The Relationship Between Humeral Torsion and Arm Injury in Baseball Players: A Systematic Review and Meta-analysis

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Context: Humeral torsion (HT) has been linked to various injuries and benefits. However, the exact interplay between HT, shoulder range of motion (ROM), competition level differences, and injury risk is unclear.

Objective: To determine the relationship between HT, ROM, and injury risk in baseball players. Secondarily, to determine HT based on competition level.

Data Sources: PubMed, Embase, Web of Science, CINAHL, and Cochrane databases were searched from inception until November 4, 2018.

Study Selection: Inclusion criteria consisted of (1) HT measurements and (2) arm injury or shoulder ROM.

Study Design: Systematic review.

Level of Evidence: Level 3.

Data Extraction: Two reviewers recorded patient demographics, competition level, HT, shoulder ROM, and injury data.

Results: A total of 32 studies were included. There was no difference between baseball players with shoulder and elbow injuries and noninjured players (side-to-side HT difference: mean difference [MD], 1.75 [95% CI, -1.83 to 2.18]; dominant arm: MD, 0.17 [95% CI, -1.83 to 2.18]). Meta-regression determined that for every 1° increase in shoulder internal rotation (IR), there was a subsequent increase of 0.65° in HT (95% CI, 0.28 to 1.02). HT did not explain external rotation (ER ROM: 0.19 [95% CI, -0.24 to 0.61]) or horizontal adduction (HA ROM: 0.18 [95% CI, -0.46 to 0.82]). There were no differences between HT at the high school, college, or professional levels.

Conclusion: No relationship was found between HT and injury risk. However, HT explained 65% of IR ROM but did not explain ER ROM or HA ROM. There were no differences in HT pertaining to competition level. The majority of IR may be nonmodifiable. Treatment to restore and maintain clinical IR may be important, especially in players with naturally greater torsion. HT adaptation may occur prior to high school, which can assist in decisions regarding adolescent baseball participation.

Keywords: retrotorsion; retroversion; glenohumeral joint; shoulder; range of motion

The unique anatomic adaption characteristics of the dominant shoulder in baseball players are well-defined.¹⁰ Throwing a baseball transmits significant mechanical forces throughout the shoulder, resulting in numerous responses in both the osseous and soft tissue structures.²⁴ There is mounting evidence linking these structural adaptations to alterations in shoulder range of motion (ROM) characteristics, specifically increased external rotation (ER) and decreased

internal rotation (IR).^{3,8,10,12,15,33} Furthermore, there is high-quality evidence suggesting that deficits in throwing arm total ROM and IR are associated with upper extremity injury in baseball players.⁷

The contribution of specific tissue changes to functional ROM differences is not always clear. Several authors^{3,8,33,54,59} have proposed that changes in rotator cuff stiffness, not glenohumeral joint mobility or humeral torsion (HT), are most

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likely associated with shoulder ROM deficits observed in baseball players. Conversely, other researchers^{20,44} have found HT to be a significant factor in shoulder rotation ROM. Several authors have suggested that deficits in IR ROM result mainly from soft tissue tightness in the posterior shoulder,^{3,46} while others postulate that IR ROM is influenced more by bony tissue adaptations such as HT.^{2,20,21,35,58}

Overall, there is greater consensus regarding the difference in HT between the throwing and nonthrowing shoulders.^{10,18,36,40,44,51,63} Torsion is measured as the angle between 1 line that bisects the articular surface of the humeral head and a second line along the transepicondylar axis. HT is smallest in utero and increases throughout development until ages 16 to 20 years old.²⁶ Torsion generally exhibits a less than 5% side-to-side difference,⁵ except in the case of overhead throwing athletes, such as swimmers, volleyball players, softball players, and baseball players.^{20,51,63} Participation in a throwing sport may slow down or even reverse the natural change in torsion that occurs as humans develop into adulthood.^{50,51} The angle measured in the opposite direction of torsion is known as retroversion; an increase in retroversion is the same as a decrease in torsion.⁴⁹ For consistency, this review will utilize the term *torsion*, the term most frequently used.

Reports have linked HT to various outcomes, including ROM differences,^{20,44,58} shoulder and elbow injury risk,^{35,36,39,43,62} and even success in athletics.⁶¹ However, there remains debate regarding the relationship between HT and injury risk. Noonan et al³⁹ found a significant relationship between HT and upper extremity injury in professional baseball players. However, Oyama et al⁴² did not find a significant relationship between HT and upper extremity injury risk in high school baseball players. Schwab and Blanch⁵¹ found that torsion was not significantly related to ROM differences in elite volleyball players. Therefore, the purpose of this systematic review, meta-analysis, and meta-regression was to determine, through evaluation of all the best available literature, the relationship between HT, ROM, and injury risk in baseball players. We also sought to understand the normative values for HT at varying competition levels and the relationship between torsion and shoulder ROM. We hypothesized that decreased HT corresponds with decreased risk for upper extremity injury in baseball players.

METHODS

Study Design

This review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.³² The web-based software platform for systematic review production, Covidence (Veritas Health Innovation), was used to manage all stages of the review process. This review was registered with Prospero (CRD42018116134) prior to data extraction.

Search Strategy

A comprehensive literature search was assembled to search PubMed, Embase, Web of Science, CINAHL, and Cochrane

databases up through November 4, 2018. Medical Subject Headings and designated free-text terms are presented in Appendix 1 (available in the online version of this article).

Eligibility Criteria

The inclusion criteria included original studies on baseball players (1) that measured HT; (2) that included 10 or more participants; (3) that involved either injury prevention, intervention, morphological adaption, changes in flexibility, ROM, strength, or other similar physical parameters; (4) whose outcomes involved either arm injury, potential injury by loading, performance, strength, speed, ROM, return to sport, or performance; (5) for which the full text was available in English; (6) that were published in a peer-reviewed journal; and (7) that were either a randomized control trial, a prospective cohort trial, a retrospective cohort study, or a case series. Exclusion criteria consisted of (1) case and surgical technical reports; (2) in situ, cadaveric, narrative, or biomechanical studies; (3) articles including athletes other than baseball players that did not stratify outcomes based on sport played; (4) editorials, periodicals, or letters to the editor; and (5) participants aged younger than 16 years.

Study Selection

Two authors independently screened titles and abstracts based on aforementioned eligibility criteria. If the title and abstract provided insufficient information to conclude whether eligibility criteria were met, the study was entered for full-text review. The same 2 authors then independently assessed the full-text studies for inclusion (Figure 1). In cases of disagreement on study eligibility, a third author had final authority.

Data Extraction

Two authors performed the data extraction, including author, date of publication, number of participants, competition level, torsion in both dominant and nondominant shoulder when available, shoulder ROM in both dominant and nondominant arm when recorded, and data regarding injury.

Data Reduction

Studies reported humeral adaptation as HT or retrotorsion. All studies were converted to HT by calculating the difference of humeral rotation from horizontal (90°).

Quality Assessment and Level of Evidence

Two authors conducted a quality assessment via the modified Downs and Black tool.¹³ The Downs and Black scale has established reliability for case-control and cohort studies. Any disputes regarding individual study rating were discussed by reviewing authors, with disputes resolved by a third author.

Statistical Methods

Percentage agreement was calculated to provide absolute agreement between raters. Studies that reported on more than 1 individual cohort were each calculated as individual studies.

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram demonstrating the systematic review of the literature humeral retrotorsion in baseball players. Adapted from Moher D, Liberati A, Tetzlaff J, Altman DG; The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the PRISMA statement. *PLoS Med*. 2009;6:e1000097. For more information, visit <https://www.prisma-statement.org>.

HT in healthy cohorts was analyzed by pooling the study means through a random-effects inverse variance approach, originally described by DerSimonian and Laird.¹¹ The relationship between HT and upper extremity injury risk was assessed through a random-effects model with inverse variance. Effect sizes were reported as mean difference (MD) with 95% CIs.¹¹ Specific subgroup differences between competition levels and the relationship between HT and shoulder ROM were analyzed using random-effects meta-regressions. Shoulder ROM was individually analyzed for shoulder IR, ER, and horizontal adduction. Heterogeneity was assessed with the Cochrane Q and I^2 , with high heterogeneity designated by a P value <0.10 and $I^2 >50\%$.²² Funnel plots were used to assess publication bias in the meta-analyses. Additionally, a weighted means analysis was performed to calculate injury and torsion differences at various performance levels. All analyses were performed in R Version 3.5.1 (R Core Team), using the *meta*⁵²

package for meta-analyses, and *metafor*⁶⁰ package for meta-regression.

RESULTS

Study Selection

A total of 3318 titles were identified, with a total of 1311 titles included after duplicate removal. A total of 32 studies were included in the systematic review and meta-analysis (Figure 1).

Study Characteristics

The 32 studies included a total of 2961 baseball players (mean age, 20.2 ± 12.3 years; mean height, 162 ± 24.9 cm; mean weight, 91 ± 35.7 kg) (see Table A1 in Appendix 2, available online). Overall, the mean dominant limb torsion was 14.08 (95% CI, 10.83 to 17.33), nondominant limb torsion was 24.65 (95% CI, 22.14 to 27.16), and dominant to nondominant torsion

Figure 2. Absolute humeral torsion meta-analysis.

Figure 3. Humeral torsion side-to-side difference meta-analysis.

difference was 11.10 (95% CI, 8.30 to 13.90) (see Table A2 in Appendix 2).

Study Quality Assessment

A total of 16 studies were cross-sectional studies,^{19,21,23,27,31,34,38,48,58,61,63,64} 4 were prospective cohort studies,^{9,41,42,62} 6 were descriptive anatomic studies,^{40,44,47,54,56,57} 3 were case-control studies,^{30,39,43} and 3 were controlled laboratory studies^{3,4,10} (Table A1 in Appendix 2). Study quality ranged from 11 to 13 out of a maximum of 15. All studies compared metrics in dominant and nondominant shoulders. Five studies compared throwing athletes with nonthrowing controls.^{9,10,20,31,35} Five studies looked at torsion in relation to injury.^{30,36,39,41,55} None of the studies attempted to blind the assessors of the main outcomes to the intervention (Table A1 in Appendix 2).

Torsion and Injury Risk

Five studies were included in the meta-analysis of the relationship between overall HT and injury risk (1406 players).^{30,39,41,43,62} Four of the 5 studies looked at aggregate upper extremity injuries risk; only Noonan et al³⁹ looked at shoulder and elbow injuries separately. The overall pooled assessment did not demonstrate a significant difference in injury risk depending on the total dominant arm torsion (MD, 0.17; 95% CI, -1.83 to 2.18; $P = 0.865$), with low heterogeneity between studies ($\tau^2 = 1.01$; $I^2 = 16.0\%$; $P = 0.310$) (Figure 2). The

overall pooled assessment demonstrated that difference in torsion between dominant and nondominant limbs was not significantly associated with injury risk (MD, 1.746; 95% CI, -1.83 to 2.18; $P = 0.174$) (Figure 3). These findings had a high heterogeneity ($\tau^2 = 16.14$; $I^2 = 85\%$; $P < 0.01$). Additionally, the subgroup weighted means comparison demonstrated that dominant arm torsion was 13.4° in injured high school players and 12.4° in noninjured players. Dominant arm torsion was 9.24° in injured college/professional athletes and 9.73° in noninjured athletes. Side-to-side HT differences in high school athletes were 13.3° and 12.5° in injured and noninjured players, respectively. In college/professional athletes, side-to-side HT differences were 18.2° and 12.5° in injured and noninjured athletes, respectively.

HT and Shoulder ROM

A meta-regression was performed to compare shoulder ROM and measured torsion. A total of 18 studies^{3,4,9,10,19,21,31,35,37,38,40,42,44,47,54,57,58} (2346 players) reported IR ROM measurements, which were incorporated into a mixed-effects model. HT and IR were significantly related (intercept: 32.04 [95% CI, 25.09 to 39.00], $P < 0.001$; IR: 0.65 [95% CI, 0.28 to 1.02], $P < 0.001$). For every degree increase in IR, there was a subsequent increase in 0.65° of HT. Torsion as a moderator of IR accounted for a moderate amount of study heterogeneity ($\tau^2 = 142.2$; $R^2 = 30.28\%$; $P < 0.001$), indicating that variation in torsion helps explain reported IR

differences in disparate included studies. A total of 16 studies^{3,4,9,10,31,35,37,38,40-42,44,47,54,57,58} (2030 players) reported ER ROM. Torsion and ER did not have a statistically significant relationship (intercept: 114.72 [95% CI, 106.39 to 123.05], $P < 0.001$; ER: 0.19 [95% CI, -0.24 to 0.61], $P = 0.385$). These data were homogeneous (τ^2 , 186.9; R^2 , 0.00%). A total of 14 studies^{3,4,9,10,19,31,35,37,38,41,42,44,54,58} (2113 players) reported total ROM (TROM), with torsion and TROM not being statistically significant (intercept: 151.80 [95% CI, 141.52 to 162.07], $P < 0.001$; TROM: 0.51 [95% CI, -0.02 to 1.05], $P = 0.059$). These data were homogeneous (τ^2 , 252.4; R^2 , 11.35%). Five studies^{3,4,35,41,58} (238 players) reported horizontal adduction (HA), with no significant relationship between HT and HA (intercept: 1.07 [95% CI, -8.32 to 10.45], $P < 0.824$; HA: 0.18 [95% CI, -0.46 to 0.82], $P = 0.581$). These data were heterogeneous (τ^2 , 41.86; R^2 , 0%).

Torsion at Various Competition Levels

In all, 18 studies^{3,4,9,10,19,21,31,35,37,38,40-42,44,47,54,57,58} were included in the meta-regression of the relationship between torsion and competition level, with 7 studies on high school athletes,^{3,4,19,21,31,41,42} 7 studies on college athletes,^{3,4,35,40,44,57,58} and 7 studies on professional athletes.^{3,4,9,10,38,47,54} There were no differences between absolute dominant limb HT and competition level (intercept: 27.53 [95% CI, 13.06 to 42.00], $P < 0.001$; high school: -19.28 [95% CI, -38.97 to 0.41], $P = 0.055$; college: 17.37 [95% CI, -26.48 to 61.21], $P = 0.438$; professional: -15.21 [95% CI, -35.68 to 5.25], $P = 0.145$). There was high heterogeneity in the analysis (τ^2 , 327.16; I^2 , 73.60%; $P < 0.001$). There were no differences between dominant and nondominant limb HT and competition level (intercept: 9.68 [95% CI, 2.48 to 16.88]; high school: 3.57 [95% CI, -7.10 to 14.24], $P = 0.656$; college: -20.28 [95% CI, -47.11 to 6.55], $P = 0.138$; professional: -1.10 [95% CI, -12.41 to 10.21], $P = 0.849$). There was high heterogeneity in analysis (τ^2 , 102.69; I^2 , 84.28%; $P < 0.001$).

DISCUSSION

The results of this systematic review and meta-analysis show that overall and side-to-side difference in HT are not significantly associated with pitching arm injury. Interestingly, HT influences shoulder IR but not ER or HA ROM. Additionally, competition level did not influence overall or side-to-side HT differences.

Total HT and side-to-side torsion differences were not identified as upper extremity injury risk factors. However, this portion of the analysis was limited to 5 studies, suggesting low power and a propensity for type II error. Furthermore, this analysis had high heterogeneity.

All 32 studies failed to account for individual variation in pitching frequency. There is a significant association between pitch count and risk of shoulder and elbow pain.²⁸ According to statistics from the 2018 Major League Baseball season, median innings pitched (IP) for starting pitchers was 72.5 versus 27.1 IP

for relief pitchers.⁶ Furthermore, position players have a lower risk of throwing-related injury.⁵³ In this investigation, 10 studies^{10,36,38-40,43,47,54,55,58} controlled for differences in positional injury rates by only including pitchers, while Hibberd et al²⁰ only included position players. However, none of the aforementioned studies compared results between starting versus relief pitchers, or otherwise controlled for innings pitched. Seven studies^{21,27,30,37,41,44,56} considered pitchers versus position players, but again did not stratify based on pitcher type (starter versus relief) or pitch count.

The meta-regression demonstrated that torsion and IR are significantly related but did not show a significant relationship between torsion and TROM, ER, and HA. This suggests that IR is influenced by the degree of HT. This is important given prior research has shown IR to be significantly associated with injury risk.⁷ IR ROM decreases after an episode of pitching⁴⁶ and increases after stretching and manual therapy,^{3,4} suggesting that IR may be an amendable injury risk factor.

Similarly, there was no evidence that HT was significantly associated with ER. ER has been associated with elbow injury risk.^{14,17} These results suggest that the majority of ER changes appear to be primarily influenced by soft tissue adaptation rather than osseous changes. Last, there was no relationship between torsion and HA, although the sample size was limited. This result is consistent with prior research that suggests that loss of shoulder HA is primarily influenced by posterior soft tissues, which precludes translation of the humeral head during the pitching motion that occurs during maximum ER.²⁹ Thus, HA may be a modifiable injury risk factor in baseball players, though the viability of HA as an upper extremity injury risk factor remains inconclusive.⁷

There were no differences in total or side-to-side differences in HT and competition level. Though data are limited, several authors suggest preadolescence or early adolescence as the key age at which throwing athletes acquire significant bilateral torsional asymmetry.^{16,19} The results from this study support that the majority of HT occurs prior to high school, and greater torsion is not associated with higher levels of play.

There are several recent systematic reviews touching on the topics of HT in overhead athletes,^{16,24} risk factors for upper extremity injuries in baseball players,^{1,45} and the relationship between shoulder ROM and injury in baseball players.^{7,25} Overall, study quality was scored as moderate on the modified Downs and Black scale.

Overall, these reported results must be considered with several additional limitations. Injury risk was only assessed for the entire upper extremity, which decreases the generalizability of these findings for individual shoulder and elbow injury risk. Furthermore, most investigators followed a cohort of players over the course of a single season. Any effect that torsion may have on long-term injury risk is still unknown.

We assessed the risk for publication bias via funnel plots. All studies fell within the funnel and demonstrated symmetry, suggesting no bias is present (see Figure A1 in Appendix 2).

CONCLUSION

These findings suggest that HT plays a significant role in shoulder IR but not in shoulder ER or HA. Clinical IR may be influenced by a combination of individual torsion level (nonmodifiable) and soft tissue changes produced by recent workload (modifiable). Furthermore, the competition level-HT confidence intervals were wide, suggesting that individual makeup may have more effect than competition level on HT levels. Greater than the minimum acquired HT from early baseball participation does not appear to allow for baseball players to have a competitive advantage.

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