Humeral Retroversion and Capsule Thickening in the Overhead Throwing Athlete: A Systematic Review

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Purpose: To investigate the humeral and soft-tissue adaptations, including humeral retroversion, range of motion, and posterior capsule changes, in overhead throwing athletes. **Methods:** We performed a systematic review in accordance with Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines. PubMed, MEDLINE, CENTRAL (Cochrane Central Register of Controlled Trials), and Embase were searched from January 1, 2011, through April 23, 2017, by 2 reviewers independently and in duplicate. The methodologic quality of all included articles was assessed using the Methodological Index for Non-randomized Studies criteria. Interobserver agreement for assessments of eligibility was calculated with the Cohen κ statistic. Descriptive statistics and raw counts were used to summarize data. **Results:** We identified 14 studies (6 Level IV and 8 Level III) including 1,152 overhead throwing athletes. The mean age of the included athletes was 18.37 years (standard deviation, 1.52 years), with 59% of the athletes being pitchers and 41% being position players. Significantly greater humeral retroversion was found across all studies evaluating bony morphology in the dominant arm of overhead throwing athletes (range of mean differences, 9.6°-25.8°). Each of these studies also found decreased internal rotation in the dominant arm (range of mean internal rotation differences, −28° to −7.8°). Five studies found a significant negative correlation between the difference in humeral retroversion between the 2 arms and the difference in internal rotation (range of Pearson correlation coefficients, −0.56 to −0.35). Soft-tissue adaptations were assessed in 5 studies, with 4 identifying significantly thicker posterior capsules and 2 identifying significantly stiffer posterior capsules ($P < .05$). **Conclusions:** Overhead throwing athletes consistently show several distinct changes in their dominant shoulder. These include increased humeral retroversion and the presence of a thickened and stiff posterior capsule. Concomitantly, there is often reduced internal rotation and increased external rotation of the dominant arm. **Level of Evidence:** Level IV, systematic review of Level III and IV studies.

Overhead throwing athletes, such as competitive baseball players, are known to undergo adaptive changes in their dominant shoulder, causing alterations in the characteristics of their range of motion.[1] Some authors have attributed such characteristics to the underlying osseous changes in the humerus of the dominant arm,[2] whereas others have highlighted the soft-tissue changes in the posterior capsule as the primary contributing factor.[3]

Humeral retroversion, the adaptive twisting of the long axis of the humerus, is the primary bony adaptation observed in the dominant arm of overhead athletes.[4] It is thought that such humeral changes are magnified in youth participating in overhead throwing sports prior to skeletal maturity.[5] Increased humeral retroversion in the dominant arm of overhead throwing athletes is thought to contribute to changes in internal and external rotation of the shoulder.[6] Although athletes with a high degree of humeral retroversion have reduced internal rotation, the soft tissues of the posterior capsule in some athletes may lack any significant degree of tightness.[7]

During the follow-through phase of the throwing motion, an overhead throwing athlete endures distraction forces to the posterior capsule with magnitudes of more than 80% of the athlete's weight.[8] Such repetitive

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stress to the posterior capsule is thought to cause changes in the thickness and elasticity of the capsule as a result of the subsequent hypertrophic healing process that occurs.[3] These changes in the posterior capsule are theorized to contribute to the changes in the arc of motion in these athletes.[9] Although the aforementioned individual studies have reported changes in humeral retroversion and the capsules of the dominant shoulder of overhead throwing athletes, it is unclear whether these changes are identified in all overhead throwing athletes, as well as how these changes affect the risk of injury in these overhead throwing athletes.

The purpose of this study was to investigate the humeral and soft-tissue adaptations, including humeral retroversion, range of motion, and posterior capsule changes, in overhead throwing athletes. The hypothesis was that athletes would have reduced internal rotation and increased humeral retroversion of their dominant arm.

Methods

This study was conducted according to the methods described in the *Cochrane Handbook for Systematic Reviews of Interventions*[10] and is reported according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement.[11]

Assessment of Study Eligibility

A priori establishment of the research question and study eligibility criteria was used. We included studies that (1) were published in a peer-reviewed journal between 2011 and 2017, (2) reported on either bony or soft-tissue adaptations in the shoulder of overhead throwing athletes in patients of any age or either sex, and (3) were published in English. There were no restrictions regarding level of evidence, country, sport, number of patients, length of follow-up, or journal of publication. We excluded studies without full text available, animal studies, cadaveric reports, book chapters, review articles, and technical studies.

Identification of Studies

A systematic literature search of potentially eligible trials was conducted in the Cochrane Central Register of Controlled Trials (CENTRAL), PubMed, MEDLINE, and Embase from January 1, 2011, through April 23, 2017. Investigators with methodologic and content expertise (M.K., J.M.K.) developed and performed the search. Medical Subject Headings (MeSH) and Emtree headings and subheadings were used in various combinations in Ovid and supplemented with free text to increase sensitivity. The PubMed search included articles published online ahead of print. A manual search of related references and cited articles was also performed. We searched conference proceedings from the previous 3 years and ClinicalTrials.gov to identify relevant unpublished trials.

Study Screening

Two reviewers (N.B., M.G.) independently screened the titles and abstracts of all studies for eligibility using piloted screening forms. Both reviewers evaluated the full text of all potentially eligible studies identified by title and abstract screening to determine final eligibility. Any disagreements were discussed between reviewers, and all discrepancies were resolved by a consensus decision requiring rationale with the first author.

Data Abstraction

Data were collected independently and in duplicate by 2 reviewers (S.E., N.H.) using piloted electronic data extraction (Excel; Microsoft, Redmond, WA). Abstracted data included the authors; year of publication; study design; mean age; sample size; and sport, level, and position of participants. The level of evidence was graded according to the criteria of Wright et al.[12]

Statistical Analysis

Interobserver agreement for assessments of eligibility was calculated with the Cohen κ statistic. Agreement was established a priori, with a κ of 0.61 or greater considered to indicate substantial agreement; κ of 0.21 to 0.60, moderate agreement; and κ of 0.20 or less, slight agreement.[13] Given the nonuniform nature of the studies included in this systematic review in terms of techniques and outcome reporting, the results are presented in a narrative summary fashion. Descriptive statistics including means, proportions, standard deviations, and 95% confidence intervals (CIs) were calculated using Minitab statistical software (version 17; Minitab, State College, PA).

Quality Assessment

The methodologic quality of the included studies was assessed using the Methodological Index for Non-randomized Studies (MINORS) instrument. This tool was designed to assess the methodologic quality of comparative and noncomparative, nonrandomized surgical studies.[14] By use of the MINORS checklist, noncomparative studies are assigned a score with a maximum of 16 whereas comparative studies can achieve a maximum score of 24. The intraclass correlation coefficient (ICC) was calculated for the quality assessment using the MINORS criteria. Agreement was established a priori, with an ICC of 0.61 or greater considered to indicate substantial agreement; ICC of 0.21 to 0.60, moderate agreement; and ICC of 0.20 or less, slight agreement.[13]

Results

Search Strategy

The initial search of the online databases resulted in 1,362 total studies, with an additional 4 studies identified through other sources. Of these studies, 350 were removed immediately because they were identified as being duplicates. The systematic screening and assessment of eligibility identified 14 full-text articles that satisfied the inclusion and exclusion criteria (Fig 1). The κ value for overall agreement between reviewers for the final eligibility decision was 0.98 (95% CI, 0.96-0.99), indicating almost perfect agreement.

Study Characteristics

In total, 1,152 overhead throwing athletes with a mean age of 18.37 years (standard deviation, 1.52 years) were assessed for bony or soft-tissue adaptations in the throwing shoulder. Of the included athletes, 3.8% were female athletes. All of the athletes played baseball, and of those whose position was reported, 508 (59%) were pitchers whereas 356 (41%) were position players. Of the athletes, 493 participated in professional baseball (Major League Baseball and Minor League Baseball), 306 participated in collegiate-level baseball, 340 played high school–level baseball, and 36 participated in organized youth baseball (Table 1).

Study Quality

Overall, 6 studies were of Level IV evidence and 8 were of Level III evidence. The median MINORS score for all noncomparative studies was 9.5 of 16. In total, 13 studies lacked prospective calculation of sample size, an unbiased assessment of study endpoints was not identified in 10 studies, 9 studies lacked reporting of appropriate endpoints for assessment, and 9 studies did not include consecutive patients. Of the 8 comparative studies, 5 did not have baseline equivalence of the control group and 4 lacked a control group that was deemed adequate (Table 1). There was substantial inter-rater agreement for the MINORS score, with an ICC of 0.821 (95% CI, 0.780-0.862).

Humeral Retroversion

Ten studies (n = 909) evaluated the difference in humeral retroversion between the dominant and nondominant arms. All 10 studies identified significantly higher humeral retroversion in the dominant arm of overhead throwing athletes.[2,4,5,9,15,17-19,21-23] The mean (standard deviation) differences in humeral retroversion between the dominant and nondominant arms were 9.6° (5.9°), 10.85° (8.94°), 11.18° (10.58°), 12.75° (11°), 13.1° (11.4°), 14.1° (9.8°), 14.3° (11.7°), 15.8° (10.8°), 16.2° (11.2°), and 25.8° (13.0°). Three studies assessed the difference in humeral retroversion in the context of injuries to the shoulder or elbow.[5,20,22] Myers et al.[5] and Noonan et al.[20] found that the

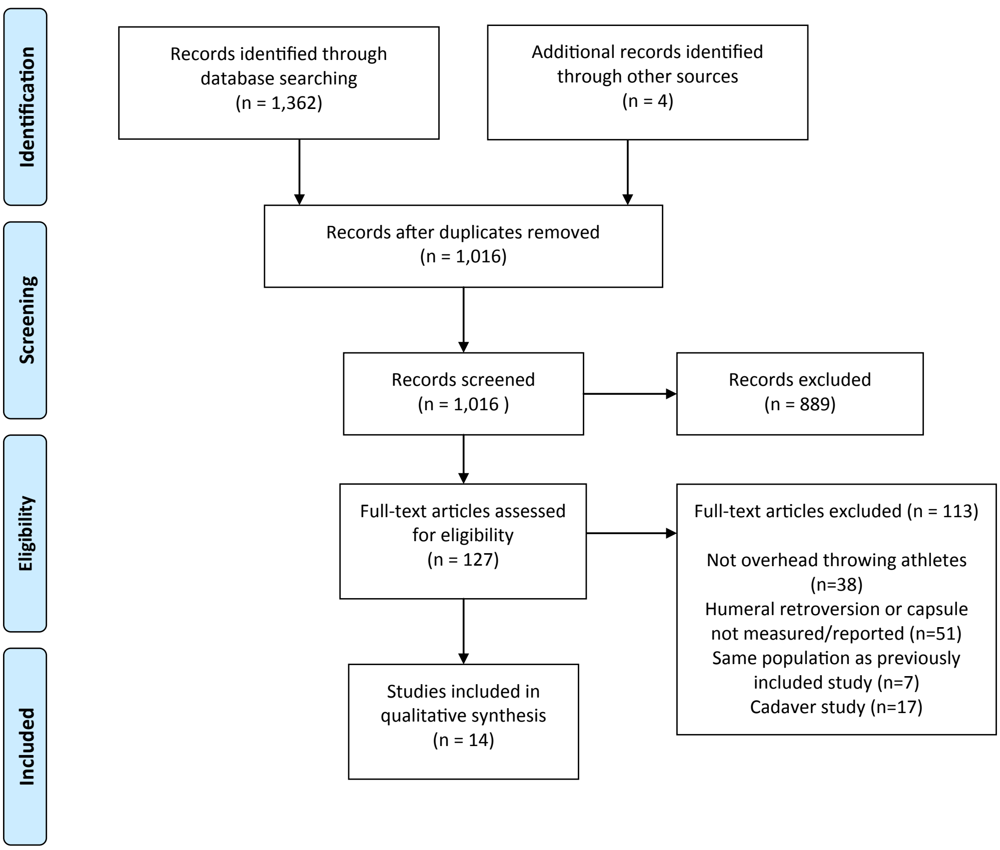

Fig 1. Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flow diagram describing systematic review of literature on adaptations in overhead throwing athlete.

Table 1. Study Characteristics

Authors (Year)	Study Design (Level of Evidence)	Sample Size	% Male	Mean Age (SD), yr	Sport	Position	Level of Competition	MINORS Score
Astolfi et al.[2] (2015)	Case series (IV)	36	100	10.94 (1.34)	Baseball	16 pitchers, 20 position players	Organized youth baseball	9 of 16
Bailey et al.[15] (2015)	Case series (IV)	60	100	19 (2)	Baseball	24 pitchers, 35 position players	High school (21), collegiate (37), professional (2)	11 of 16
Garrison et al.[16] (2012)	Retrospective case series (IV)	60	100	18.36 (1.21)	Baseball	44 pitchers, 16 position players	High school (32), collegiate (28)	10 of 16
Hibberd et al.[17] (2015)	Case series (IV)	156	100	15.9 (1.4)	Baseball	47 pitchers, 109 position players	High school	8 of 16
Hibberd et al.[18] (2014)	Retrospective comparative (III)	287	NR	13.9 (0.8)	Baseball	NR	Local youth or high school	13 of 24
Hibberd et al.[19] (2014)	Retrospective comparative (III)	132	59	19.4 (1.3)	Baseball	All position players	Collegiate	14 of 24
Myers et al.[5] (2011)	Retrospective comparative (III)	40	100	19.3 (1.2)	Baseball	Pitchers	Collegiate	13 of 24
Noonan et al.[20] (2016)*	Retrospective comparative (III)	183	100	NR	Baseball	Pitchers	Professional (MLB and Minor League Baseball)	16 of 24
Noonan et al.[21] (2015)*	Retrospective comparative (III)	222	100	23.9 (2.3)	Baseball	Pitchers	Professional (MLB and Minor League Baseball)	15 of 24
Polster et al.[22] (2013)	Retrospective comparative (III)	25	100	21.7 (1.5)	Baseball	Pitchers	Professional (MLB and Minor League Baseball)	15 of 24
Shanley et al.[23] (2012)	Retrospective case series (IV)	33	100	23.4 (2.6)	Baseball	Pitchers	Professional (MLB and Minor League Baseball)	9 of 16
Takenaga et al.[9] (2015)	Retrospective comparative (III)	45	100	19.7 (0.96)	Baseball	13 pitchers, 32 position players	Collegiate	16 of 24
Thomas et al.[3] (2011)	Retrospective case series (IV)	24	100	19.6 (1.32)	Baseball	12 pitchers, 12 position players	Collegiate	10 of 16
Wyland et al.[4] (2012)	Retrospective comparative (III)	32	100	23.4 (2.6)	Baseball	Pitchers	Professional	17 of 24

MINORS, Methodological Index for Non-randomized Studies; MLB, Major League Baseball; NR, not reported; SD, standard deviation.
*These studies report on the same population of athletes. The patient characteristics are reflected only once in our summary. Both studies were included for review, however, because each reports on separate, important findings in terms of adaptations in the included athletes.

difference in humeral retroversion between the dominant and nondominant arms was significantly higher in athletes who had undergone an elbow injury than in those who had not. Conversely, Noonan et al.[20] and Polster et al.[22] found that the difference in humeral retroversion between the dominant and nondominant arms was significantly lower in athletes who had undergone a shoulder injury than in those who had not (Table 2).

Range of Motion

Overall, 11 studies (n = 1,095) reported data on the range of motion in the dominant arm in comparison with the nondominant arm in overhead throwing athletes. All 11 of these studies assessed the difference in internal rotation of the shoulder, with the dominant arm showing decreased internal rotation in each study.[2,3,5,9,15-19,21,23] In 7 of the studies, the difference in internal rotation was statistically significant ($P < .05$).[2,9,15,17-19,23] The mean (standard deviation) differences in internal rotation between the dominant and nondominant arms were 7.8° (9.9°), 7.9° (8.1°), 8.3° (8.1°), 9.9° (9.5°), 10.2° (13°), 13.0° (11°), 13.2° (12°), 13.6° (6.1°), 16.5° (8.2°), 25.9° (11.7°), and 28.0° (9.5°). The difference in external rotation between the dominant and nondominant shoulders was reported by 7 studies (n = 460),[2,3,5,9,16,21,23] 3 of which found a statistically significant ($P < .05$) increase in external rotation in the dominant arm.[2,9,23] The mean (standard deviation) differences in external rotation across the included studies were 5.2° (13.1°), 5.8° (12.1°), 6.2° (6.1°), 10.6° (8.1°), 12° (10°), 14.6° (11.8°), and 21° (14°). Five studies found a significant negative correlation between the difference in humeral retroversion between the 2 arms and the difference in internal rotation (range of Pearson correlation coefficients, −0.56 to −0.35)[2,15,17,21,23] (Table 3).

Table 2. ROM and Humeral Adaptations in Throwing Shoulder

Authors (Year)	Measurement Tool	HR, °	ROM, °	Correlation Between HR and ROM	Primary Findings
Astolfi et al.[2] (2015)	US (Titan; SonoSite, Bothell, WA), 13-MHz linear transducer	Dominant arm: 11.18 ± 13.39 Nondominant arm: 24.04 ± 10.58 ($P < .001$)	IR: dominant arm, 61.93 ± 12.01; nondominant arm, 75.10 ± 8.50 ($P < .001$) ER: dominant arm, 152.47 ± 14.08; nondominant arm, 131.50 ± 12.14 ($P < .001$)	Pearson correlation coefficient HR and IR: −0.431 ($P = .01$) HR and ER: 0.448 ($P = .007$)	Dominant arm: significantly increased HR and GH ER; decreased GH IR Negative correlation between HR and IR Positive correlation between HR and ER
Bailey et al.[15] (2015)	US (SonoSite Edge, 6-cm 6- to 15-MHz linear transducer), inclinometer for ROM (Fabrication Enterprises)	Dominant hand: −13.9 ± 8.6 with ISTM vs −13.0 ± 11.2 with no ISTM ($P > .05$) Nondominant hand: −33.0 ± 7.4 vs −38.8 ± 13.0 ($P < .001$)	IR: dominant hand, 20.7 ± 10.9 with ISTM vs 20.7 ± 9.5 with no ISTM ($P > .05$); nondominant hand, 44.5 ± 11.3 with ISTM vs 48.7 ± 8.6 with no ISTM	Pearson correlation coefficient HR and IR: −0.35 ($P = .034$)	No direct comparison between dominant arm and nondominant arm Negative correlation between HR and IR
Garrison et al.[16] (2012)	Bubble goniometer	NR	Dominant: IR, −20.9 ± 6.08; ER, 119.70 ± 11.77 Nondominant: IR, −34.53 ± 5.88; ER, 105.13 ± 10.58	NR	
Hibberd et al.[17] (2015)	US (LOGIQe; GE, Milwaukee, WI)	Dominant: 78.1 ± 10.8 Nondominant: 62.3 ± 10.8 ($P < .05$)	IR: dominant, 45.6 ± 8.1; nondominant, 53.9 ± 7.8 ($P < .0005$)	Regression model HR difference between dominant and nondominant arms significant predictor of IR difference ($\beta = 0.243$, $P < .01$)	Dominant arm had significantly increased HR, as well as decreased IR Increased HR significant predictor of decreased IR
Hibberd et al.[18] (2014)	US (LOGIQe), Saunders digital inclinometer (Saunders Group, Chaska, MN)	Dominant vs nondominant ($P < .05$ for all) YG: 83.5 ± 12.9 vs 76.1 ± 11.1 JH: 73.6 ± 12.5 vs 62.8 ± 12.1 JV: 77.9 ± 9.6 vs 62.5 ± 11.1 V: 78 ± 11.2 vs 61.8 ± 10.4	IR, dominant vs nondominant ($P < .05$ for all) YG: 52.0 ± 12.1 vs 54.9 ± 13.7 JH: 53.6 ± 11.2 vs 56.5 ± 10.1 JV: 46.2 ± 8.0 vs 54.5 ± 7.9 V: 45.1 ± 8.3 vs 53.0 ± 8.1	Significantly higher HR, IR differences in older age groups ($P < .001$)	In every age group, significantly decreased IR and significantly increased HR in dominant arm
Hibberd et al.[19] (2014)	US (LOGIQe, 4-cm linear transducer), Saunders digital inclinometer	HR difference between dominant and nondominant Baseball players: 14.1 ± 9.8 Softball players: 7.9 ± 9.0 Male controls: 6.3 ± 12.3 Female controls: 6.9 ± 7.9	IR difference between dominant and nondominant Baseball players: 9.9 ± 9.5 Softball players: 2.5 ± 6.4 Male controls: 4.7 ± 9.3 Female controls: −0.5 ± 12.8	NR	Significantly increased HR and lower IR in dominant arm of baseball players compared with controls No significant difference in softball players
Myers et al.[5] (2011)	4-cm linear array US transducer (LOGIQe)	Dominant: elbow injury, 83.9 ± 9.4; shoulder injury, 82.7 ± 9.8; no injury, 81.4 ± 7.1 Nondominant: elbow injury, 63.6 ± 12.9; shoulder injury, 67.1 ± 11.2; no injury, 67.0 ± 7.9	Dominant: ER, 126.0 ± 12.1; IR, 40.6 ± 13.0 Nondominant: ER, 120.2 ± 10.8; IR, 50.8 ± 10.7	NR	Participants with history of elbow injury had significantly increased HR difference compared with participants with no history of injury

(continued)

Table 2. Continued

Authors (Year)	Measurement Tool	HR, °	ROM, °	Correlation Between HR and ROM	Primary Findings
Noonan et al.[20] (2016)	US (SonoSite, 5-MHz linear transducer)	Dominant: UCL injury, 4.1 ± 8.1; no UCL injury, 7.6 ± 12.5; Nondominant: UCL injury, 27.3 ± 10.6; no UCL injury, 22.1 ± 11.7 Dominant: shoulder injury, 11.1 ± 13.8; no shoulder injury, 7.6 ± 12.5 ($P < .05$) Nondominant: shoulder injury, 23.4 ± 10.4; no shoulder injury, 22.1 ± 11.7	NR	NR	Pitchers with shoulder injury had decreased HR Pitchers with elbow injury had significantly increased HR
Noonan et al.[21] (2015)	US (SonoSite, 5-MHz linear transducer), digital inclinometer	Dominant: 8.8 ± 11.7 Nondominant: 23.1 ± 11.5	IR: dominant arm, 28.8 ± 9.6 with GIRD vs 39.9 ± 9.9 with no GIRD ($P < .01$); nondominant arm, 54.3 ± 10.0 with GIRD vs 47.7 ± 6.7 with no GIRD ER: dominant arm, 131.8 ± 14.3 with GIRD vs 132 ± 14.2 with no GIRD ($P = .03$); nondominant arm, 126.6 ± 13.1 with GIRD vs 47.7 ± 6.7 with no GIRD	Pearson correlation coefficient HR and IR: −0.48 ($P = .02$)	Significantly increased HR in dominant arm Significantly decreased IR in dominant arm Significant inverse correlation between HR and IR No concurrent gain in ER
Polster et al.[22] (2013)	CT with 3D reconstruction	Dominant torsion: 38.48 ± 8.94 Nondominant torsion: 27.63 ± 7.96	NR	NR	Significantly increased torsion in dominant arm Significant inverse relation between HR and incidence of injury
Shanley et al.[23] (2012)	Digital inclinometer for ROM, US for torsion (SonoSite, 5-MHz transducer)	Dominant: 10 ± 11 Nondominant: 22.75 ± 11	ER, dominant vs nondominant 2009: 127 ± 9 vs 139 ± 10 2010: 139 ± 10 vs 126 ± 9 ($P = .02$) IR, dominant vs nondominant 2009: 46 ± 11 vs 50 ± 12 2010: 38 ± 11 vs 51 ± 10 ($P = .03$)	Pearson correlation coefficient HR and IR: −0.56 ($P < .01$) HR and ER: 0.38 ($P < .01$)	HR correlated with decreased IR and increased ER Dominant shoulder had significantly greater ER and significantly lower IR
Takenaga et al.[9] (2015)	Aixplorer US diagnostic device and SuperLinear SL10-2 linear-array transducer (SuperSonic Imagine)	Dominant: 78.8 ± 5.6 Nondominant: 69.2 ± 5.9 ($P < .001$)	Dominant: IR, 41.7 ± 11.7; ER, 105.6 ± 8.1 Nondominant: IR, 67.6 ± 9.0; ER, 95.0 ± 7.7 ($P < .001$ for both)	NR	Significantly increased HR, as well as ER, and decreased IR in dominant arm compared with nondominant arm

(continued)

Table 2. Continued

Authors (Year)	Measurement Tool	HR, °	ROM, °	Correlation Between HR and ROM	Primary Findings
Thomas et al.[3] (2011)	Saunders digital inclinometer, US (Titan)	NR	IR: dominant, 42.19 ± 8.24; nondominant, 58.72 ± 7.23 ER: dominant, 72.25 ± 6.09; nondominant, 66.01 ± 5.87 ($P > .05$ for both)	NR	Nonsignificant decrease in IR and increase in ER in dominant arm
Wyland et al.[4] (2012)	US (Philips Imaging, Andover, MA, or SonoSite)	Dominant: 9.0 ± 11.4 Nondominant: 22.1 ± 10.7 ($P < .001$)	NR	NR	Mean HR difference of 11.1° ± 10.9° between dominant and nondominant shoulders

NOTE. Data are presented as mean ± standard deviation unless otherwise indicated.
CT, computed tomography; ER, external rotation; GH, glenohumeral; GIRD, glenohumeral internal rotation deficit; HR, humeral retroversion; IR, internal rotation; ISTM, instrument-assisted soft-tissue mobilization; JH, junior high; JV, junior varsity; NR, not reported; ROM, range of motion; 3D, 3-dimensional; UCL, ulnar collateral ligament; US, ultrasound; V, varsity; YG, youth.

Posterior Capsule

Five studies evaluated the effect of throwing on the posterior capsule. Of these studies, 3 assessed the elasticity of the posterior capsule whereas 4 evaluated the thickness of the capsule. In terms of capsular stiffness, 2 studies identified significantly stiffer posterior capsular tissue in the dominant arm than in the nondominant arm.[9,17] Takenaga et al.[9] also identified a significant negative correlation between the stiffness of the posterior capsule and the degree of internal rotation of the shoulder (Pearson correlation coefficient, −0.56; $P < .001$). Bailey et al.[15] found no correlation between the dominant and nondominant arms but did identify a significant negative correlation between the stiffness of the shoulder and the degree of internal rotation (Pearson correlation coefficient, −0.35; $P < .034$). In terms of capsular thickness, all 4 studies identified a significantly thicker posterior capsule in the dominant arm (ranging from 1.29 to 2.03 mm) than in the nondominant arm (ranging from 1.04 to 1.65 mm).[2,3,9,17] Three of these studies identified significant negative correlations between the thickness of the posterior capsule and the degree of internal rotation of the shoulder (Pearson correlation coefficients of −0.33, −0.43, and −0.50).[2,3,9] One study found a significant positive correlation between the posterior capsule thickness and the degree of external rotation (Pearson correlation coefficient, 0.45; $P = .002$) (Table 3).

Discussion

The most significant findings in this review are the distinct changes in the dominant shoulder of overhead throwing athletes. In terms of osseous adaptations, the dominant arms of overhead athletes consistently show significantly higher degrees of humeral retroversion than the nondominant arms, with the literature reporting mean differences in humeral retroversion between the dominant and nondominant arms of throwers ranging from 9.6° to 25.8°. Overhead throwing athletes also show significant differences in the relative internal and external rotation of their throwing shoulder, with significantly less internal rotation (range of mean internal rotation differences, −28° to −7.8°) and increased external rotation (range of mean external rotation differences, 5.2°-21°) in the dominant arms than in the nondominant arms. Moreover, the degree of humeral retroversion significantly correlates with the difference in internal rotation between the arms.

Regarding soft-tissue adaptations in the throwing shoulder, we found that the literature suggests overhead throwing athletes generally have thicker and stiffer posterior capsules in their dominant shoulder in comparison with their nondominant shoulder. Furthermore, the degree of thickness and stiffness of

Table 3. Soft-Tissue Adaptations in Throwing Shoulder

Authors (Year)	Measurement Tool	Posterior Capsule Elasticity	Posterior Capsule Thickness	Correlation With ROM (Pearson Correlation Coefficient)	Important Correlations Identified
Astolfi et al.[2] (2015)	Ultrasound (Titan), 13-MHz linear transducer	NR	Throwing shoulder: 1.29 ± 0.24 mm Non-throwing shoulder: 1.11 ± 0.19 mm ($P = .004$)	Posterior capsule thickness and IR: −0.334 ($P = .05$) Posterior capsule thickness and ER: 0.322 ($P = .059$)	Significantly thicker capsule in dominant arm Increased posterior capsule thickness correlated with significantly decreased IR, trending toward increased ER
Bailey et al.[15] (2015)	Ultrasound (SonoSite-Edge, 6-cm 6- to 15-MHz linear transducer), inclinometer for ROM (Fabrication Enterprises)	ISTM: dominant, 1.6 ± 0.6 kPa; nondominant, 1.5 ± 0.4 kPa No ISTM: dominant, 1.4 ± 0.4 kPa; nondominant, 1.5 ± 0.3 kPa	NR	Posterior capsule stiffness and IR: −0.35 ($P = .034$) Posterior capsule stiffness and horizontal adduction: −0.44 ($P = .008$)	No significant difference in stiffness between dominant and nondominant arms Decreased stiffness correlated with increased IR and horizontal adduction
Hibberd et al.[17] (2015)	Ultrasound (LOGIQe)	Deltoid stiffness, dominant vs nondominant: 18.0 ± 10.0 N/cm vs 14.8 ± 4.0 N/cm ($P < .05$) Infraspinatus stiffness, dominant vs nondominant: 18.6 ± 7.65 N/cm vs 21.5 ± 14.2 N/cm ($P < .05$) Teres minor stiffness, dominant vs nondominant: 18.0 ± 13.3 N/cm vs 16.5 ± 9.5 N/cm ($P < .05$)	Dominant: 1.7 ± 0.2 mm Nondominant: 1.6 ± 0.3 mm ($P < .05$)	No significant predictors	Dominant arm had significantly higher capsule thickness, deltoid stiffness, and teres minor stiffness and lower infraspinatus stiffness
Takenaga et al.[9] (2015)	Aixplorer ultrasound diagnostic device and SuperLinear SL10-2 linear-array transducer (SuperSonic Imagine)	Posterior capsule: throwing shoulder, 40.0 ± 5.5 kPa; non-throwing shoulder, 32.2 ± 5.7 kPa ($P < .001$) Posteroinferior capsule: throwing shoulder, 39.4 ± 7.4 kPa; non-throwing shoulder, 31.6 ± 5.4 kPa ($P < .001$)	Posterior capsule: throwing shoulder, 1.34 ± 0.2 mm; non-throwing shoulder, 1.04 ± 0.09 mm ($P < .001$) Posteroinferior capsule: throwing shoulder, 1.40 ± 0.2 mm; non-throwing shoulder, 1.04 ± 0.13 mm ($P < .001$)	Posterior capsule Thickness and IR: −0.43 ($P < .001$) Elasticity and IR: −0.56 ($P < .001$) Posteroinferior capsule Thickness and IR: −0.51 ($P < .001$) Elasticity and IR: −0.52 ($P < .001$)	Dominant arm had significantly thicker and stiffer posterior and posteroinferior capsule Increased thickness and stiffness correlated with decreased IR Elasticity showed strongest correlation
Thomas et al.[3] (2011)	Compact ultrasound system (Titan) and 10-MHz linear transducer, which has measurement accuracy of 0.1 mm	NR	Dominant arm: 2.03 ± 0.269 mm Nondominant arm: 1.65 ± 0.284 mm ($P < .05$)	Posterior capsule thickness and IR: −0.498 ($P = .0001$) Posterior capsule thickness and ER: 0.450 ($P = .002$)	Dominant arm had significantly thicker posterior capsule Decreased thickness correlated with increased IR Increased thickness correlated with increased ER

NOTE. Data are presented as mean ± standard deviation unless otherwise indicated.
ER, external rotation; IR, internal rotation; ISTM, instrument-assisted soft-tissue mobilization; NR, not reported; ROM, range of motion.

the posterior capsule correlates with reduced internal rotation of the shoulder.

Increased humeral retroversion in the dominant shoulder of overhead throwing athletes was noted among athletes of all skill levels, from those participating in organized youth leagues to those playing Major League Baseball. These findings are consistent with the previous observation that humeral adaptations primarily occur before the age of 12 years, when the growth plates are at their highest level of activity.[24,25] It is thought that in athletes who participate in overhead throwing activities at a young age, the humeral adaptations will develop, whereas athletes who begin their participation after adolescence will not show such adaptations.[18] It is suggested that such changes occur because of stress incurred during overhead throwing activities as described by Wolff's law.[26,27] Such changes may be an adaptation to reduce the load incurred by eccentric loads during deceleration. Astolfi et al.[2] identified posterior capsule thickness in the dominant arm of youth athletes, suggesting that soft-tissue adaptations begin at a young age in overhead throwing athletes as well.

Although a definitive cause-effect relation between the adaptations in the dominant arm of overhead throwing athletes and the incidence of injury has not yet been identified, certain trends have been reported in the included studies. One of these trends is the decreased incidence of shoulder injuries among athletes with greater humeral retroversion in their dominant arms. Several theories exist to explain this correlation. It has been postulated that injuries to the shoulders of overhead throwing athletes may be caused by internal impingement, whereby pathologic contact is made between the margin of the glenoid and the articular side of the rotator cuff tendons.[28] Although the precise mechanism has yet to be definitively described, adaptations of the throwing shoulder, including both humeral changes and posterior capsule changes, have been implicated in the pathogenesis of such impingement.[28] Injuries resulting from such pathologic contact between the posterosuperior labrum and the articular surface of the rotator cuff tendons can cause a range of injuries including partial- and full-thickness rotator cuff tears, labral tears, chondral erosion, and chondromalacia, as well as anterior capsule injury.[28] Baseball players require greater external rotation of the shoulder to optimize throwing velocity. In athletes with greater humeral retroversion, such positioning is achieved with less external rotation of the shoulder, which is thought to limit the degree of impingement on the rotator cuff from the superior glenoid.[29] The increased external rotation required in athletes with decreased humeral retroversion likely results in higher tensile forces on several soft-tissue structures in the shoulder including the long head of the biceps and the rotator cuff tendons.[26] Another theory relates to the possible tensile forces on the soft-tissue structures of the shoulder. A lesser degree of external rotation forces in athletes with greater humeral retroversion may cause decreased shear forces on the long head of the biceps tendon, rotator cuff tendons, and labrum, decreasing the risk of injury to these structures during the throwing motion.[26]

The potential relation between soft-tissue adaptations and shoulder injuries has not yet been evaluated. However, there are several theories regarding the mechanisms by which changes in the posterior capsule may predispose overhead throwing athletes to shoulder injuries. Previous cadaveric studies have described changes in the translation of the humeral head in flexion and the late cocking phase of throwing when the posterior capsule is plicated, simulating increased stiffness of the capsule.[30,31] It is thought that increased superior translation of the humeral head could be a source of impingement and microtrauma to surrounding soft tissues such as the rotator cuff tendons.[32] However, further research is needed to assess the true impact of increased thickness and stiffness of the posterior capsule in the dominant arm and the risk of shoulder injuries in overhead throwing athletes.

Conversely, 2 studies included in this review identified an increased risk of elbow injuries in athletes with higher degrees of humeral retroversion. It is suggested that those with higher degrees of humeral retroversion in the dominant arm have a longer cocking and early acceleration phase during the throwing motion. It is during this phase that the ulnar collateral ligament is under the highest degree of valgus stress. Thus, athletes with increased humeral retroversion in the dominant arm may be predisposed to an increased risk of ulnar collateral ligament injuries.[20] Although these findings have yet to be definitively proved, the implications are significant. Future research evaluating the association and degree of humeral retroversion and injuries may lend itself toward individualized training programs aimed at injury prevention.

All studies in our review identified changes in relative internal and external rotation in overhead throwing athletes. Some studies attributed the difference primarily to increased humeral retroversion in the arm, whereas other studies showed correlations between the degree of internal rotation deficit and posterior capsular changes. One study assessed both humeral retroversion and posterior capsule stiffness and their effect on the differences in relative internal and external rotation between arms.[15] Although both were significantly correlated with decreased internal rotation, regression analyses indicated that these adaptations were responsible for only 25% of the total change in the range of motion.[15] Possible explanations of additional contributors to the changes in range of motion are alterations in the resting muscle tension controlled by central mediated neural modulators.[33] However, the effect of neural mediation on rotator cuff stiffness, as well as range-of-motion deficits, has not yet been evaluated in overhead athletes. Another study assessing both humeral and posterior capsule adaptations in youth athletes identified a stronger correlation with the bony adaptations.[2] The authors have postulated that in the younger age group, posterior capsular changes are not significant enough to result in meaningful range-of-motion changes.[2] Moreover, because of the lack of skeletal maturity of the athletes in this age group, it is conceivable that other structures, such as the proximal humeral epiphysis, absorb most of the stress, limiting changes in range of motion, and perhaps even contribute to the development of humeral retroversion.[34] Future studies should focus on throwing history, as well as length of time participating in overhead sports, and the effect on adaptations of the shoulder.

Limitations

This systematic review was limited by the quality of studies available in the literature. There were no high-level evidence studies (graded as Level I or II evidence) in this systematic review. Although valuable information can be gleaned through assessment of observational studies, high-quality prospective studies are needed to draw reliable conclusions. Furthermore, the data were too heterogeneous to allow for their meta-analysis and to provide additional statistical data analysis. The data in this review also do not allow for comparative analysis to determine the relation of the humeral changes with posterior capsule changes or the severity of these changes and how they relate to injury. Although multiple databases were searched for this systematic review, it is possible that certain studies eluded the search strategy. In addition, this study included only English-language articles and therefore did not assess studies written in other languages. The lack of standardized measurement devices across studies may have contributed to the variability in measurement across studies. Moreover, confounding variables such as length of time participating in sports and injury history were not adequately reported by all studies and, therefore, could not be properly accounted for in this review. Potential symptoms resulting from the changes in humeral retroversion and capsule thickening were not commented on by the individual studies as well.

Conclusions

Overhead throwing athletes consistently show several distinct changes in their dominant shoulder. These include increased humeral retroversion and the presence of a thickened and stiff posterior capsule. Concomitantly, there is often reduced internal rotation and increased external rotation of the dominant arm.

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