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# Risk factors for ulnar collateral ligament injury in professional and amateur baseball players: a systematic review with meta-analysis

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**Background:** Risk factors for ulnar collateral ligament injury (UCLI) are unclear despite increasing injury rates. We sought to summarize UCLI risk factors in baseball players.
**Methods:** A computer-assisted search of 4 databases was performed using keywords related to UCLI risk factors. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines were used for study methodology. Odds ratios and 95% confidence intervals were calculated for dichotomous outcomes, and mean differences and 95% confidence intervals were calculated for continuous outcomes using a random-effects model.
**Results:** Thirteen studies qualified for inclusion. A greater nondominant (ND) shoulder internal rotation (IR) range of motion (ROM) at 90° abduction arm demonstrated strong evidence as a significant risk factor for UCLI ($P < .001$) compared with a control group. Mean overall velocity ($P < .001$), fastball velocity ($P < .001$), changeup velocity ($P = .03$), and curveball velocity ($P = .01$), as well as fewer years of player experience ($P < .001$), less humeral retrotorsion in the ND arm ($P < .001$), and greater absolute side-to-side differences in retrotorsion ($P = .006$) were all moderate-evidence risk factors compared with control groups. Strong evidence suggests total ROM arc at 90° abduction in the dominant arm was not a risk factor for UCLI ($P = .81$).
**Conclusions:** Greater ND shoulder IR ROM and less humeral retrotorsion (in professional and amateur players) as well as pitching velocity (in professional players) demonstrated strong to moderate evidence as risk factors for UCLI. Dominant arm total arc of motion, external, or IR ROM were not risk factors for UCLI. Standardized collection and reporting of risk factors is recommended to more clearly elucidate definitive risk factors for UCLI.
**Level of evidence:** Level III; Systematic Review


**Keywords:** Elbow; pitching; risk factors; UCL; pitching velocity; Tommy John surgery; collateral ligament; injury

Institutional Review Board approval was not required for this review article.

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The prevalence of ulnar collateral ligament (UCL) injuries (UCLI) currently stands at 15% to 25%[12] among Major League Baseball (MLB) players, Minor League Baseball players, and high school and youth players, respectively, with rates continuing to rise in all competition levels.[1,34,49,61] The prevalence of UCL reconstructive surgery in baseball has only recently been documented.

Arm injuries related to throwing are thought to be due to the repetitive stresses of throwing, which can exceed 5 times the athlete's body weight and 7000°/s.[47] In particular, the UCL is at risk due to the large valgus torque across the medial elbow during pitching.[9,21,26,51] Pitching velocity and volume are purported risk factors for UCLI,[10,14,44,51,61] which has been supported by a steady increase in MLB pitch fastball velocity (from 89.9 mph [144.7 kph] to 91.8 mph [147.7 kph] from 2002 to 2014) and mirrors the rise in Tommy John surgery prevalence over the same period.[51]

Pitch count guidelines have been developed in response to the UCLI epidemic spreading into the youth baseball community, and pitch counts are meticulously monitored in professional baseball.[5] These guidelines and approaches currently attempt to address the concern that increased exposure and frequency are risk factors for injury. Other commonly described risk factors for UCLI include year-round play/sport specialization,[8] throwing mechanics,[10] joint kinetics,[23] and ball velocity.[16,23]

The repetitive nature of throwing results in well-documented adaptive alterations in dominant shoulder external (ER) and internal rotation (IR) range of motion (ROM) as well as humeral retrotorsion, over time, in baseball players.[11,13,19,35,42,45,50,53] These alterations are hypothesized to reflect soft tissue adaptations in addition to the osseous adaptations in humeral retrotorsion from the stress of repetitive throwing, with deficits in ROM reflecting an unhealthy response to throwing and resulting in increasing injury risk.[40,67] Some studies have suggested deficits in IR ROM,[57] whereas others have shown deficits in ER ROM increase injury risk.[64,66]

When evaluated independently, to what extent, if any, these risk factors contribute to UCLI is unclear. To our knowledge, a synthesis grading of published risk factors for UCLI does not currently exist. Therefore, in attempts to discern and properly address future risk factors for UCLI, the aim of this review was to summarize currently published UCLI risk factors across professional and amateur baseball players.

## Materials and methods

### Protocol and registration

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used during the search and reporting phase of this review. The PRISMA statement includes a 27-item checklist that is designed to be used as a basis for reporting systematic reviews of randomized trials[37] and can be applied to other research methodologies.[59] The study was registered with the International Prospective Register of Systematic Reviews (PROSPERO CDR 42016042125).

### Identification and selection of the literature

A medical librarian-assisted computerized search of electronic databases was performed using the MEDLINE, SPORTDiscus, Cochrane Library, and Embase databases from each database inception to July 1, 2016, and updated September 12, 2017, with a detailed MEDLINE search provided in Appendix S1. Reference lists for all selected publications were also hand searched for potential study inclusion. Screening filters were initially used during assessment of the title, abstract, and full-text documents to optimize the sensitivity of our search strategy.[62,63] The search was further limited to humans and English language publications. Because computerized search results for diagnostic accuracy data frequently omit relevant articles,[17] systematic reviews and included articles were additionally screened to detect eligible studies that were not identified by the electronic search.

Studies examining risk factors for UCLI were eligible if they met the following inclusion criteria: (1) reported risk factors, contributors, or predictors of UCLI, (2) UCL or Tommy John surgery for UCLI, (3) assessed any level of baseball player with UCLI, (4) any experimental study design except case studies or reviews, and (5) English language. Exclusion criteria included (1) studies not reporting UCL risk factors (eg, only surgical technique, diagnostic imaging, return-to-sport protocol for UCLI), (2) studies not involving baseball players (3) studies without experimental groups, (4) studies that did not directly address UCLI (eg, studies describing only medial elbow pain, avulsion fractures, or not differentiated between shoulder and elbow pathologies), (5) language other than English.

To identify relevant articles, the titles and abstracts of all identified citations were independently screened by 2 reviewers (E.K. and M.D.W.). Full-text articles were reviewed for eligibility by the same 2 reviewers. Disagreements among the reviewers were discussed and resolved by consensus.

### Quality assessment and risk of bias

Two reviewers (M.P.R. and G.E.G.) independently conducted methodologic quality assessment on each included article using the modified Downs and Black scale,[18] which is appropriate for cohort and case–control study designs. The Downs and Black scale[18] is reliable, and the modified version used in this study had a maximum score of 16.[30,38,39] The methodologic quality of each article was stratified, as in previous reviews,[38,39] with a total score ≥12 deemed to be high quality (HQ), 10 or 11 to be moderate quality (MQ), and low quality (LQ) if the score was ≤9. Disagreements in initial ratings of methodologic quality assessment were discussed between the 2 reviewers.

A best evidence synthesis was undertaken because many of the studies presented a heterogeneous study design, statistical methods, or overall quality. This combined approach enables clarification of the strength of evidence around a particular measured variable.[58] A best evidence synthesis has been described previously[58,60] and used in systematic reviews to qualitatively analyze according to 5 hierarchical criteria aligned to study quality and clinical results presented.[26,55,56] Each article was graded for level of evidence.[9] Definitions for "levels of evidence" for pooled and nonpooled results on the various risk factors were guided by previous recommendations and use[52,60]:

- *Strong evidence*: pooled results derived from ≥3 studies, including a minimum of 2 high methodologic quality (HMQ) studies, that are statistically homogenous ($P > .05$); may be associated with a statistically significant or nonsignificant pooled result.
- *Moderate evidence*: statistically significant pooled results derived from multiple studies, including at least 1 HMQ study, that are statistically heterogeneous ($P < .05$), or from multiple low methodologic quality (LMQ) or moderate methodologic quality (MMQ) studies that are statistically homogenous ($P > .05$).
- *Limited evidence*: pooled results from multiple LMQ or MMQ studies that are statistically heterogeneous ($P < .05$) or from 1 HMQ study.
- *Very limited evidence*: results from 1 LMQ or MMQ study.
- *Conflicting evidence*: pooled results are insignificant and derived from multiple studies, regardless of quality, of which some show statistical significance individually, that are statistically heterogeneous ($P < .05$; ie, inconsistent).

## Data extraction

Data were extracted independently by 1 reviewer (M.D.W.) and independently verified by 3 additional reviewers (S.P., M.P.R. and C.A.T.). Extracted data were organized into a population (eg, baseball players), exposure (eg, velocity, experience/frequency, and shoulder measurements), and outcome (eg, UCLI) table. Although each study involved a baseball population, ages varied, ranging from Little League Baseball to MLB players.

## Data synthesis and analysis

Articles to be included for meta-analysis were determined by using clinical and statistical judgment of study heterogeneity and assessment of the risk of bias. Clinical judgment criteria involved assessment of similarity of populations, assessment context (eg, player type a priori), and method in which specific risk factors were assessed.[2] In addition, after approval using clinical judgment, studies were statistically pooled when ≥2 studies examined the same risk factor and assessment method. Sample sizes, means, and standard deviations were extracted to allow calculation of mean difference (MD). When only a range of data was provided, standard deviations were calculated. The number of UCLI player and the total number of players per variable assessed (eg, geographic location) was also extracted to allow odds ratio (OR) calculation. ORs and 95% confidence interval (CIs) were calculated for dichotomous outcomes, and the MDs and 95% CIs were calculated for continuous outcomes. After data extraction was verified by a second author, the MDs and ORs were calculated using a random effects model in Review Manager 5.3 software (Cochrane Collaboration, Oxford, UK). The level of statistical heterogeneity for pooled data was estimated using a standard $\chi^2$ test significant at $P$ values of <.05 and $I^2$ values of >50%.[29]

# Results

## Study selection

We identified 1255 titles after the initial review, with 13 studies[10,14,15,20,21,24,25,31,36,43,51,61,68] (9959 subjects) eventually qualifying for inclusion in the quality assessment and analysis after full-text review (Appendix S2). Excluded studies are reported in Appendix S3, and study conflicts are reported in Appendix S4. The inter-rater reliability suggests substantial agreement ($\kappa = 0.65$; 95% CI, 0.45-0.84) for the title screens and almost perfect agreement ($\kappa = 0.80$; 95% CI, 0.64-0.97) for abstract screens.

## Demographic characteristics of included studies

Among the 9959 patients in the included studies, there were 1198 sustaining UCLI and 8761 controls. Included studies examined players ranging from high school and college level[15,24,25,36,68] to professional level[10,14,15,20,21,31,43,51,61] (Table I). Players sustaining UCLI were overall younger in age ($P = .006$) but not different in height ($P = .98$) or weight ($P = .31$) than controls (Table II; Appendix S5). No demographic variables were significant risk factors for UCLI (Table II).

## Quality assessment of studies

All included studies were Level 3.[9] There were 5 low-quality,[10,20,21,51,68] 4 moderate-quality,[14,15,43,61] and 4 high-quality[24,25,31,36] scores using the modified Downs and Black[18] tool (Appendix S6). Attempting to blind the main outcomes was most frequently missing across included studies, with only 3 studies (23% of the included studies)[31,36,43] meeting this criterion. Clearly described demographic data were presented in only 11 studies (85%).[14,15,21,24,25,27,31,36,44,61] Power calculations were generally not reported because sample size calculation reporting was included in only 5 studies (38%),[15,21,24,25,36] and sufficient power for clinically important effects was included in only 3 (23%)[24,25,36] of those studies.

## Meta-analysis

### Demographics

Age, height, and weight were assessed as potential risk factors for UCLI in both professional and amateur players (Table II, Appendix S3).[10,15,21,24,25,31,36,61] Overall, demographic risk factors demonstrated conflicting evidence. Players sustaining UCLI were younger than controls ($P = .006$)[10,15,21,24,25,31,36,61] but no different in height ($P = .98$)[10,14,15,31,36,61] or weight ($P = .31$) than controls.[10,15,31,36,61]

### Geographic location

Geographic location of the high school that the player attended was measured in 2 studies assessing professional and amateur players (Table II, Appendix S3).[21,68] Geographic location was defined accordingly: Erickson et al[21] studied MLB players by retrospectively examining the location of their high schools, using states south of or within the 33rd parallel to designate warmer climates while also including countries within Central and South America. Zaremski et al[68] delineated based on state average temperature using >55°F as warm weather climates by studying the high schools attended by collegiate baseball players. At the time of analysis, these

**Table I** Included study and player characteristics

| Study | Study design | Methodologic quality | UCLI athletes | Control athletes | Competition level |
|---|---|---|---|---|---|
| | | | No; mean age, yr | No; mean age, yr | |
| Chalmers et al[10] (2016) | Case-control study | Low | 309; 26.7 | 1018; 28.1 | Professional (MLB) |
| DeFroda et al[14] (2016) | Cohort study | Moderate | 118; NR | 118; NR | Professional (MLB) |
| Dines et al[15] (2009) | Case-control study | Moderate | 29; 21.17 | 29; NR | Professional (MLB), college, high school |
| Erickson et al[21] (2014) | Descriptive epidemiologic study | Low | 247; 27.57 | 108; 28.44 | Professional (MLB) |
| Erickson et al[20] (2017) | Cohort study | Low | 3; NR | 635; NR | Professional (MLB) |
| Garrison et al[25] (2012) | Cross-sectional study | High | 30; 18.2 | 30; 18.57 | College, high school |
| Garrison et al[24] (2013) | Cross-sectional study | High | 30; 18.5 | 30; 19 | College, high school |
| Keller et al[31] (2016) | Case-control design; epidemiologic study | High | 83; 28 | 83; 28 | Professional (MLB) |
| Meyer et al[36] (2017) | Case-control study | High | 56; 17.96 | 56; 17.57 | College and high school |
| Noonan et al[43](2016) | Case-control study | Moderate | 17; NR | 195; NR | Professional (MLB) |
| Prodromo et al[51] (2016) | Case-control study | Low | 114; NR | 3780; NR | Professional (MLB) |
| Whiteside et al[61] (2016) | Case-control study | Moderate | 104; 27.3 | 104; 27.8 | Professional (MLB) |
| Zaremski et al[68] (2015) | Descriptive epidemiologic study | Low | 58; NR | 2575; NR | College |

*UCLI*, ulnar collateral ligament injury; *MLB*, Major League Baseball; *NR*, not reported.

collegiate players were attending a university within the Southeastern Conference or Big Ten Conference.

Combined meta-analysis demonstrated a greater number of UCLI were found in warm weather geographic locations (Table II). Limited evidence for both professional and amateur players ($P = .03$) and very limited evidence ($P < .00001$) for professional players alone found a greater number of UCLI injuries occurred in warm than cold weather geographic locations.

## Pitching velocity

Pitching velocity across 5 different pitch types in professional players was assessed in 6 studies.[10,14,31,44,51,61] Mean fastball ($P = .0003$), mean changeup ($P = .03$), mean curveball ($P = .01$), and mean overall velocity ($P = .00001$) all demonstrated moderate evidence of higher velocity in mph for those players sustaining UCLI than controls (Fig. 1; Appendix S7). Conflicting evidence for mean slider pitching velocity (mph) was found ($P = .43$) across 2 studies.[31,51]

## Player experience

Six studies assessed player experience in professional and amateur players.[10,21,24,25,31,36] Moderate evidence suggests professional players sustaining UCLI had fewer years of experience than controls ($P < .00001$), whereas conflicting evidence found no difference ($P = .55$) in years of experience vs. controls in amateur players.

## Shoulder ROM (°) and retrotorsion (°)

Six[15,24,25,36,43] of the 13 studies assessed ROM and retrotorsion across amateur and professional players. Significant risk factors were (1) strong evidence that players greater ND shoulder IR ROM at 90° abduction in professional and amateur players ($P < .00001$; Fig. 2), as well as amateur players alone ($P < .00001$), in players sustaining UCLI than controls; (2) moderate evidence that professional and amateur players with less ND humeral retrotorsion (°) in athletes sustaining UCLI compared to controls ($P = .00009$; Fig. 2); as well as (3) moderate evidence that professional and amateur players with greater absolute side-to-side difference (ND vs. dominant arm) in humeral retrotorsion sustaining UCLI to a greater extent than controls ($P = .03$). Dominant arm IR ROM demonstrated conflicting evidence in professional and amateur players ($P = .57$) compared with controls.

Total arc of motion (ER plus IR ROM measured at 90° abduction) of the dominant shoulder was not different (nonsignificant risk factor) in professional and amateur players sustaining UCLI than controls ($P = .81$; strong evidence).

Conflicting evidence findings related to shoulder ROM and humeral retrotorsion were (1) dominant arm IR ROM in professional and amateur players sustaining UCLI vs. controls ($P = .57$), (2) dominant arm humeral retrotorsion in professional and amateur players sustaining UCLI vs. controls ($P = .74$); and (3) absolute side-to-side differences in IR ROM in professional and amateur players vs. controls ($P = .40$).

**Table II** Summary of risk factors for ulnar collateral ligament injury

| Significant risk factors | Nonsignificant risk factors |
|---|---|
| *Strong evidence* | *Strong evidence* |
| 1. Greater IR ROM (°)–nondominant arm in professional and amateur players | 1. Total ROM (°)–dominant arm in professional and amateur UCLI players |
| *Moderate evidence* | *Very limited evidence* |
| 1. Higher mean fastball velocity (mph) in professional players | 1. High school geographic location in amateur players |
| 2. Higher mean changeup velocity (mph) in professional players | 2. Career overall pitch count in professional players |
| 3. Higher mean curveball velocity (mph) in professional players | 3. Career fastball pitch count in professional players |
| 4. Higher mean overall velocity (mph) in professional players | 4. Career changeup pitch count in professional players |
| 5. Fewer years of player experience in professional players | 5. Career slider pitch count in professional players |
| 6. Less humeral retrotorsion (°)–nondominant arm in professional and amateur players | 6. Annual slider pitch count |
| 7. Greater absolute side-to-side differences (ND-D) in humeral retrotorsion (°) in professional and amateur players | 7. Elbow ROM (°)–dominant arm in professional and amateur players |
| | 8. Elbow ROM (°)–nondominant arm in professional and amateur players |
| *Limited evidence* | 9. Pronation (°)–dominant arm in professional and amateur players |
| 1. Warmer high school geographic location for professional and amateur players | 10. Pronation (°)–nondominant arm in professional and amateur players |
| *Very limited evidence* | 11. Supination (°)-dominant arm in professional and amateur players |
| 1. Higher career breaking pitch count in professional players | 12. Supination (°)–nondominant arm in professional and amateur players |
| 2. More likely to violate pitch count in amateur players | 13. Elbow extension difference (°)–dominant arm in amateur players |
| 3. Higher annual breaking pitch count in professional players | 14. Horizontal adduction difference (°)–dominant arm in amateur players |
| 4. Warmer high school geographic location in professional UCLI players | 15. Spin rate (revs/s) in professional players |
| 5. Lower annual pitch count in professional players | 16. Vertical release location in professional players |
| 6. Lower annual fastball pitch count in professional players | 17. Horizontal release location in professional players |
| 7. Lower annual changeup pitch count in professional players | |
| 8. Fewer mean days in professional players between consecutive games | |
| 9. Fewer unique pitch types thrown in professional players | |
| 10. Less composite LQYBT lead leg reach distance in amateur players | |
| 11. Less composite LQYBT stance leg reach distance in amateur players | |
| **Conflicting risk factors** | |
| 1. Age–professional and amateur UCLI players | |
| 2. Height–professional and amateur players | |
| 3. Weight–professional and amateur players | |
| 4. Mean slider velocity (mph)–professional players | |
| 5. Years of player experience–amateur players | |
| 6. IR ROM (°)–dominant arm in professional and amateur players | |
| 7. Humeral retrotorsion (°)–dominant arm in professional and amateur players | |
| 8. Absolute side-to-side differences (ND-D) between arms-IR deficit (°)–professional and amateur players | |

*IR*, internal rotation; *ROM*, range of motion; *UCLI*, ulnar collateral ligament injury; *ND*, nondominant, *D*, dominant; *LQYBT*, Lower Quarter Y Balance Test; *revs/s*, revolutions per second.

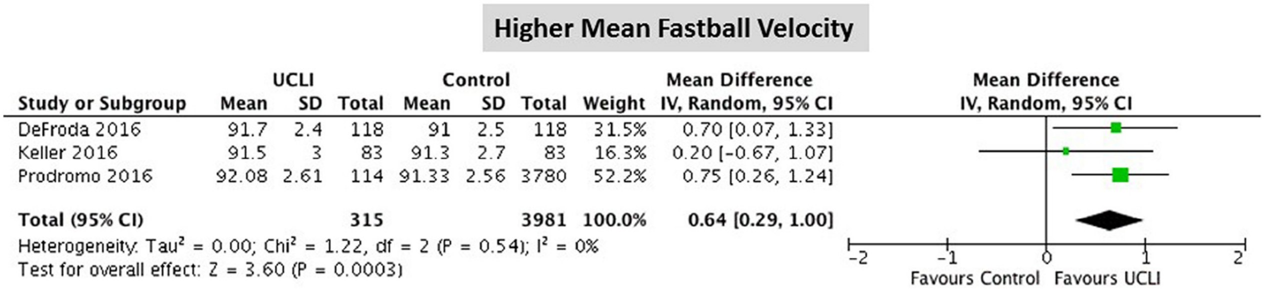


**Figure 1** Moderate evidence risk factors for ulnar collateral ligament injury (*UCLI*)—mean fastball pitching velocity. The *solid squares* indicate the mean difference and are proportional to the weights used in the meta-analysis. The *solid vertical line* indicates no effect. The *diamond* indicates the weighted mean difference, and the *lateral tips* of the diamond indicate the associated 95% confidence intervals (*CI*). The *horizontal lines* represent the 95% CI. *SD*, standard deviation; *IV*, inverse variance.

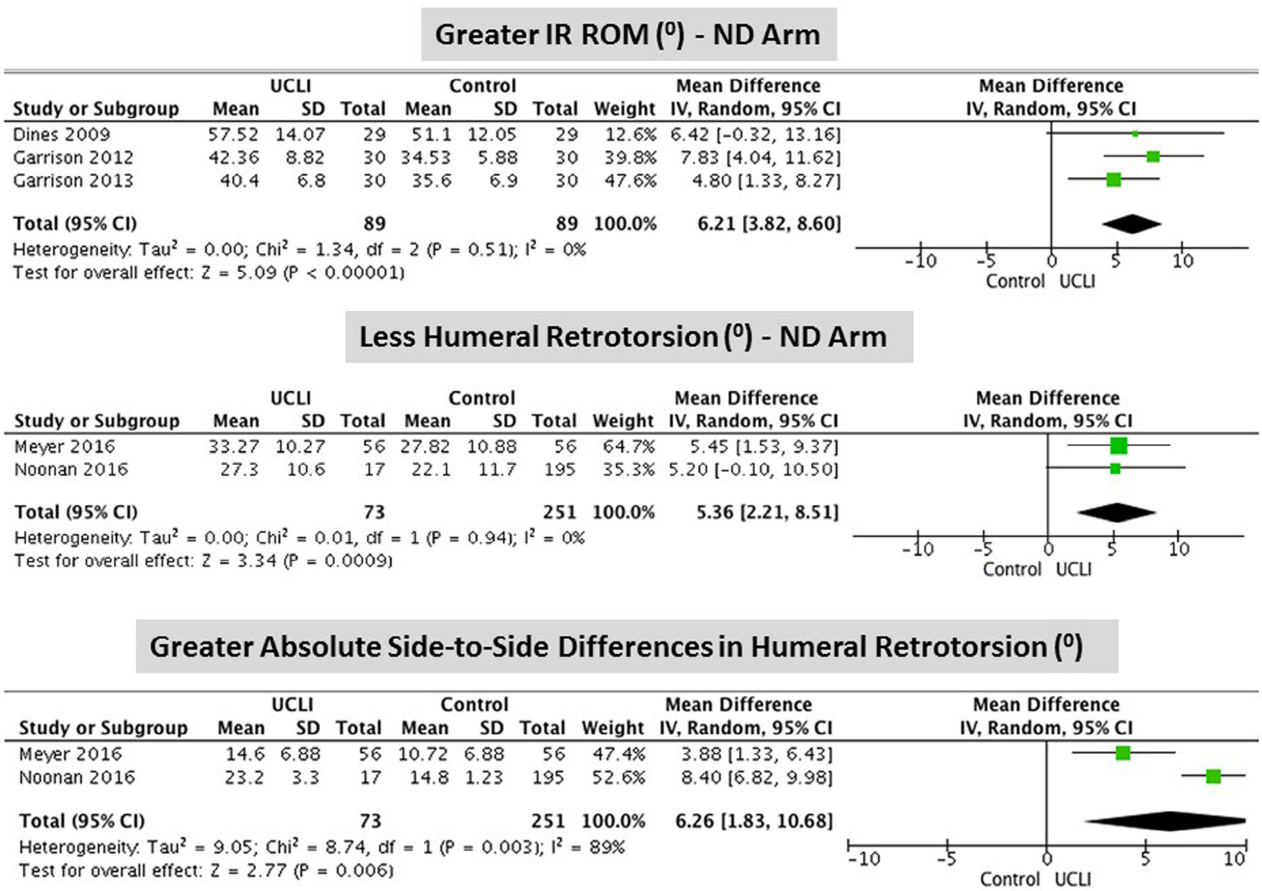


**Figure 2** Significant range of motion (*ROM*)-related risk factors for ulnar collateral ligament injury (*UCLI*): greater internal rotation (*IR*) ROM (°)—nondominant arm (*ND*) arm (strong evidence); less humeral retrotorsion (°)—ND arm (moderate evidence); greater absolute side-to-side differences in humeral retrotorsion (°) (moderate evidence). The *solid squares* indicate the mean difference and are proportional to the weights used in the meta-analysis. The *solid vertical line* indicates no effect. The *diamond* indicates the weighted mean difference, and the *lateral tips* of the diamond indicate the associated 95% confidence intervals (*CI*). The *horizontal lines* represent the 95% CI. *SD*, standard deviation; *IV*, inverse variance.

## Results of individual studies examining risk factors

Studies not qualifying for meta-analysis, due to single study investigation, examined shoulder ROM,[25] elbow ROM,[15,25] pitching frequency,[10,44,61] pitch count,[10] pitch count violation,[20] advanced baseball statistics,[61] and single leg stability.[24] Significant risk factors among these variables were:

1. Very limited evidence suggests professional players sustaining UCLI pitched a higher career breaking pitch count than controls (MD, 40; 95% CI, 36.6-43.4; $P = .012$).
2. Very limited evidence suggests amateur players sustaining UCLI pitched in a greater number of career showcases than controls (MD, 2.8; 95% CI, 1.6-3.96; $P < .01$).
3. Very limited evidence suggests amateur players sustaining UCLI were more likely to violate pitch count than controls (OR, 57.0; 95% CI, 3.52-922.4; $P = .004$).
4. Very limited evidence suggests professional players sustaining UCLI pitched (*a*) lower annual pitch count than controls (MD, 48; 95% CI, 31-65; $P = .002$); (*b*) lower annual fastball pitch count than controls (MD, 41; 95% CI, 30.3-51.7; $P = .001$); (*c*) lower annual changeup pitch count than controls (MD, 12; 95% CI, 10.6-13.4; $P = .017$); (*d*) higher annual breaking pitch count than controls (MD, 5; 95% CI, 4.5-5.8; $P = .003$); (*e*) fewer mean days between consecutive games (OR, 0.69; 95% CI, 0.54-0.87; $P = .002$); (*f*) fewer unique pitch types (OR, 0.67; 95% CI, 0.49-0.92; $P = .012$); (*g*) very limited evidence suggests amateur players had a smaller composite reach distance on both the lead (MD, –6.7; 95% CI, –10.1 to 3.4; $P < .001$) and stance leg (MD, –7.2; 95% CI, –10.9 to 3.5; $P < .001$). Nonsignificant risk factors across various studies are listed in Table II and Appendix S2.

## Discussion

To our knowledge, this is the first systematic review examining the risk factors for UCLI including 13 studies and more than 30 different variables. Our results suggest there is limited consistent evidence to guide preventive strategies across all levels of baseball. Our analyses revealed strong evidence supporting greater ND IR ROM as a significant risk factor for UCLI, whereas total arc of motion was not a risk factor for UCLI. There is also a moderate level of evidence that significant risk factors included higher mean pitching velocity for fastball, changeup, curveball, and overall pitches; fewer years of player experience, less ND retrotorsion, and greater absolute side-to-side differences in humeral retrotorsion. Our results highlight the inconsistency in populations, methods, and results across the literature.

Demographics, performance factors, and playing history have been suggested as risk factors for UCLI. However, age, height, weight, and years of playing experience in amateurs displayed conflicting evidence across studies.[10,14,15,21,24,25,31,36,61] There is limited evidence that the geographic location of the high school players attended showed a significant increase in risk for warmer weather pitchers.[21,68] However, this is likely an indirect measure of pitching frequency, multisport participation, and year-long baseball activities because geographic location is much easier to analyze than these variables. Zaremski et al[68] also postulated that there is an increased tendency to pitch while fatigued in warmer climates, which has been shown to increase injury risk up to 36 times.[44] Unfortunately, without adequate data on pitching frequency, multisport participation, and year-long baseball activities risk on UCLI, the geographic location of high school is interesting but remains a hypothetical proxy variable. A direct connection between geographic location in high school and pitching frequency, multisport participation, year-long baseball activities, or another modifiable risk factor would be required to mitigate risk.

Increasing pitching velocity showed moderate evidence, because greater mean fastball, changeup, curveball, and overall velocity were shown to increase UCLI risk. Interestingly, there was conflicting evidence for slider velocity, which is often anecdotally attributed to elbow injury risk. This finding is consistent, because mean fastball velocities in MLB have significantly increased in the last decade,[51] with an increased reliance on velocity as a predictor of future pitching success.

Anz et al[4] showed increased maximal elbow valgus torque correlated with an increased risk for elbow injury. Although this suggests that increased stress results in a higher likelihood of UCLI, velocity as a variable may be confounded by the fact that pitchers who throw harder may be more likely to be successful and therefore pitch more frequently, particularly at the youth level. To this end, only 2 studies[10,61] analyzed pitching frequency and career pitch counts. Chalmers et al[10] found significant reductions in annual pitch counts in professional players, but there was a total pitch count of 673 (control) vs. 589 (UCLI group), far less than an anticipated Major League season. Whiteside et al,[61] however, found no difference in total pitches per year, pitches per game, or pitches per inning in MLB players. Although increased pitch counts have been shown to increase the risk for elbow pain[33,44] and that elbow pain may be a proxy for future UCLI is certainly plausible, no current literature supports that increased pitch counts lead directly to UCLI. The only study[20] examining this in our review was of low quality, with a very limited number of UCLI, rendering it unable to clarify this question.

That increased pitch velocity is one of the risk factors for UCLI (moderate evidence) is troubling, because pitch velocity cannot be controlled as easily as many of the other commonly controlled variables, such as days between pitching or total pitch counts. In an attempt to address this variable, Chalmers et al[10] suggested that higher-velocity pitchers may require different pitch counts than lower-velocity pitchers. Because recent literature has shown adherence to simple pitch counts is already questionable,[22,46] it is unlikely that this additional complexity is a feasible solution, especially given the competitive edge that increased velocity provides.

This is a challenging result to develop clear recommendations for prevention of UCLI. One solution may be less emphasis on use of radar guns in developmental baseball (youth up to high school). Instead of emphasizing velocity, developing the ability to control location and repeatable pitching mechanics and overall conditioning may result in better long-term performance and injury outcomes.[48,69]

## Shoulder ROM

The past decade has seen a tremendous increase in the focus on shoulder ROM of the throwing athlete, particularly as it relates to total arc of motion and the phenomenon of glenohumeral IR deficits (GIRD). Multiple groups have shown that an IR deficit consistently exists in baseball pitchers, is increased after throwing,[54] is responsive to treatments,[3,7,32] and is likely multifactorial in cause.[6,28] However, the role of GIRD on pitching injury remains unclear. In 2011, for example, Wilk et al[67] found professional pitchers with GIRD were nearly twice as likely to sustain a shoulder injury, whereas in 2015, Wilk et al[65] found professional pitchers with GIRD were no more likely to sustain a shoulder injury. The latter study, likely the most comprehensive study on professional baseball players ROM, found no correlation of GIRD and elbow injury either.[65]

Our meta-analysis shows that there was no significant effect on dominant arm IR ROM measured at 90° abduction, side-to-side differences in IR deficit, or total ROM when assessing risk for UCLI compared with control groups. Interestingly, Garrison et al, in 2012[25] and in 2013,[24] actually showed significantly less GIRD in players with UCLI. Surprisingly, despite the lack of effect of other ROM variables, strong evidence was observed showing players with increased ND IR ROM were more likely to sustain a UCLI compared with controls. This suggests that there are inherent arm characteristics that may predispose a pitcher for UCLI. It should be noted only 2 studies[15,25] addressed elbow ROM, with no difference found in elbow extension, elbow flexion, forearm supination, or forearm pronation. The effect of elbow ROM on UCLI will require further study to draw meaningful conclusions.

## Humeral retrotorsion

Humeral retrotorsion and its effect on injury risk has increased recently in light of a series of cross-sectional and case-control studies linking deficits in shoulder ROM to differences in humeral retrotorsion. There was a large difference in the range of retrotorsion values obtained in the dominant arm by Meyer et al[36] and Noonan et al.[43] Although both used the methods outlined by Myers et al,[41] the difference in humeral retrotorsion values reported for the dominant arm in the UCLI groups were 18.7°[36] and 4.1°,[43] respectively. The side-to-side difference are less dramatic (15° and 23°), suggesting the differences in level and intensity of pitching may explain the drastic differences in dominant humeral retrotorsion. It is important to note that Meyer et al[36] included all throwers with UCLI, with mostly high school players, whereas Noonan et al[43] included only professional pitchers. Interestingly, less ND humeral retrotorsion was a risk factor for UCLI, suggesting this inherent bony alignment may drive the increased IR ROM and the subsequent side-to-side differences in humeral retrotorsion that were observed as moderate risk factors for UCLI.

## Limitations

As with any systematic review and meta-analysis, the overall analysis is no better than the methodology and biases of the individual studies that comprise it. We attempted to mitigate this using a modified Downs and Black assessment of methodologic quality,[24] but many studies are small, contain no control group, no sample size calculations, no blinding, and poorly recorded demographic variables. Despite this, we found 4 high-quality studies[42-44] and recommend future authors adhere to these quality criteria during study design. In particular, standardization of demographic and reporting criteria, assessment of ROM and humeral retrotorsion, and return to play/participation criteria should be considered.

## Conclusion

Strong evidence supports ND shoulder IR ROM as a risk factor for UCLI in professional and amateur baseball players, whereas total rotation ROM in the dominant shoulder demonstrates strong evidence support as a nonrisk factor for UCLI. Moderate evidence supports less ND humeral retrotorsion, greater absolute side-to-side differences in humeral retrotorsion, greater pitching velocity, and fewer years of experience in professional players as UCLI risk factors. Total arc ROM at 90° abduction in the dominant arm, as well as elbow ROM (among many other variables) were not evidence-supported risk factors for UCLI. Dominant arm IR ROM and humeral retrotorsion demonstrated conflicting evidence. Improved reporting and study quality are suggested to more clearly discern which risk factor(s) pose the greatest risk to baseball players in regards to future UCLI.

## Disclaimer

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## Supplementary data

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