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Shoulder Range of Motion and Baseball Arm Injuries: A Systematic Review and Meta-Analysis

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Objective: Arm injuries in baseball players are a common problem. The identification of modifiable risk factors, including range of motion (ROM), is essential for injury prevention. The purpose of this review was to assess the methodologic quality and level of evidence in the literature and to investigate the relationship between shoulder ROM and the risk of arm injuries in baseball players.

Data Sources: Relevant studies in PubMed, CINAHL, Embase, and SPORTDiscus published from inception to August 1, 2017.

Study Selection: Only studies that encompassed healthy baseball cohorts who were assessed for shoulder ROM and prospectively evaluated for injuries throughout a baseball season or seasons were included.

Data Extraction: Six articles met the search criteria. Only 3 studies were included in the meta-analysis due to disparate participant groups.

Data Synthesis: The modified Downs and Black scale (0–15 points) was used to analyze methodologic quality. Study quality ranged from 11 to 14. Four studies received high-quality ($\geq$12) and 2 studies received moderate-quality ($\geq$10) scores. The overall pooled analysis demonstrated that absolute and internal-rotation deficits (–5.93 [95% confidence interval {CI} = –9.43, –2.43], $P < .001$ and 4.28 [0.71, 7.86], $P = .02$, respectively) and absolute total ROM (TROM; –6.19 [95% CI = –10.28, –2.10]; $P = .003$) were predictors of injury, and these data exhibited homogeneity (absolute IR P value = .77, $I^2 = 0\%$; IR deficit P value = .41, $I^2 = 0\%$; absolute TROM P value = .78, $I^2 = 0\%$). No significance was observed for absolute external rotation (–2.86 [95% CI = –6.56, 0.83], $P = .13$), which had data with high heterogeneity ($P = .003$; $I^2 = 83\%$). A deficit in horizontal adduction was a predictor of injury (–8.32 [95% CI = –12.08, –4.56]; $P < .001$); these data were homogeneous but yielded a moderate heterogenic effect ($P = .16$; $I^2 = 50\%$).

Conclusions: High-quality evidence demonstrated that deficits in throwing-arm TROM and IR were associated with upper extremity injury in baseball players. Heterogeneity across studies for horizontal adduction suggested that this may be a modifiable risk factor for injury, but it requires further research.

Key Words: glenohumeral internal-rotation deficit, posterior shoulder tightness, pitching, retrotorsion

Upper extremity injuries in baseball players are a persistent and significant problem. Such injuries are common,[1–3] and injury rates are increasing.[4] In the last decade, the injury rates of high school, collegiate, and professional baseball players were 4.0, 5.8, and 3.61, respectively, per 1000 athlete-exposures, with the greatest incidence of injury at the shoulder and elbow.[1–3] These injuries can be attributed to increases in overall playing volume[5] and changes in shoulder range of motion (ROM)[6] among other factors. As a result, clinicians have investigated shoulder ROM with the aims of understanding and predicting upper extremity injuries in baseball athletes.[7]

Throwing is a complex and high-demand movement that produces high segmental velocities and joint forces,[8] with the highest proportion of forces occurring in the upper extremity.[9–12] Previous researchers[13–20] proposed that pitching forces can affect the osseous and soft tissue structures of the upper extremity. The large stresses caused by external-rotation (ER) torque during the pitching motion could induce adaptations in the humeral epiphyseal cartilage, orienting it to a more posterior and medial position.[15,17] Due to throwing-shoulder structural alterations,[13–15,21] some ROM differences between the throwing and nonthrowing limbs are necessary adaptations in high-level throwers.[22] Although long-term, osseous, throwing-specific ROM adaptations occur,[13–15,22] short-term soft tissue ROM changes have also been observed[18,19,23] and have demonstrated disparate results in terms of upper extremity injuries.[18,23] Given the multiple factors that affect shoulder ROM[13–15,18,22,23] and differing conclusions concerning shoulder ROM changes,[18,23] shoulder ROM changes have many confounding factors and are poorly understood.

Soft tissue pitching adaptations can be modified through specific interventions.[24–26] The sleeper stretch reduced shoulder ROM recovery time compared with time alone.[25] Instrumented soft tissue mobilization combined with self-stretching decreased shoulder ROM risk factors compared with self-stretching alone in baseball players.[26] Due to the heterogeneity of studies investigating the association between shoulder ROM and injury in baseball players[18,27] as well as the ability to effect soft tissue ROM adaptations through specific interventions,[24–26] we need to investigate and summarize the evidence.

Shoulder injuries in baseball continue to be a significant problem for athletes, coaches, parents, and sports medicine providers.[1–4] The identification of modifiable risk factors, including ROM, is essential for injury prevention.[1,7] Several groups[1,5,7,18,27] have prospectively examined modifiable risk factors for upper extremity injuries, but varied results made it unclear if shoulder ROM was a risk factor for upper extremity injury. This has limited the development and integration of effective upper extremity injury-prevention strategies for baseball players. Therefore, the purpose of our systematic review and meta-analysis was to critically assess the methodologic quality and level of evidence in the literature and to investigate the relationship between shoulder ROM and the risk of upper extremity injuries in baseball players. We anticipated that this systematic review would provide clinicians with evidence-based insights that could be used to develop and integrate injury-prevention strategies.[24,25]

METHODS

Study Design

To investigate the hypothesis, we performed a systematic and comprehensive literature review on the correlation between shoulder ROM and upper extremity injury among baseball players. After an initial search, we used the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) guidelines to evaluate and assess the study methods.[28] This review was prospectively registered with Prospero (CRD42017060786) after completion of the preliminary search and the initiation of formal screening.

Search Strategy

A systematic, computerized search of the literature in PubMed, CINAHL, Embase, and SPORTDiscus was conducted by a medical research librarian (L.L.) using a controlled vocabulary and key words related to shoulder anatomy and ROM. This coauthor did not participate in the screening, full-text review, or data abstraction. Our search time frame was from database inception to August 1, 2017. The search strategies are shown in the Appendix. The reference lists of all selected publications were checked to retrieve relevant publications that were not identified in the computerized search. References in screened and included articles, abstracts, and available conference proceedings (including abstracts, posters, and publications) were also hand searched by 1 author (G.S.B.). To identify relevant articles, 2 reviewers (G.S.B., M.S.F.) independently screened the titles and abstracts of all identified citations. Full-text articles were retrieved if the abstract provided insufficient information to establish eligibility or if the article passed the first eligibility screening.

Inclusion and Exclusion Criteria

We inspected identified articles to determine if they met the following inclusion and exclusion criteria. The inclusion criteria were baseball players aged 13 years or older at any competition level (professional, college, high school or middle school, or amateur). Shoulder ROM (internal rotation [IR], total ROM [TROM], external rotation [ER], or horizontal adduction [HA]) had to be assessed in either the supine or prone position. Study prerequisites were healthy cohorts who were tracked prospectively or retrospectively for injury and full-text articles that were published in a peer-reviewed journal. Each study was required to include injury incidence or injury rate. Exclusion criteria consisted of cross-sectional studies that compared healthy participants and those who were in pain or injured, case studies, papers written in a language other than English, shoulder ROM measurements not taken in the prone or supine position, participation in a sport other than baseball, or any study that lacked injury data.

Study Selection

Two reviewers (G.S.B., M.S.F.) assessed the titles and abstracts for adherence to the inclusion and exclusion criteria. Full-text documents identified by either reviewer as possibly applicable were then held for further examination (Figure 1). In case of disagreement between the 2 reviewers, a third reviewer (T.C.S.) was asked to resolve the discrepancy.

Quality Assessment

Two reviewers (G.S.B., M.S.F.) independently performed quality assessment using a modified Downs and Black scale.[28] This scale has been established as a reliable tool (test-retest $r = 0.88$; interrater $r = 0.75$) for case-control and cohort studies.[28] The modified version is scored from 0 to 15. Any disputes about methodologic quality were debated between the 2 reviewers. If a consensus could not be reached, a third author (T.C.S.) resolved the disagreement.

Data Extraction

Data were extracted by 1 reviewer (G.S.B.) and input into a database by a second reviewer (M.S.F.). Disputes concerning the study inclusion and exclusion criteria were resolved through deliberation between the 2 reviewers. If the dispute could not be solved, a third reviewer (T.C.S.) arbitrated the disagreement to achieve a consensus. Data elements were sample size; competition level; injury rates; reinjury rates; shoulder IR, ER, TROM, and HA; quality characteristics; athletes' demographic characteristics (ie, age and handedness); and level of evidence.

Meta-Analysis

Injured and uninjured group differences for absolute shoulder ROM and throwing- versus nonthrowing-shoulder ROM deficits for IR, ER, and TROM were incorporated into the meta-analysis. Injured and uninjured group differences for HA were assessed solely for absolute ROM due to a lack of data reporting for throwing- versus nonthrowing-shoulder ROM deficits. Participants were divided into groups by comparing the injured versus the uninjured,[1,7,18] those with values 1 standard deviation above or below sample normative values,[27] or previously established passive ROM measurements.[6,29] Due to the disparate data groupings in the included investigations, only 3 studies[1,7,18] that compared injured versus noninjured participants were considered in the meta-analysis. Furthermore, authors of the 3 studies that were not included in the meta-analysis did not report shoulder ROM values but

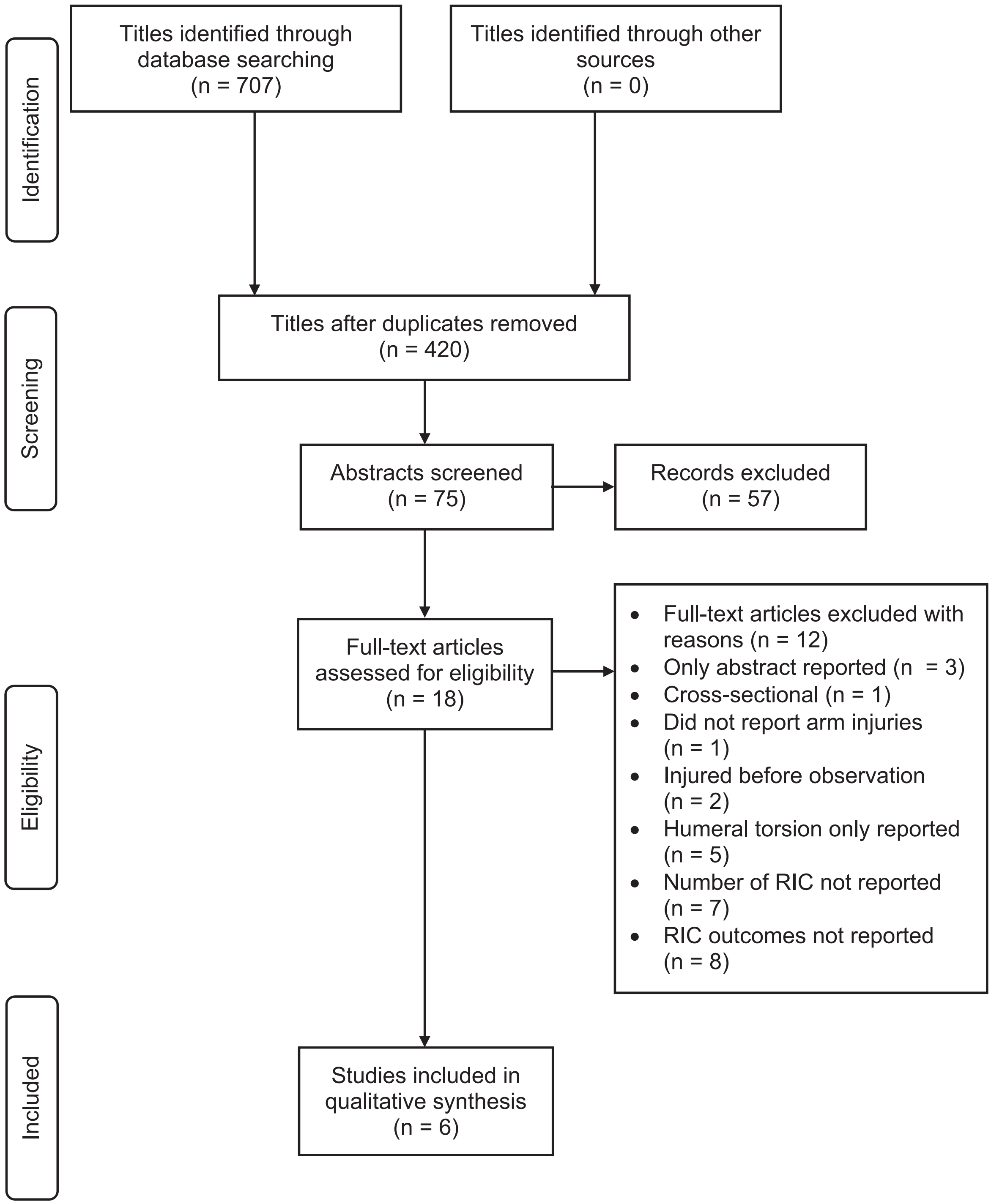


Figure 1. PRISMA flow diagram. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med*. 2009;6(7):e1000097.

instead provided the number of participants in each group. As a result, it was not possible to determine the shoulder ROM means or standard deviations for each individual or group or to include these studies in the meta-analysis. A χ^2 test and a pooled 95% confidence interval (CI) for studies that analyzed shoulder ROM as a continuous variable were calculated. Random-effects models with inverse variance weighting were used for all analyses. Heterogeneity was assessed using the Cochrane Q and I^2; high heterogeneity was determined by a Q P value $< .10$ and $I^2 > 50\%$. Analyses were performed in Review Manager (version 5.3; The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen, Denmark).

RESULTS

A total of 707 studies were identified in an initial exploration of database and reference searches. After duplicates were removed (n = 287), 420 titles were screened. Eligibility for inclusion was assessed in 75 abstracts, and 18 studies were evaluated via full-text review. Six studies were included in the quality assessment and analysis (n = 1056 participants).

Study Quality Assessment

All 6 studies reviewed[1,6,7,18,27,29] were prospective; therefore, all provided level 2b evidence (Table 1).[30] Study quality scores (modified Downs and Black scale[28]) ranged from 11 to 14 out of a maximum of 15. Comparison groups were included in all 6 studies. The authors of all 6 studies compared throwing with nonthrowing arms.[1,6,7,18,27,29] Three sets of authors[1,7,18] blinded examiners to the participant's throwing arm. One group[27] considered confounding variables (eg, pitch count) in the data analysis. Lastly, investigators in 3 studies[1,18,27] calculated sample size a priori, and only 2 studies[18,27] had sufficient power (Table 2).

Shoulder ROM Assessments

Three sets of authors[1,7,18] analyzed shoulder ROM as a continuous variable, whereas 1 group[27] categorized participants by shoulder ROM into ordinal groups (1 standard deviation above or below the mean); the other 2 sets of researchers[6,29] used shoulder ROM as a nominal risk factor variable, as established from previous studies. All 6 groups[1,6,7,18,27,29] measured IR, ER, and TROM, whereas 3 sets of investigators[1,7,27] measured HA, and 2 sets of authors[6,29] measured shoulder flexion.

Meta-Analysis

We analyzed the absolute shoulder ROM pooled variance for IR, ER, and TROM from 3 studies[1,7,18] and HA from 2 studies.[1,7] The pooled ROM bilateral deficit was assessed for IR[1,7,18] and TROM.[1,7,18] The overall pooled assessment demonstrated that the absolute shoulder IR ROM was a predictor of injury ($P < .001$; –5.93 [95% CI = –9.43, –2.43]) that exhibited homogeneity ($P = .77$; $I^2 = 0\%$; Figure 2).[1,7,18] The IR shoulder ROM pooled bilateral deficit was a predictor of injury ($P = .02$; 4.28 [95% CI = 0.71, 7.86]) that had homogeneous data ($P = .41$; $I^2 = 0\%$; Figure 3).[1,7,18] The overall pooled assessment for absolute shoulder TROM was a predictor of injury ($P = .003$; –6.19 [95% CI = –10.28, –2.10]) that had homogeneous data ($P = .78$; $I^2 = 0\%$; Figure 2).[1,7,18] The shoulder TROM pooled bilateral deficit was not a predictor of injury ($P = .60$; 1.04 [95% CI = –2.84, 4.91]); the data were homogeneous, with a moderate heterogeneous effect ($P = .19$; $I^2 = 39\%$; Figure 3).[1,7,18] The overall pooled assessment for absolute shoulder ER ROM was not a predictor of injury ($P = .13$; –2.86 [95% CI = –6.56, 0.83]), which had highly heterogeneous data ($P = .003$; $I^2 = 83\%$; Figure 2).[1,7,18] The overall pooled assessment for absolute shoulder HA was a predictor of injury ($P < .001$; –8.32 [95% CI = –12.08, –4.56]); the data were homogeneous, with a moderate heterogenic effect ($P = .16$; $I^2 = 50\%$; Figure 2).[1,7]

DISCUSSION

The purpose of this systematic review was to evaluate the methodologic quality and level of evidence in the literature and to investigate the relationship between shoulder ROM and the risk of upper extremity injuries among baseball players. A total of 6 articles met the inclusion criteria for the review. We found that absolute shoulder IR and TROM and the throwing versus nonthrowing upper extremity deficit were associated with time-loss upper extremity injuries. The meta-analysis revealed absolute shoulder IR and TROM less than 44° and 160° and side-to-side deficits in excess of 5° and 8,° respectively, which should be considered when designing upper extremity injury-prevention programs. These values should be measured as part of baseline injury and return-to-sport screening in an effort to decrease the upper extremity injury risk.

All 6 groups[1,6,7,18,27,29] used prospective cohort designs, and their study scores ranged from 11 to 15 on the modified Downs and Black scale.[28] Investigators were blinded in only 3 studies,[1,7,18] indicating that the other studies may have had potential investigator bias. Only 1 group[27] accounted for a confounding variable: pitch count, which has been associated with fatigue and pain.[5,31] Furthermore, the number of pitches and pitch types thrown during a game and over a season were associated with pain.[5] Finally, only 3 sets of authors quantified power a priori,[1,18,27] and only 2 had sufficient samples.[18,27] This shows that the majority of studies lacked ample sample size to adequately compare shoulder ROM and injuries.

Our pooled analysis demonstrated that absolute IR <44° and side-to-side dominant-shoulder deficit >5° indicated a greater risk of arm injury. Decreased IR has been associated with posterior shoulder tightness and increased humeral retrotorsion.[32,33] Pitchers with internal impingement developed greater posterior shoulder tightness (deficits in HA and IR) than healthy pitchers.[32] In addition, increased posterior shoulder tightness may affect the biomechanics by increasing the subacromial contact pressure and contact area during pitching.[34] The increased contact pressure and greater contact area may contribute to the risk of rotator cuff injury during pitching.[34]

The studies not included in the meta-analysis had conflicting results. Tyler et al[27] observed an injury incidence of 1.14/1000 pitches for the below-normative mean, whereas Wilk et al[6,29] did not detect a relationship between shoulder IR ROM deficit and injury. This disparity may have been because their participants were professional pitchers rather than adolescent amateur athletes. Previous authors[35,36] have observed that athletes at higher competition levels have greater proficiency in fundamental movements. Also, pitchers at higher competition levels may receive more specifically tailored screening for shoulder IR ROM discrepancies.

Our pooled results further showed that absolute TROM <160° and side-to-side deficits >10° increased the arm injury risk. During the pitching motion, the greatest degree of ER occurs during the late-cocking phase.[37] The extreme ER is followed by an acute acceleration and subsequent IR torque, increasing the susceptibility to injury.[8] Other researchers[38] detected that a decrease in TROM correlated with a decrease in IR ROM. As stated earlier, IR has been shown to be a factor in pitching injuries.[1,7,18,27] This highlights the fact that TROM may also be a risk factor in upper extremity injuries among baseball players.

Interestingly, shoulder ER was not related to upper extremity injury. This supports previous retrospective and cross-sectional studies.[39,40] In all of the studies included in

Table 1. Study Demographics and Design

Article	No. of Participants	Age, y (Mean ± SD)	Competition Level(s)	No. of Seasons Followed	Participant Grouping Methodology	Injury Definition	Range-of-Motion Correlation to Injury, *P* Value
Shanley et al[1] (2011)	143	15.8 ± 1.3 (range, 13–18)	High school	1	Injured versus uninjured	>7 d missed in baseball activities	IR = .04[a] ER = .25 Total = .05 HA = .01[a]
Shanley et al[7] (2015)	115	14.9 ± 1.2 (range, 13–19)	High school	1	Injured versus uninjured	>7 d missed in baseball activities	IR = .06 ER = .50 Total = .32 HA = .005[a]
Shitara et al[18] (2017)	78	16.3 ± 0.6	High school	1	Injured versus uninjured	>7 d missed in baseball activities	IR = .02[a] ER: not given Total = .04[a]
Tyler et al[27] (2014)	101	Not given	High school	4	Above, normal, or below 1 standard deviation for mean range of motion	1 missed game or practice	IR = .03[a] ER = .35 Total = .56 HA = .21
Wilk et al[29] (2014)	296	24.7 ± 4.1	Professional (Major League Baseball and Minor League Baseball)	8	Previously determined injury cut points	Disabled list	IR = .55 ER = .32 Total = .007[a] Flexion = .008[a]
Wilk et al[6] (2015)	296	24.7 ± 3.9	Professional (Major League Baseball and Minor League Baseball)	8	Previously determined injury cut points	Disabled list	IR = .20 ER = .01[a] Total = .21 Flexion = .20

Abbreviations: ER, external rotation; HA, horizontal adduction; IR, internal rotation.

[a] Indicates difference ($P < .05$).

A

Study or Subgroup	Injured Group Mean ± SD, °	Injured Group Total, no.	Uninjured Group Mean ± SD, °	Uninjured Group Total, no.	Weight, %	Mean Difference Inverse Variance, Fixed (95% CI)
Shanley et al[1] (2011)	49.5 ± 10.4	18	54.0 ± 11.5	125	45.1	−4.50 (−9.71, 0.71)
Shanley et al[7] (2015)	41.4 ± 11.9	15	48.6 ± 10.6	53	27.6	−7.20 (−13.86, −0.54)
Shitara et al[18] (2017)	35.7 ± 14.5	21	42.7 ± 11.9	84	27.3	−7.00 (−13.70, −0.30)
Total		54		262	100.0	−5.93 (−9.43, −2.43)

Heterogeneity: $\chi^2_2 = 0.53$, $P = .77$, $I^2 = 0\%$

Test for overall effect: $Z = 3.32$; $P = .001$

B

Study or Subgroup	Injured Group Mean ± SD, °	Injured Group Total, no.	Uninjured Group Mean ± SD, °	Uninjured Group Total, no.	Weight, %	Mean Difference Inverse Variance, Fixed (95% CI)
Shanley et al[1] (2011)	112.6 ± 15.0	18	126.1 ± 11.5	125	26.2	−13.50 (−20.72, −6.28)
Shanley et al[7] (2015)	132.5 ± 15.6	15	129.7 ± 13.2	53	18.2	2.80 (−5.86, 11.46)
Shitara et al[18] (2017)	104.0 ± 10.8	21	103.7 ± 8.4	84	55.6	0.30 (−4.66, 5.26)
Total		54		262	100.0	−2.86 (−6.56, 0.83)

Heterogeneity: $\chi^2_2 = 11.55$, $P = .003$, $I^2 = 83\%$

Test for overall effect: $Z = 1.52$; $P = .13$

C

Study or Subgroup	Injured Group Mean ± SD, °	Injured Group Total, no.	Uninjured Group Mean ± SD, °	Uninjured Group Total, no.	Weight, %	Mean Difference Inverse Variance, Fixed (95% CI)
Shanley et al[1] (2011)	172.1 ± 16.1	18	180.1 ± 16.2	125	26.4	−8.00 (−15.96, −0.04)
Shanley et al[7] (2015)	173.9 ± 11.1	15	178.2 ± 15.8	53	33.7	−4.30 (−11.35, 2.75)
Shitara et al[18] (2017)	139.8 ± 13.6	21	146.4 ± 13.3	84	39.9	−6.60 (−13.07, −0.13)
Total		54		262	100.0	−6.19 (−10.28, −2.10)

Heterogeneity: $\chi^2_2 = 0.49$, $P = .78$, $I^2 = 0\%$

Test for overall effect: $Z = 2.97$; $P = .003$

D

Study or Subgroup	Injured Group Mean ± SD, °	Injured Group Total, no.	Uninjured Group Mean ± SD, °	Uninjured Group Total, no.	Weight, %	Mean Difference Inverse Variance, Fixed (95% CI)
Shanley et al[1] (2011)	23.9 ± 7.8	18	31.0 ± 11.4	125	83.3	−7.10 (−11.22, −2.98)
Shanley et al[7] (2015)	5.8 ± 15.7	15	20.2 ± 17.3	53	16.7	−14.40 (−23.61, −5.19)
Total		33		178	100.0	−8.32 (−12.08, −4.56)

Heterogeneity: $\chi^2_1 = 2.01$, $P = .16$, $I^2 = 50\%$

Test for overall effect: $Z = 4.33$; $P < .001$

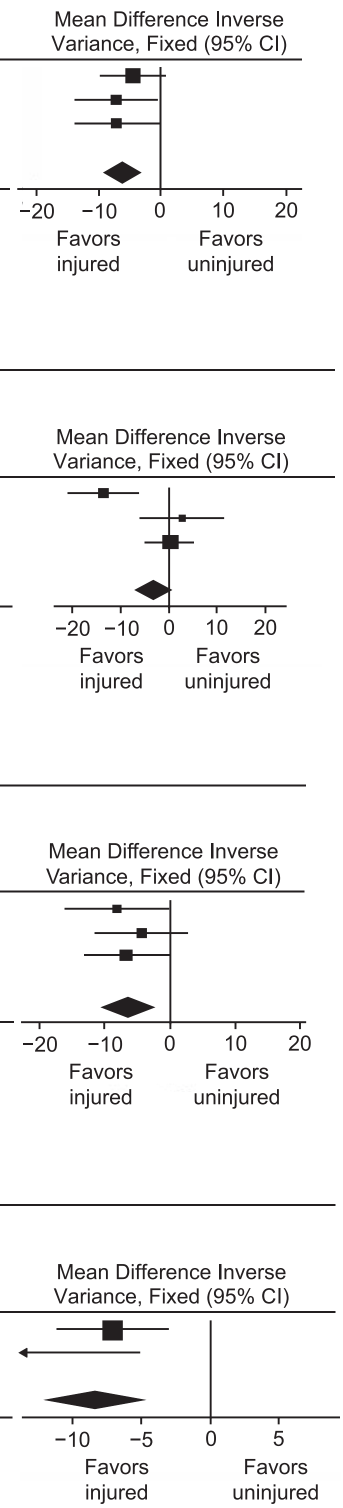


Figure 2. Pooled proportion for absolute shoulder range of motion. A, Internal rotation. B, External rotation. C, Total range of motion. D, Horizontal adduction. Abbreviation: CI, confidence interval.

the meta-analysis, ER for total and increased ROM was analyzed.[1,7,18] However, a deficit in ER ROM was associated with injury in 1 study[6] that was not included in the meta-analysis. Pitchers who had less than 5° greater ER in their throwing versus nonthrowing shoulder were more likely to incur an upper extremity injury.[6] It has been hypothesized[22] that some ROM changes between the throwing and nonthrowing limbs are a necessary adaptation in high-level throwers. Previous authors[41,42] have described an inverse relationship between humeral retrotorsion and

Table 2. Methodologic Quality Scores of Included Studies (Modified Downs and Black Scale)

Study	Item No. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total Score
Shitara et al[18] (2017)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	14
Shanley et al[1] (2011)	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	13
Tyler et al[27] (2014)	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	13
Shanley et al[7] (2015)	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	12
Wilk et al[29] (2014)	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	11
Wilk et al[6] (2015)	1	1	1	1	1	1	1	0	1	1	1	1	0	0	0	11

shoulder injuries in overhead athletes. These findings suggest that humeral retrotorsion offers protection to the shoulder joint in overhead throwers.[6,41,42] Furthermore, humeral retrotorsion explained 24% of the difference in ER and 16% of the difference in IR between limbs.[43] Thus, while screening for the risk of arm injury, measuring ER alone may not be sufficient; further inquiry into the relationship between ER and humeral retrotorsion as well as pitching development is needed.

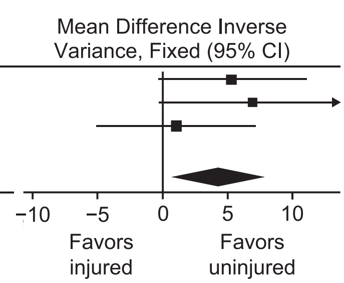
Absolute shoulder HA had a statistically significant correlation with injury. However, the effect was heterogeneous, which reflects the data inconsistencies. The discrepancy within the meta-analysis may be due to the smaller samples that were assessed for HA: only 2 groups[1,7] assessed HA. Other researchers[27] assessed HA but did not find any association with injury. Loss of shoulder HA ROM has been postulated to be due primarily to shoulder capsule and rotator cuff decrements, which hinder humeral head translation during pitching and cause subsequent injury.[44] In other studies,[32,45] decreased HA with shoulder impingement symptoms was noted. Although decreased HA ROM has been associated with shoulder injury in individual studies, data discrepancies mean that the current evidence is insufficient to support this relationship.

Of the 2 sets of authors[6,29] who measured shoulder flexion, one[29] found a relationship only with elbow injuries in professional pitchers. The authors hypothesized that this relationship may have been due to decreased tissue flexibility, specifically within the latissimus dorsi,[29] which is highly active during pitching.[46] The greatest latissimus dorsi electromyography activity occurs during the late-cocking and acceleration phases of pitching, with the highest power generation during the latter.[46] Due to the latissimus dorsi's contribution to pitching power production, decreased flexibility could correlate with a deficit in shoulder flexion, a measurement that may be clinically important.

These summary results should be considered in light of the limitations of the available studies. Only English-language articles were used in this review, which is a publication bias, and only American baseball players were investigated. As a result, these data cannot be generalized to other countries or cultures. Most investigators followed the athletes for only 1 season. Little is known about how

A

Study or Subgroup	Injured Group Mean ± SD, °	Injured Group Total, no.	Uninjured Group Mean ± SD, °	Uninjured Group Total, no.	Weight, %	Mean Difference Inverse Variance, Fixed (95% CI)
Shanley et al[1] (2011)	−2.1 ± 11.8	18	−7.5 ± 8.6	125	40.0	5.40 (−0.26, 11.06)
Shanley et al[7] (2015)	17.6 ± 12.9	15	10.6 ± 11.1	53	24.8	7.00 (−0.18, 14.18)
Shitara et al[18] (2017)	−9.0 ± 12.9	21	−10.1 ± 11.4	84	35.2	1.10 (−4.93, 7.13)
Total		54		262	100.0	4.28 (0.71, 7.86)

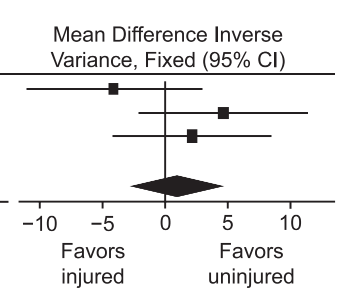


Heterogeneity: $\chi^2_2 = 1.77$, $P = .41$, $I^2 = 0\%$

Test for overall effect: $Z = 2.35$; $P = .02$

B

Study or Subgroup	Injured Group Mean ± SD, °	Injured Group Total, no.	Uninjured Group Mean ± SD, °	Uninjured Group Total, no.	Weight, %	Mean Difference Inverse Variance, Fixed (95% CI)
Shanley et al[1] (2011)	−4.6 ± 14.4	18	−0.52 ± 11.6	125	31.0	−4.08 (−11.04, 2.88)
Shanley et al[7] (2015)	5.7 ± 11.9	15	1.0 ± 12.0	53	32.1	4.70 (−2.13, 11.53)
Shitara et al[18] (2017)	3.1 ± 13.0	21	0.95 ± 14.6	84	36.9	2.15 (−4.23, 8.53)
Total		54		262	100.0	1.04 (−2.84, 4.91)



Heterogeneity: $\chi^2_2 = 3.30$, $P = .19$, $I^2 = 39\%$

Test for overall effect: $Z = 0.53$; $P = .60$

Figure 3. Pooled proportion for shoulder range-of-motion deficit. A, Internal rotation. B, Total range of motion. Abbreviation: CI, confidence interval.

changes in shoulder ROM over multiple years affect injury rates. Shanley et al[19] observed that shoulder ROM in professional pitchers changed over the course of 2 seasons. These findings suggest that shoulder ROM alters over time; however, to date, no researchers have looked at the effects of these changes on upper extremity injuries. Most authors assessed athletes at only 1 competition level, the majority of whom were adolescents. Pitchers at higher competition levels throw at greater velocities and play more games in a season compared with those at lower competition levels.[47,48] Furthermore, the studies we reviewed included players from young adolescents to professionals. Due to the physical differences among the varying age ranges, these findings should not be considered ubiquitous for all baseball player ages and competition levels. Understanding age- and competition-level normative data for shoulder ROM may be beneficial in elucidating specific athletes' prophylactic needs. Finally, the cut-off values of 5° and 8° were statistically significant in the larger samples and our pooled analysis. However, it is likely that 10° of IR and 15° of TROM are the smallest changes that can be measured clinically.[49] Clinicians should carefully consider their ROM assessment techniques to optimize the meaningfulness of their measures. Given that the purpose of screening is to identify athletes who may be at risk and to provide relatively simple, noninvasive, effective stretching interventions, smaller cut-offs may be considered.

In summary, the moderate to high methodologic scores demonstrated that a relationship was present between IR and TROM and upper extremity injury in baseball pitchers. Overall, ER did not have a significant correlation with injury; however, 1 group[6] observed that a deficit in ER ROM was associated with injury. Although HA and shoulder flexion ROM were associated with injury, an association between HA and shoulder flexion and injury cannot be claimed because of data heterogeneity and low sampling power. Future research is necessary to confirm these results in larger prospective studies. Also, more work is required to understand the effect of multiple years of shoulder ROM changes in relation to injury and normative shoulder ROM data for athletes at different competition levels. This systematic review and meta-analysis demonstrated important relationships between shoulder ROM and the future risk of upper extremity injury. These data provide the foundation for screening tools and the design of individualized or team-based injury-prevention programs.

Appendix. Search Strategy

PubMed

With All Studies Filter. ("shoulder"[MeSH Terms] OR "shoulder"[tiab] OR Glenohumeral[tiab] OR "Shoulder Injuries"[Mesh] OR "Shoulder Joint"[Mesh] OR "Scapula"[Mesh]) AND ("range of motion, articular"[MeSH Terms] OR "range of motion"[tiab] OR "External rotation"[tiab] OR "internal rotation"[tiab] OR "horizontal adduction"[tiab] OR "joint motion"[tiab]) AND ("baseball"[MeSH Terms] OR "baseball"[tiab] OR pitcher[tiab] OR pitchers[tiab])) AND (randomized controlled trial[pt] OR controlled clinical trial[pt] OR randomized[tiab] OR randomised[tiab] OR randomization[tiab] OR randomisation[tiab] OR placebo[tiab] OR drug therapy[sh] OR randomly[tiab] OR trial[tiab] OR groups[tiab] OR Clinical trial[pt] OR "clinical trial"[tiab] OR "clinical trials"[tiab] OR "evaluation studies"[Publication Type] OR "evaluation studies as topic"[MeSH Terms] OR "evaluation study"[tiab] OR evaluation studies[tiab] OR "intervention studies"[tiab] OR "intervention study"[tiab] OR "intervention studies"[tiab] OR "case-control studies"[MeSH Terms] OR "case-control"[tiab] OR "cohort studies"[MeSH Terms] OR cohort[tiab] OR "longitudinal studies"[MeSH Terms] OR "longitudinal"[tiab] OR longitudinally[tiab] OR "prospective"[tiab] OR prospectively[tiab] OR "retrospective studies"[MeSH Terms] OR "retrospective"[tiab] OR "follow up"[tiab] OR "comparative study"[Publication Type] OR "comparative study"[tiab] OR systematic[subset] OR "meta-analysis"[Publication Type] OR "meta-analysis as topic"[MeSH Terms] OR "meta-analysis"[tiab] OR "meta-analyses"[tiab]) NOT (Editorial[ptyp] OR Letter[ptyp] OR Case Reports[ptyp] OR Comment[ptyp]) NOT (animals[mh] NOT humans[mh])

Embase

('shoulder'/de OR shoulder:ab,ti OR glenohumeral:ab,ti OR 'shoulder injury'/de OR 'scapula'/de OR scapula:ab,ti) AND ('joint characteristics and functions'/de OR 'range of motion'/de OR 'range of motion':ab,ti OR 'joint motion':ab,ti OR 'external rotation':ab,ti OR 'joint mobility'/de OR 'internal rotation'/de OR 'horizontal adduction':ab,ti) AND ('baseball'/de OR baseball:ab,ti OR pitcher:ab,ti OR pitchers:ab,ti) AND ([article]/lim OR [article in press]/lim OR [conference abstract]/lim OR [conference paper]/lim OR [review]/lim OR [short survey]/lim) AND [humans]/lim AND [english]/lim AND [embase]/lim

CINAHL

Limiters: Research Article; English Language; Peer Reviewed. ((MH "Shoulder") OR "shoulder" OR (MH "Shoulder Injuries+") OR (MH "Shoulder Joint+") OR (MH "Scapula+") OR "scapula") AND ((MH "Range of Motion") OR "range of motion" OR "External rotation" OR "internal rotation" OR "horizontal adduction" OR "joint motion") AND ((MH "Baseball") OR "baseball" OR pitcher OR pitchers)

SPORTDiscus

(DE "SHOULDER" OR DE "SHOULDER joint" OR shoulder OR DE "SCAPULA") AND (DE "JOINTS (Anatomy) – Range of motion" OR OR "range of motion" OR "External rotation" OR "internal rotation" OR "horizontal adduction" OR "joint motion") AND (DE "BASEBALL" OR OR pitcher OR pitchers)

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