[35], horizontal release location[35], and the number of pitches per game[35].

### *Risk of bias*

All low risk of bias cohort studies had a clear research question, their outcomes were clearly defined and all included clearly defined populations at risk (pitchers had no restrictions in throwing or baseball participation at the time of enrolment).[10,29–33] All cohort studies had a follow-up rate of at least 95%.[10,29–33] All case-control studies (3/3) clearly defined cases and controls and the exposure was measured in a standard, valid and reliable way.[34–36] The cases and controls were taken from comparable populations in 100% (3/3) of the case-control studies.[34–36] Potential confounders (age, height, weight, position, major league experience, innings pitched) were identified and controlled for in all case-control studies.[34–36]

Twenty-five cohort studies had a high risk of bias.[1–3,11,12,37–56] The limitations of these cohort studies included lack of blinding of outcome assessment (15/25)[2,11,12,37–43,45,53–56] and lack of evidence to demonstrate the outcome assessment was valid and reliable (15/25)[2,11,12,37,38,40,42–45,52–56]. 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 (8/25).[1,3,46–51] Five high-risk of bias case-control studies[6,57–60] had important limitations including lack of an appropriate control group (1/5)[57], pre-injury exposure data available for less than half of the eligible participants (1/5)[58], and lack of consideration for potential confounding variables (5/5)[6,57–60].

## *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.[30] The incidence of elbow pain in the same sample was 2.5 complaints per 1000 athletic-exposures (95% CI: 1.8-3.5).[30] An athletic-exposure was defined as one athlete participating in one practice or game during which a player was at risk of sustaining an injury. The incidence of time-loss elbow musculoskeletal disorders was 21.3% per baseball season (95% CI: 12.0-34.9) in pitchers younger than 13 years of age.[10] A time-loss injury was defined as an injury that was verified by the team's athletic trainer or research physical therapist and required the player to miss a minimum of one practice or game. As expected, musculoskeletal disorders of the elbow requiring medical attention are more common than those requiring time-loss in youth baseball pitchers.[10,30]

### *Adolescent and high school baseball pitchers*

The reported incidence of time-loss musculoskeletal disorders of the elbow, per season, is lower in adolescents than in youth or professional baseball pitchers. Hibberd *et al*.[33] reported that 2.3% (95% CI: 1.2-4.4) of high school baseball pitchers (between the ages of 14-19 years) sustained a time-loss musculoskeletal disorder of the elbow over the course of a season. Shanley *et al*.[10] documented a higher incidence of 11.8% (95% CI: 6.1-21.5) of adolescent 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 disorders 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%).[29,31,32] The definitions used for time-loss musculoskeletal disorders of the elbow were: (1) any

Table 1.

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

| Author(s), year | Study design | Subjects and setting | Follow-up period | Case definition | Incidence (95% CI) |
|---|---|---|---|---|---|
| **Youth injuries** | | | | | |
| Sakata et al., 2016[30] | Cohort study | 69 junior baseball pitchers (ages 6-12 years) with no history of elbow pain | 12 months | **Physical complaint (elbow pain):**<br>• Elbow pain lasting greater than 2 weeks, elbow pain that caused them not to play in a game or practice, or recurrent elbow pain<br>**Elbow injury requiring medical attention:**<br>• 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)<br>**Elbow injury requiring medical attention incidence density:** 2.2/1000 AEs (1.5-3.2/1000 AEs)<br>**Elbow injury requiring medical attention annual incidence:** 40.6% (29.8-52.4) |
| Shanley et al., 2015[10] | Cohort study | 47 asymptomatic youth (8-12 years old) | One baseball season | **Time-loss elbow injury:**<br>• 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[10] | Cohort study | 68 adolescent (13-18 years old) pitchers | One baseball season | **Time-loss elbow injury:**<br>• 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[33] | Cohort study | 384 high school baseball pitchers (age 14-19 years) | One spring baseball season | **Time-loss elbow injury:**<br>• 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[29] | Cohort study | 207 pitcher-seasons from 144 Major and Minor League Baseball pitchers | One season | **Time-loss elbow injury:**<br>• An injury to the elbow that resulted in placement on the disabled list and/or missing at least one game<br>**Non-operative time-loss elbow injury:**<br>• An elbow injury that did not require surgery<br>**Operative time-loss elbow injury:**<br>• An elbow injury that did require surgery | **Time-loss elbow injury incidence per season:** 13.5% (9.5-18.9)<br>**Non-operative time-loss elbow injury incidence per season:** 5.8% (3.4-9.9)<br>**Operative time-loss elbow injury incidence per season:** 7.7% (4.8-12.2) |
| Camp et al., 2018[31] | 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:**<br>• 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[32] | 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:**<br>• 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[29]; or (2) any elbow injury that resulted in at least one day out of play[31,32]. 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.[29,31,32]

## Risk factors for musculoskeletal disorders of the elbow

### High school baseball pitchers

Data from Hibberd *et al*.[33] 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*.[35], 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*.[36] 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.[36] 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.[36]

#### 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*.[34] 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*.[35] 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.[35]

#### 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*.[35] 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.[35] 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.[35]

Table 2.
*Risk factors for elbow injuries in baseball pitchers. Abbreviations: OR = odds ratio; RR= relative risk; CI = confidence interval; mph = miles per hour.*

| Author(s), year | Risk factor(s) Considered | Study design | Cases and control | Risk factors |
|---|---|---|---|---|
| Keller et al., 2016[34] | Percentage of fastballs, sliders, curveballs & change-ups thrown | Case-Control Study | **Cases:** 83 Major League Baseball pitchers who had undergone primary UCL reconstruction between 2008 and 2015. **Controls:** 83 Major League Baseball pitchers matched for year, age, position, size, experience and innings pitched | **One percent increase in fastballs thrown:** OR=1.02; 95% CI=1.00-1.03; p=0.035 **One percent increase in sliders thrown:** OR=0.98; 95% CI=0.96-1.00; p=0.11 **One percent increase in curveballs thrown:** OR=1.00; 95% CI=0.97-1.03; p=0.88 **One percent increase in change-ups thrown:** OR=1.03; 95% CI=0.99-1.07; p=0.13 |
| Prodromo et al., 2016[36] | Fastball, slider, cut fastball, curveball, changeup & split-fingered fastball velocity | Case-Control Study | **Cases:** 114 Major League Baseball pitchers who underwent UCL reconstruction between 2003-2015 and had more than 20 innings in the season before UCL reconstruction. **Controls:** All (3780) age-matched Major League Baseball controls in the same preoperative season who pitched more than 20 innings. | **Fastball velocity greater by 1-mph:** OR=1.15; 95% CI=1.06-1.24; p=0.001 **Slider velocity greater by 1-mph:** OR=1.10; 95% CI=1.02-1.20; p=0.02 **Cut fastball velocity greater by 1-mph:** OR=1.01; 95% CI=0.94-1.08; p=0.85 **Curveball velocity greater by 1-mph:** OR=1.11; 95% CI=1.03-1.20; p=0.009 **Changeup velocity greater by 1-mph:** OR=1.09; 95% CI=1.02-1.18; p=0.016 **Split-fingered fastball velocity greater by 1-mph:** OR=1.13; 95% CI=0.94-1.34; p=0.191 |
| Whiteside et al., 2016[35] | Mean days between consecutive games, number of unique pitch types thrown, standing height, horizontal release location, mean pitch speed (m/s), mean pitches/game | Case-Control Study | **Cases:** 104 pitchers who had UCL reconstruction since 2010. **Controls:** 104 age and position-matched controls. | **One more day off between consecutive games pitched:** OR=0.69; 95% CI=0.54-0.87; p=0.002 **One more unique pitch type thrown:** OR=0.67; 95% CI=0.49-0.92; p=0.012 **1cm greater standing height:** OR=0.94; 95% CI=0.90-0.99; p=0.013 **Greater horizontal release location (release locations normalized to standing height):** OR=0.03; 95% CI=0.001-0.64; p=0.025 **1m/s greater mean pitch speed:** OR=1.38; 95% CI=1.10-1.73; p=0.005 **Increase of one pitch to mean pitches/game:** OR=1.02; 95% CI=1.01-1.03; p=0.003 |
| Hibberd et al., 2018[33] | Playing catcher as a secondary position in high school baseball pitchers | Cohort study | **Pitcher/Catcher:** A player who primarily identifies as a pitcher but plays catcher as a secondary position. **Pitcher/Other:** A players who primarily identifies as a pitcher and does not play catcher as a secondary position | **Playing catcher as a secondary position:** RR=3.14; 95% CI=0.68-14.50; p=0.14 |

### *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*.[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,

Table 3.
*Summary of elbow injury incidence in baseball pitchers.* [a] *Numbers in parentheses indicate 95% confidence interval.*

| | Youth pitchers | Adolescents and high school pitchers | Professional pitchers |
|---|---|---|---|
| Physical complaints of the elbow | **Incidence Density:** 2.5 (1.8-3.5)[a] physical complaints per 1000 athletic-exposures[30] | | |
| Musculoskeletal disorders of the elbow requiring medical attention | **Incidence:** 40.6% (29.8-52.4) of pitchers per year[30] **Incidence Density:** 2.2 (1.5-3.2) injuries per 1000 athletic-exposures[30] | | |
| Time-loss musculoskeletal disorders of the elbow | **Incidence:** 21.3% (12.0-34.9) of pitchers per season[10] | **Incidence:** 2.3% (1.2-4.4) to 11.8% (6.1-21.5) of pitchers per season[10,33] | **Incidence:** 13.5% (9.5-18.9) to 21.7% (15.5-29.6) of pitchers per season[29,31,32] |

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

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.[17] However, Grantham *et al*.[7] reported no increased risk of elbow injury associated with the curveball. Escamilla *et al*.[67] 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 changeups do not appear to have an effect on the risk of injury.[34] 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.[35] Overuse injuries are thought to be the result of repetitive microtrauma to tissue.[68] 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.[35]

Our synthesis suggests that pitcher workload may be associated to 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.[35] 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.[69] There is evidence suggesting a relationship between pitching biomechanics and stresses placed on the shoulder and elbow.[70,71] 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.[34–36] 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:


1. Ciccotti MG, Pollack KM, Ciccotti MC, D'Angelo J, Ahmad CS, Altchek D, et al. Elbow injuries in professional baseball: epidemiological findings from the Major League Baseball Injury Surveillance System. Am J Sports Med. 2017;45(10): 2319–2328.
2. Collins CL, Comstock RD. Epidemiological features of high school baseball injuries in the United States, 2005-2007. Pediatrics. 2008;121(6):1181–1187.
3. Chaudhari AMW, McKenzie CS, Pan X, Oñate JA. Lumbopelvic control and days missed because of injury in professional baseball pitchers. Am J Sports Med. 2014;42(11):2734–2740.
4. Conte S, Camp CL, Dines JS. Injury trends in Major League Baseball over 18 seasons: 1998-2015. Am J Orthop. 2016; 45(3):116–123.
5. Yang J, Mann BJ, Guettler JH, Dugas JR, Irrgang JJ, Fleisig GS, et al. Risk-prone pitching activities and injuries in youth baseball: findings from a national sample. Am J Sports Med. 2014;42(6): 1456–1463.
6. Olsen SJ, Fleisig GS, Dun S, Loftice J, Andrews JR. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. Am J Sports Med. 2006;34(6): 905–912.
7. Grantham WJ, Iyengar JJ, Byram IR, Ahmad CS. Thevcurveball as a risk factor for injury: a systematic review. Sports Health. 2013;7(1): 19–26.
8. Wilk KE, MacRina LC, Fleisig GS, Aune KT, Porterfield RA, Harker P, et al. Deficits in glenohumeral passive range of motion increase risk of elbow injury in professional baseball pitchers: a prospective study. Am J Sports Med. 2014;42(9): 2075–2081.
9. Tajika T, Kobayashi T, Yamamoto A, Kaneko T, Shitara H, Shimoyama D, et al. A clinical and ultrasonographic study

of risk factors for elbow injury in young baseball players. J Orthop Surg. 2016;24(1): 45–50.
10. Shanley E, Kissenberth MJ, Thigpen CA, Bailey LB, Hawkins RJ, Michener LA, et al. Preseason shoulder range of motion screening as a predictor of injury among youth and adolescent baseball pitchers. J Shoulder Elb Surg. 2015;24(7): 1005–1013.
11. Polster JM, Bullen J, Obuchowski NA, Bryan JA, Soloff L, Schickendantz MS. Relationship between humeral torsion and injury in professional baseball pitchers. Am J Sports Med. 2013;41(9):2015–2021.
12. Douoguih WA, Dolce DL, Lincoln AE. Early cocking phase mechanics and upper extremity surgery risk in starting professional baseball pitchers. Orthop J Sport Med. 2015;3(4):1–5.
13. Fleisig GS, Andrews JR, Cutter GR, Weber A, Loftice J, McMichael C, et al. Risk of serious injury for young baseball pitchers: a 10-year prospective study. Am J Sports Med. 2011;39(2):253–257.
14. Matsuura T, Suzue N, Iwame T, Arisawa K, Sairyo K. Epidemiology of shoulder and elbow pain in youth baseball players. Physician Sportsmed. 2016;44(2): 97–100.
15. Whiteley RJ, Adams RD, Nicholson LL, Ginn KA. Reduced humeral torsion predicts throwing-related injury in adolescent baseballers. J Sci Med Sport. 2010;13(4):392–396.
16. Yukutake T, Nagai K, Yamada M, Aoyama T. Risk factors for elbow pain in Little League baseball players: a cross-sectional study focusing on developmental factors. J Sports Med Phys Fitness. 2015;55(9):962–968.
17. American Sports Medicine Institute: Position Statement for Adolescent Baseball Pitchers. [cited 2019 Feb 6].
18. USA Baseball Medical & Safety Advisory Committee Guidelines: May 2006. 2006.
19. Salamh P, Jones E, Bashore M, Liu X, Hegedus EJ. Injuries and associated risk factors of the shoulder and elbow among adolescent baseball pitchers: a systematic review and meta-analysis. Phys Ther Sport. 2020;43:108–119.
20. Norton R, Honstad C, Joshi R, Silvis M, Chinchilli V, Dhawan A. Risk factors for elbow and shoulder injuries in adolescent baseball players: a systematic review. Am J Sports Med. 2019;47(4):982–990.
21. Agresta CE, Krieg K, Freehill MT. Risk factors for baseball-related arm injuries: a systematic review. Orthop J Sport Med. 2019;7(2):1–13.
22. Fletcher RH, Fletcher SW, Fletcher GS. Clinical Epidemiology: The Essentials. 5th Ed. Philadelphia: Lippincott Williams & Wilkins; 2014.
23. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 2009;339(jul21 1):b2535–b2535.
24. Fuller CW, Ekstrand J, Junge A, Andersen TE, Bahr R, Dvorak J, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. Br J Sport Med. 2006;40: 193–201.
25. McGowan J, Sampson M, Salzwedel DM, Cogo E, Foerster V, Lefebvre C. PRESS Peer Review of Electronic Search Strategies: 2015 Guideline Statement. J Clin Epidemiol. 2016;75:40–46.
26. Scottish Intercollegiate Guidelines Network. Checklists and notes. [cited 2019 Mar 5].
27. Slavin RE. Best evidence synthesis: an intelligent alternative to meta-analysis. J Clin Epidemiol. 1995;48(1):9–18.
28. Cohen J. A Coefficient of agreement for nominal scales. Educ Psychol Meas. 1960;20(1):37–46.
29. Byram IR, Bushnell BD, Dugger K, Charron K, Harrell FE, Noonan TJ. Preseason shoulder strength measurements in professional baseball pitchers: Identifying players at risk for injury. Am J Sports Med. 2010;38(7):1375–1382.
30. Sakata J, Nakamura E, Suzukawa M, Akaike A, Shimizu K. Physical risk factors for a medial elbow injury in junior baseball players. Am J Sports Med. 2017;45(1):135–143.
31. Camp CL, Spiker AM, Zajac JM, Pearson D, Sinatro AM, DInes JS, et al. Decreased hip internal rotation increases the risk of back and abdominal muscle injuries in professional baseball players: analysis of 258 player-seasons. J Am Acad Orthop Surg. 2018;26(9):e198–206.
32. Camp CL, Zajac JM, Pearson DB, Sinatro AM, Spiker AM, Werner BC, et al. Decreased shoulder external rotation and flexion are greater predictors of injury than internal rotation deficits: analysis of 132 pitcher-seasons in professional baseball. Arthrosc – J Arthrosc Relat Surg. 2017;33(9):1629–1636.
33. Hibberd EE, Oyama S, Myers JB. Rate of upper extremity injury in high school baseball pitchers who played catcher as a secondary position. J Athl Train. 2018;53(5):0–0.
34. Keller RA, Marshall NE, Guest JM, Okoroha KR, Jung EK, Moutzouros V. Major League Baseball pitch velocity and pitch type associated with risk of ulnar collateral ligament injury. J Shoulder Elb Surg. 2016;25(4):671–675.
35. Whiteside D, Martini DN, Lepley AS, Zernicke RF, Goulet GC. Predictors of ulnar collateral ligament reconstruction in major league baseball pitchers. Am J Sports Med. 2016;44(9):2202–2209.
36. Prodromo J, Patel N, Kumar N, Denehy K, Tabb LP, Tom J. Pitch characteristics before ulnar collateral ligament reconstruction in major league pitchers compared with age- matched controls. Orthop J Sport Med. 2016;4(6):1–5.
37. Noonan TJ, Thigpen CA, Bailey LB, Wyland DJ, Kissenberth M, Hawkins RJ, et al. Humeral torsion as a

risk factor for shoulder and elbow injury in professional baseball pitchers. Am J Sports Med. 2016;44(9):2214–2219.
38. Grana WA, Rashkin A. Pitcher 's elbow in adolescents. Am J Sport Med. 1980;8(5):333–336.
39. Lyman S, Fleisig GS, Waterbor JW, Funkhouser EM, Pulley L, Andrews JR, et al. Longitudinal study of elbow and shoulder. Med Sci Sport Exerc. 2001;33(11):1803–1810.
40. Grana WA, Boscardin JB, Schneider HJ, Takao AH, Vera T, Goin SG. Evaluation of elbow and shoulder problems in professional basebal pitchers. Am J Orthop. 2007;36(6):308–313.
41. Lyman S, Fleisig GS, Andrews JR, Osinski ED. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. Am J Sports Med. 2002;30(4):463–468.
42. Mueller FO, Marshall SW, Kirby DP. Injuries in little league baseball from 1987 through 1996: Implications for prevention. Physician Sportsmed. 2001;29(7):41–48.
43. Erickson BJ, Chalmers PN, Axe MJ, Romeo AA. Exceeding pitch count recommendations in little league baseball increases the chance of requiring Tommy John surgery as a professional baseball pitcher. Orthop J Sport Med. 2017;5(3):1–6.
44. Gutierrez NM, Granville C, Kaplan L, Baraga M, Jose J. Elbow MRI Findings do not correlate with future placement on the disabled list in asymptomatic professional baseball pitchers. Sports Health. 2017;9(3):222–229.
45. Hodgins JL, Trofa DP, Donohue S, Littlefield M, Schuk M, Ahmad CS. Forearm flexor injuries among Major League Baseball players: epidemiology, performance, and associated injuries. Am J Sports Med. 2018;46(9):2154–2160.
46. Li X, Zhou H, Williams P, Steele JJ, Nguyen J, Jäger M, et al. The epidemiology of single season musculoskeletal injuries in professional baseball. Orthop Rev. 2013;5(1):3.
47. Myers JB, Oyama S, Hibberd EE. Scapular dysfunction in high school baseball players sustaining throwing-related upper extremity injury: a prospective study. J Shoulder Elb Surg. 2013;22(9):1154–1159.
48. Posner M, Cameron KL, Wolf JM, Belmont PJ, Owens BD. Epidemiology of Major League Baseball injuries. Am J Sports Med. 2011;39(8):1676–1680.
49. Rothermich MA, Conte SA, Aune KT, Fleisig GS, Cain EL, Dugas JR. Incidence of elbow ulnar collateral ligament surgery in collegiate baseball players. Orthop J Sport Med. 2018;6(4):4–9.
50. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS. Incidence of injuries in high school softball and baseball players. J Athl Train. 2011;46(6):648–654.
51. Tyler TF, Mullaney MJ, Mirabella MR, Nicholas SJ, McHugh MP. Risk factors for shoulder and elbow injuries in high school baseball pitchers: the role of preseason strength and range of motion. Am J Sports Med. 2014;42:1993–1999.
52. Yukutake T, Kuwata M, Yamada M, Aoyama T. A preseason checklist for predicting elbow injury in little league baseball players. Orthop J Sport Med. 2015;3(1):1–7.
53. Bushnell BD, Anz AW, Noonan TJ, Torry MR, Hawkins RJ. Association of maximum pitch velocity and elbow injury in professional baseball pitchers. Am J Sports Med. 2010;38(4):728–732.
54. Anz AW, Bushnell BD, Griffin LP, Noonan TJ, Torry MR, Hawkins RJ. Correlation of torque and elbow injury in professional baseball pitchers. Am J Sports Med. 2010;38(7):1368–1374.
55. Wilk KE, Macrina LC, Fleisig GS, Aune KT, Porterfield RA, Harker P, et al. Deficits in glenohumeral passive range of motion increase risk of elbow injury in professional baseball pitchers: a prospective study. Am J Sports Med. 2014;42(9):2075–2081.
56. Matsuura T, Suzue N, Kashiwaguchi S, Arisawa K, Yasui N. Elbow injuries in youth baseball players without prior elbow pain: a 1-year prospective study. Orthop J Sport Med. 2013;1(5):1–4.
57. Erickson BJ, Harris JD, Tetreault M, Bush-Joseph C, Cohen M, Romeo AA. Is Tommy John surgery performed more frequently in major league baseball pitchers from warm weather areas? Orthop J Sport Med. 2014;2(10):1–6.
58. Chalmers PN, Erickson BJ, Ball B, Romeo AA, Verma NN. Fastball pitch velocity helps predict ulnar collateral ligament reconstruction in Major League Baseball pitchers. Am J Sports Med. 2016;44(8):2130–2135.
59. DeFroda SF, Kriz PK, Hall AM, Zurakowski D, Fadale PD. Risk sttratification for ulnar collateral ligament injury in Major League Baseball players: a retrospective study from 2007 to 2014. Orthop J Sport Med. 2016;4(2):1–6.
60. Meyer CJ, Garrison JC, Conway JE. Baseball players with an ulnar collateral ligament tear display increased nondominant arm humeral torsion compared with healthy baseball players. Am J Sports Med. 2017;45(1):144–149.
61. Cain EL, McGonigle O. Return to play following ulnar collateral ligament reconstruction. Clin Sports Med. 2016;35(4):577–695.
62. Dun S, Loftice J, Fleisig GS, Kingsley D, Andrews JR. A biomechanical comparison of youth baseball pitches: Is the curveball potentially harmful? Am J Sports Med. 2008;36(4):686–692.
63. Fleisig GS, Kingsley DS, Loftice JW, Dinnen KP, Ranganathan R, Dun S, et al. Kinetic comparison among the fastball, curveball, change-up, and slider in collegiate baseball pitchers. Am J Sports Med. 2006;34(3): 423–430.
64. Nissen CW, Westwell M, Õunpuu S, Patel M, Solomito M,

Tate J. A biomechanical comparison of the fastball and curveball in adolescent baseball pitchers. Am J Sports Med. 2009;37(8):1492–1498.
65. Thompson RW, Dawkins C, Vemuri C, Mulholland MW, Hadzinsky TD, Pearl GJ. Performance metrics in professional baseball pitchers before and after surgical treatment for neurogenic thoracic outlet syndrome. Ann Vasc Surg. 2017;39: 216–227.
66. Lehman G, Drinkwater EJ, Behm DG. Correlation of throwing velocity to the results of lower-body field tests in male college baseball players. J Strength Cond Res. 2013;27(4):902–908.
67. Escamilla RF, Fleisig GS, Andrews JR. A kinematic and kinetic comparison while throwing different types of baseball pitches. Med Sci Sport Exerc. 1994;26 (Supple):S176.
68. Roos KG, Marshall SW. Definition and usage of the term "overuse injury" in the US high school and collegiate sport epidemiology literature: a systematic review. Sports Med. 2014;44(3):405–421.
69. Fortenbaugh D, Fleisig GS, Andrews JR. Baseball pitching biomechanics in relation to injury risk and performance. Sport Health A Multidiscip Approach. 2009;1(4): 314–320.
70. Aguinaldo AL, Chambers H. Correlation of throwing mechanics with elbow valgus load in adult baseball pitchers. Am J Sports Med. 2009;37(10):2043–2048.
71. Chalmers PN, Wimmer MA, Verma NN, Cole BJ, Romeo AA, Cvetanovich GL, et al. The relationship between pitching mechanics and injury: a review of current concepts. Sports Health. 2017;9(3): 216–221.

Appendix 1.
*PubMed search strategy.*

1. Baseball*. ti,ab
2. Pitch*. ti,ab
3. Major league baseball. ti,ab
4. MLB. ti,ab
5. Hardball. ti,ab
6. Overhand athlete. ti,ab
7. Overhead athlete. ti,ab
8. Throw*. ti,ab
9. /Baseball
10. or/1-9
11. Injur*. ti,ab
12. Musculoskeletal injur*. ti,ab
13. Athletic injur*. ti,ab
14. Soft tissue injur*. ti,ab
15. Cumulative trauma disorders. ti,ab
16. Repetit*. ti,ab
17. Little league elbow. ti,ab
18. Elbow. ti,ab
19. Rotator cuff. ti,ab
20. Strain. ti,ab
21. Sprain. ti,ab
22. Tear. ti,ab
23. Disabled list. ti,ab
24. Disabil*. ti,ab
25. Absenteeism. ti,ab
26. Injured reserve. ti,ab
27. Upper extremity. ti,ab
28. Lower extremity. ti,ab
29. Shoulder. ti,ab
30. Elbow. ti,ab
31. Wrist. ti,ab
32. Hip. ti,ab
33. Arm. ti,ab
34. Tendon*. ti,ab
35. Ligament*. ti,ab
36. /Athletic Injuries
37. /Soft Tissue Injuries
38. /Tendon Injuries
39. /cumulative trauma disorders
40. /neck injuries
41. /ankle injuries
42. /foot injuries
43. /Back injuries
44. /wrist injuries
45. /leg injuries
46. /knee injuries
47. /hand injuries
48. /forearm injuries
49. /finger injuries
50. /arm injuries
51. /upper extremity
52. /lower extremity
53. /Absenteeism
54. Or/11-53
55. Inciden*. ti,ab
56. Epidemiolog*. ti,ab
57. Prevalen*. ti,ab
58. Risk factor*. ti,ab
59. Pitch count*. ti,ab
60. Athlete exposur* or Athletic exposur*. ti,ab
61. Work load. ti,ab
62. Curveball*. ti,ab
63. Range of motion. ti,ab
64. Age. ti,ab
65. Stretch*. ti,ab
66. Strength*. ti,ab
67. Etiolog*. ti,ab
68. Statistic*. ti,ab
69. Data. ti,ab
70. Informatics. ti,ab
71. Pattern*. ti,ab
72. Trend*. ti,ab
73. Rate or Rates. ti,ab
74. Number of Injur*. ti,ab
75. /Incidence
76. /Epidemiology
77. /Prevalence
78. /Epidemiologic studies
79. /Epidemiologic methods
80. /Epidemiologic factors
81. /Etiology
82. /causality (explode)
83. /Precipitating factors
84. /Protective factors
85. /Risk factors
86. Or/55-85
87. 84 and 85 and 86
88. Limit 87 to English