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Systematic Review

Scapular kinematics variability in individuals with and without rotator cuff-related shoulder pain: A systematic review with multilevel meta-regression

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ABSTRACT

Background: Traditionally, great importance has been placed on abnormal scapula kinematics in the approach to treatment of patients with rotator cuff related shoulder pain (RCRSP).
Objective: To review the literature regarding the variability of scapular position and movement in individuals with and without RCRSP.
Methods: A systematic search was performed on 18th April 2024 on nine databases. Studies evaluating scapular kinematics during arm elevation in healthy individuals and those with RCRSP were included, with a focus on 3D non-surface tracking systems.
Results: Twenty studies were included. In asymptomatic individuals, the estimated scapular position at rest was 1.00° to 11.58° of upward rotation (UR), 4.82° to 11.24° of anterior tilt, and 26.84° to 39.05° of internal rotation. During arm elevation, the scapula moves from the very beginning (no setting phase) towards UR (final position, 47.88° to 61.00° at 150° of elevation) and posterior tilt (final position, 10.78° to 11.96° at 150° of elevation), and there is a trend towards external rotation. The estimated scapulohumeral rhythm for humerothoracic elevation and scapular UR ranged from 2.86:1 to 3.13:1. There was very low certainty of evidence for differences in individuals with RCRSP in scapula resting position for UR (mean difference, -6.11°; 95 % CI: -7.36°, -4.86°), and internal rotation (mean difference, 4.21°; 95 % CI: 0.68°, 7.74°), that were below the width of the 95 % prediction intervals.
Conclusion: This meta-analysis has debunked the myth of the setting phase and the constant 3:1 scapulohumeral rhythm. There is great variability in scapular kinematics, making it difficult to detect abnormal patterns.
Prospero registration number: CRD42021259479

Introduction

Rotator cuff related shoulder pain (RCRSP) is the most common musculoskeletal shoulder disorder, and has a clinical presentation of pain and impairment of shoulder function. Although numerous factors may contribute to RCRSP (e.g., lifestyle, comorbidities, pathoanatomical issues), excessive and maladaptive loading appear to be the primary influences.[1] Traditionally, much importance has been given to the scapulothoracic joint kinematics and its relationship with RCRSP,[2–4] so the examination and treatment of scapular function is very common.[2,5,6] Nevertheless, despite some investigations finding that individuals with RCRSP may have less scapular upward rotation and posterior tilt during

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arm elevation, compared to individuals without shoulder pain,[7,8] other studies have failed to find such differences.[9,10]

Researchers have also been interested in the analysis of the coordination between the humerus and scapular motions during shoulder elevation.[11] In 1944, Inman, Saunders, and Abbott, established a scapulohumeral rhythm (SHR) of 3:1 for humerothoracic elevation, and of 2:1 for glenohumeral elevation.[12] Subsequent research extended the work of Inman et al.[12] showing different values for the scapulohumeral rhythm.[13–21]

The quality of research investigating scapular kinematics has improved over time as a consequence of the implementation of three dimensional tracking systems.[11,22,23] Researchers have advocated the use of transcortical pin placements,[11,22] fluoroscopy,[24] and other non-surface methods,[25] aiming to avoid skin-movement artifacts particularly over the scapula and clavicle, which induce bias and a decrease in the precision of the estimations.[11] Furthermore, there has been a call to standardize scapular local coordinate systems,[26,27] as well as angular sequence of rotation descriptions,[28] to improve comparability between studies, because both factors are known to influence the measured angles.[26–28]

Researchers usually evaluate scapular kinematics by calculating average scapular angles at multiple cut-off points of arm elevation, which ignores some of the repeated measures nature of the data, and assumes linearity between points of arm elevation,[11,22,23,29] instead of using multilevel non-linear regression models.[16–21,30] This way of proceeding can lead to less precise normative values,[31] incorrect statistical inference when comparing individuals with and without shoulder disorders, and biased estimates of scapulohumeral rhythm when calculating it as a ratio variable.[32–34] Recently, some investigators have considered the shape of the individuals' scapular motion temporal series within their analyses, to overcome some of these issues.[35–39] Furthermore, previously published meta-analyses have failed also to account for the multilevel nature of the data, conducting separate meta-analyses at multiple arm elevation cut-off points instead of integrating all data from the studies into a single multilevel meta-analysis.[29] A multilevel meta-regression analysis could shed some light in all these gaps of knowledge within the current literature.

The aim of this study was to systematically review current literature regarding scapular kinematics during arm elevation in individuals with and without RCRSP, to estimate normal variability of scapular movement and analyze potential differences in scapular kinematics between these two groups.

Methods

Design

This systematic review followed the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.[40] The protocol of the study was prospectively registered in PROSPERO database (CRD42021259479). Protocol deviations are presented in Supplementary Material 1.

Search strategy

A systematic literature search was performed on the following databases: Medline/Pubmed, EMBASE, Web of Science, Scopus, SciELO, CINAHL, ScienceDirect, SPORTDiscus, and Cochrane database on 30st June 2023, and updated on 18th April 2024. Neither language nor date restrictions were imposed.

A combination of terms related to the shoulder region, kinematics and RCRSP was used with adequate boolean operators. The full search strategy is detailed in Supplementary Material 2. Furthermore, references included in previously published systematic reviews related to this topic were hand-searched.

Eligibility criteria

All study designs except case reports, case series, abstracts, editorials, narrative reviews, and systematic reviews/meta-analysis studies were considered eligible for this review. Only studies published in English or Spanish language were included.

Inclusion criteria

The articles were included in this review if they met the following inclusion criteria: 1) scapular kinematics measured with 3D non-surface motion tracking devices during arm elevation or lowering in sitting or standing positions (e.g., radiographs, magnetic resonance imaging (MRI), fluoroscopy, bone-inserted pins); and 2) inclusion of a group of healthy individuals and/or individuals with RCRSP aged over 18.

Exclusion criteria

The articles were excluded if they met any of the following exclusion criteria: 1) the procedures used to record kinematic data were not properly reported, and 2) scapular posture was measured at static positions (e.g., scapular position with the arm in a static position at 90 degrees of elevation).

Screening procedure

Duplicates were removed using Covidence and Rayyan QCRI webpage applications.[41,42] Both title/abstract and full-text screening were conducted by two independent reviewers (RFM and JBF), and a third reviewer resolved any discrepancy between them (NRS), using the Rayyan QCRI webpage application.[42]

Data extraction

A standardized Excel template was used for data extraction. The following information was extracted from each study: study details, sample characteristics, measurement details, and scapular kinematics during shoulder elevation.

When processed data of scapular kinematics during shoulder movements were not presented in the study, the authors were contacted. If authors did not respond to the request, and data were only available in Fig.s, they were retrieved using the WebPlotDigitizer© application by Ankit Rohatgi. The mean and standard error was calculated for each scapular movement at each humeral elevation angle.

Quality assessment

The Appraisal tool for Cross-Sectional Studies (AXIS) was used, which is composed of 20 items.[43] Two independent reviewers (RFM and NRS) assessed methodological quality, and any discrepancy between them was resolved by a third reviewer (ELG). Finally, the GRADE approach[44] was used to rate the certainty of evidence of the comparisons between individuals with and without RCRSP.

Data analysis

For the descriptive analysis of the data, the mean and standard deviation (SD) were used for continuous outcomes, and absolute frequencies and percentages for categorical data.

Due to the repeated-measures nature of the scapular kinematics data, a multilevel restricted maximum-likelihood meta-regression analysis was conducted. The mean value of scapular kinematics at each cut-off point of the shoulder elevation angle (humerothoracic elevation) was used as the effect size, and the sampling variance was calculated by squaring the standard error of the mean.

Meta-regressions were conducted for each scapular axis of rotation (upward/downward rotation, anterior/posterior tilt, and internal/external rotation), separately for each combination of elevation plane, joint coordinate system, and angle sequence of rotation used. Details for the methodology of calculation of the multilevel models, and the SHR for scapular upward rotation and anterior-posterior tilt are presented in Supplementary Material 3.

Finally, for the comparison between individuals with and without RCRSP, the presence of pain was included as a moderator within the model, as well as its interaction with shoulder elevation.

All the analyses were conducted using the 'metafor'[45] and 'rms' (Frank E Harrell Jr (2022)) packages in R v4.1.0 (R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria).

Results

The inter-examiner agreement value of Gwet's AC1 after the pilot screening was 0.90. The systematic search retrieved 36,970 records. After removing duplicates, 12,538 studies were screened for eligibility. Finally, 20 studies were included in this review, and 9 in the meta-analyses (Fig. 1).

Characteristics of included studies and individuals

Overall, studies included mid-age female and male individuals with and without shoulder pain. Two studies compared individuals with and without RCRSP,[24,46] two compared individuals with and without partial or full-thickness rotator cuff tears,[47,48] three compared individuals with and without massive rotator cuff tears,[47,49,50] and two[51,52] compared young healthy individuals to older ones (Supplementary Material 4). Finally, all studies presented with moderate quality according to the AXIS checklist (Supplementary Material 5).

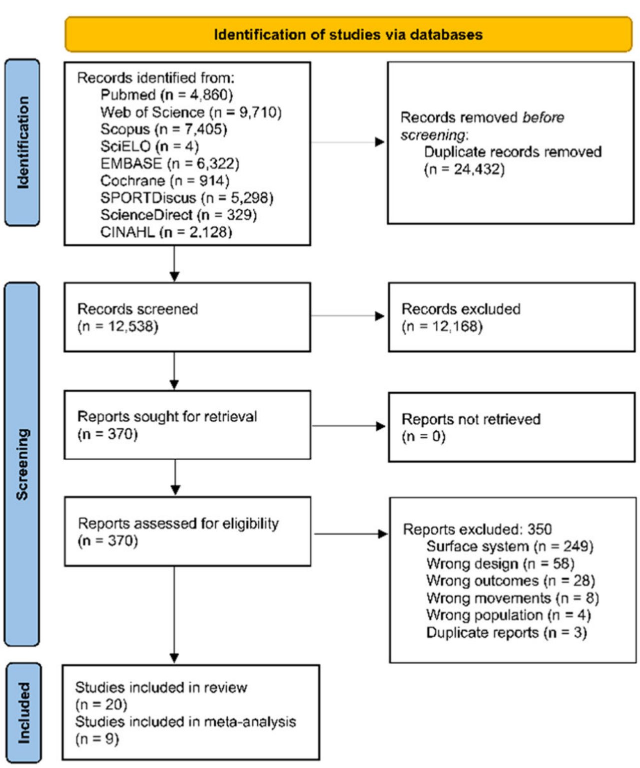

Fig. 1. PRISMA flow diagram.

Characteristics of scapular kinematic measurement procedures

The full description of the measurement procedures is presented in Table 1. Devices used for the measurement of scapular kinematics included bone-inserted pins (3 studies),[11,22,26,53] computed tomography (2 studies),[25,54] fluoroscopy (12 studies),[24,47–49,51,52,55–60] and radiography (3 studies).[50,61,62] Regarding joint coordinate systems, 4 studies[22,24,26,46] used the original ISB system, 7 studies[11,24–26,47,50,53,61,62] used the current ISB system, 12 studies[26,48,49,51,52,54–60] used the glenoid based system, and 1 study[26] used the Pearl method. The sequences used for decomposition of scapular kinematic data were the Y-X-Z Euler sequence (11 studies),[11,22,24–26,46,47,50,51,53,56,61,62] and the Z-X-Y cardan sequence (8 studies).[48,49,52,55,57–60] Some studies reported data using more than one coordinate system or decomposition sequence. Complete individual studies data are provided in Table 1.

Almost all the studies measured scapular kinematics without considering arm dominance in asymptomatic individuals but based on participant's arm preference. Furthermore, they also did not report speed of movement, and did not consider the use of free weights during scapular kinematic recordings. Regarding rest position, 13 studies used standing[11,22,26,46,50–56,58–61] and 7 studies[24,25,47–49,57,62] sitting positions. The most measured plane of elevation was the scapular plane (15 studies),[11,22,24,26,46–53,55–60,62,63] followed by the coronal plane (6 studies),[11,25,26,46,53,56,61,62] and sagittal plane (4 studies).[11,22,26,46,53,56] The range of elevation measured varied from 0-20 degrees as the starting position to 180 or maximum degrees of elevation at the end of movement (Table 1). Finally, all studies analyzed kinematic data comparing means/medians at multiple cut-off points of arm elevation (e.g., every 5 or 10 degrees), by employing various types of parametric or non-parametric analysis of variance and/or pairwise comparison tests (e.g., student t-test, Mann-Whitney, Wilcoxon…).

Scapular kinematics

The model performance statistics are presented in Supplementary Material 5 and the model regression coefficients in Supplementary Material 6. Finally, reasons for excluding some data from the meta-analysis, as well as explanations of duplicated records, are presented in Supplementary Material 7.

Scapular upward rotation in healthy individuals

The results of the meta-regressions showed a similar pattern of scapular upward rotation during arm raising, regardless of the type of joint coordinate system used, and plane of elevation (Fig. 2). The use of RCS models did not improve the performance compared to linear ones (Supplementary material 5).

Based on the RCS models, the estimated mean scapular upward rotation at rest position (intercept) varied from 1.00° to 11.58° (Supplementary Material 6), and at 150° of arm elevation, varied from 47.88° to 61.00°. The width of the 95 % prediction intervals were 21.84° (AA, scapular plane), 26.12° (AA, coronal plane), 25.73° (AC, scapular plane), and 32.25° (AC, sagittal plane) (Fig. 2).

Regarding the relationship between scapular upward rotation and arm elevation, the regression coefficients of the linear models were very similar regardless of the joint coordinate system employed and plane of elevation (Fig. 2). The linear model coefficients for humerothoracic elevation varied from 0.35 (SHR = 2.86:1) to 0.32 (SHR = 3.13:1), the lower limit of the 95 % CI varied from 0.30 (SHR = 3.33:1) to 0.32 (SHR = 3.13:1), and the upper limit varied from 0.34 (SHR = 2.94:1) to 0.38 (SHR = 2.63:1) (Supplementary Material 6).

During arm lowering, the linear model coefficients were very similar to those during arm raising, varying from 0.34 (SHR = 2.94:1) to 0.35 (SHR = 2.86:1), with the lower limit of the 95 % CI varying from 0.32 (SHR = 3.13:1) to 0.29 (SHR = 3.45:1), and the upper limit from 0.36

Table 1
Description of the measurement procedures for scapular kinematic analysis.

Study	Device	Coordinate system	Sequence (H)	Sequence (ST)	Side	Plane	Position	Range	Speed	Weights
McClure, 2001 [22]	Bone pin	TrS + AC + IA	P-E-R	ER-UR-PT	Mixed	Sagittal Scapular	Standing	0 – 150	NR	No weights
Kon, 2008 [54]	Computed Tomography	Glenoid based system	NR	NR	Mixed	Scapular	Standing	0 – 125	5.31 seconds per cycle	No weights, and 3kg
Ludewig, 2009 [11], 2010 [26]; Braman, 2009 [53] & Lawrence, 2014 [46]	Bone pin	TrS + AC + IA TrS + AA + IA Glenoid based system Pearl method	P-E-R	ER-UR-PT	Mixed	Sagittal Scapular Coronal Unconstrained	Standing	0 – 120	NR	No weights
Matsuki, 2011 [57]	Fluoroscopy	Glenoid based system	P-E-R	UR-AP-ER (Cardan sequence)	Mixed	Scapular	Sitting	0 – maximum	NR	No weights
Chu, 2012 [62]	Radiography	TrS + AA + IA	P-E-R	ER-UR-PT	Dominant	Scapular Coronal	Sitting	0 – 140	NR	No weights
Duprey, 2015 [61]	Radiography	TrS + AA + IA	NR	ER-UR-PT	Right	Coronal	Standing	0 – 180	NR	No weights
Kijima, 2015 [48]	Fluoroscopy	Glenoid based system	P-E-R	UR-AP-ER (Cardan sequence)	Mixed	Scapular	Sitting	15 – 120	NR	No weights
Kim, 2017 [58]	Fluoroscopy	Glenoid based system	NR	UR-AP-ER (Cardan sequence)	Mixed	Scapular	Standing	20 – 140	NR	No weights
Chung, 2018 [59]	Fluoroscopy	Glenoid based system	NR	UR-AP-ER (Cardan sequence)	Mixed	Scapular	Standing	0 – 135	NR	No weights
Lawrence, 2019 [4,24]	Fluoroscopy	TrS + AC + IA TrS + AA + IA	P-E-R	ER-UR-PT	Mixed	Scapular	Sitting	20 – 140	NR	No weights
Lee, 2019 [25]	Computed Tomography	TrS + AA + IA	P-E-R	ER-UR-PT	Dominant	Coronal	Sitting	0 – 135	3 seconds per cycle	No weights
Ueda, 2019 [47]	Fluoroscopy	TrS + AA + IA	P-E-R	ER-UR-PT	NR	Scapular	Sitting	0 – 120	5 seconds per cycle	No weights
Kim, 2020 [49]	Fluoroscopy	Glenoid based system	ABD-FX-R	UR-AP-ER (Cardan sequence)	Mixed	Scapular	Sitting	20 – 140	NR	No weights
Kozono, 2020 [50]	Radiography	TrS + AA + IA	ABD-FX-R	ER-UR-PT	NR	Scapular	Standing	15 – 150	NR	No weights
Kolz, 2021[51]	Fluoroscopy	Glenoid based system	ABD-FX-R	ER-UR-PT	Dominant	Scapular	Standing	20 – 130	NR	No weights
Sugi, 2021 [60]	Fluoroscopy	Glenoid based system	ABD-FX-R	UR-AP-ER (Cardan sequence)	Mixed	Scapular	Standing	0 – maximum	3 seconds per cycle	No weights
Kwon, 2021 [52]	Fluoroscopy	Glenoid based system	ABD-FX-R	UR-AP-ER (Cardan sequence)	Dominant	Scapular	Standing	0 – maximum	3 seconds per cycle	No weights
Inui, 2023 [56]	Fluoroscopy	Glenoid based system	P-E-R	ER-UR-PT	Dominant	Sagittal Scapular Coronal	Standing	0 – maximum	5 seconds per cycle	No weights
Park, 2024 [55]	Fluoroscopy	Glenoid based system	ABD-FX-R	UR-AP-ER (Cardan sequence)	Mixed	Scapular	Standing	0 – maximum	3 seconds per cycle	No weights

Abbreviations: AA, angulus acromialis; ABD, glenohumeral abduction-adduction; AC, posterior acromioclavicular joint; E, glenohumeral elevation angle; ER, scapular internal-external rotation; FX, glenohumeral flexion-extension; H, humerus; IA, inferior angle of the scapula; NR, not reported; P, glenohumeral plane of elevation; PT, scapular anterior-posterior tilt; R, glenohumeral internal-external rotation; ST, scapulothoracic; TrS, trigonum spinae; UR, scapular upward rotation;

(SHR = 2.78) to 0.40 (SHR = 2.5:1) (Supplementary material 6).

Scapular anterior-posterior tilt in healthy individuals

The results of the meta-regressions showed a similar pattern of scapular posterior tilt during arm raising, regardless of the type of joint coordinate system used, (FIG. 3) and plane of elevation. Overall, the use of RCS models did not improve the performance compared to the linear ones (Supplementary Material 5).

Based on the RCS models, the estimated mean scapular anterior tilt at rest position (intercept) in AA and AC coordinate systems varied from 4.82° to 11.24° (Supplementary Material 6), and at 150° of arm elevation the mean scapular posterior tilt varied from 10.78° to 11.96° (AA and AC coordinate systems). The width of the 95 % prediction intervals were 28.42° (AA, scapular plane), 17.65° (AA, coronal plane), 35.36° (AC, scapular plane), and 45.31° (AC, sagittal plane) (FIG. 3).

The regression coefficients were similar regardless of the joint coordinate system and plane of elevation (Supplementary Material 6). For the linear models during arm raising, the model coefficients varied from 0.13 (SHR = 7.69:1) to 0.16 (SHR = 6.25:1), the lower limit of the 95 % CI varied from 0.11 (SHR = 9.09:1) to 0.14 (SHR = 7.14:1), and the upper limit varied from 0.14 (SHR = 7.14:1) to 0.19 (SHR = 5.26:1).

During arm lowering, the model coefficients did not vary greatly to those observed during arm elevation (Supplementary Material 6),

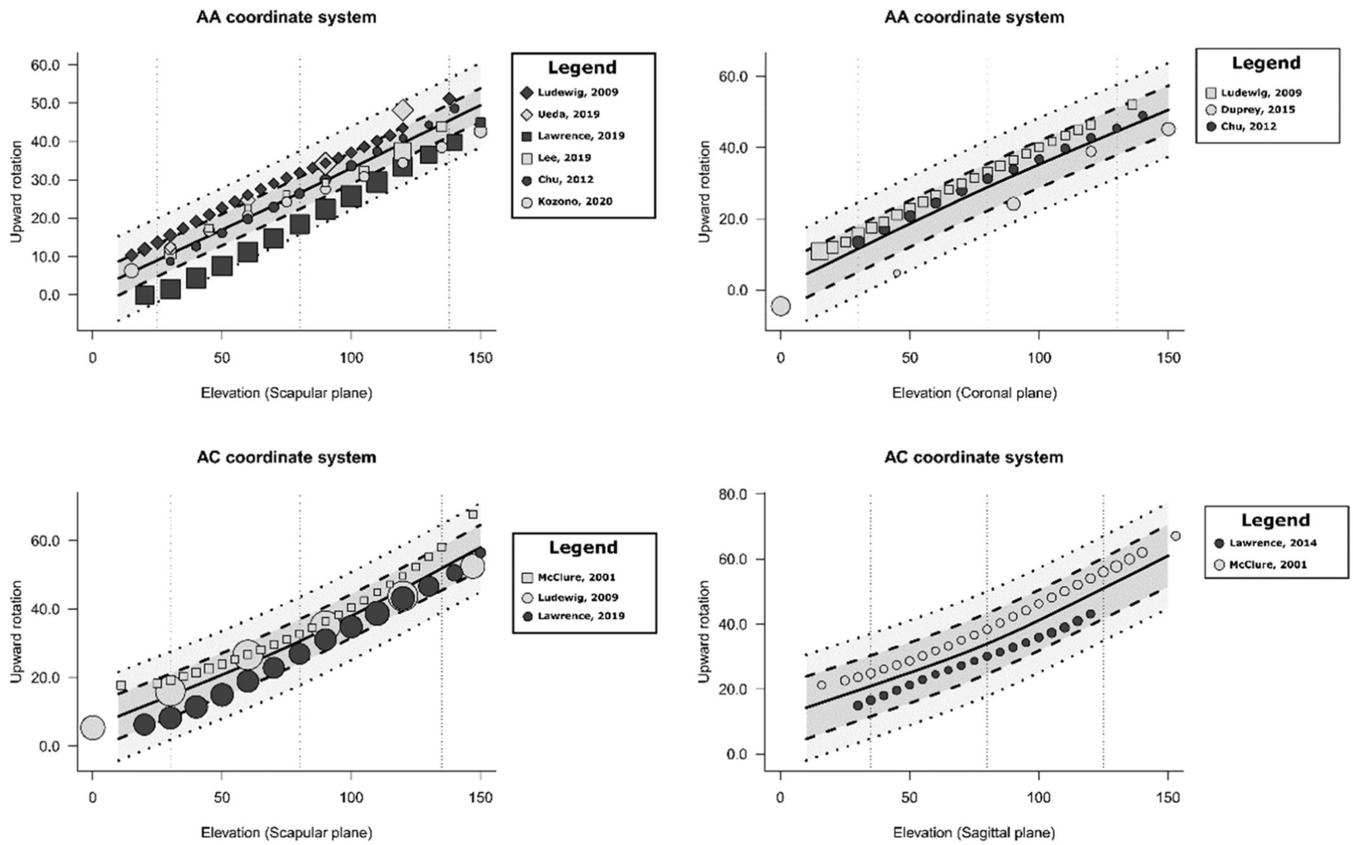

Fig. 2. . Meta-analytic scatter plots of scapular upward rotation in asymptomatic individuals during arm raising, based on restricted cubic spline multilevel meta-regression analyses. Abbreviations: AA, angulus acromialis; AC, posterior acromioclavicular joint. Legend: Solid line, regression line; dashed line, 95 % confidence interval; dotted line, 95 % prediction interval. Positive values indicate upward rotation. Dot size is proportional to the inverse of the standard error.

varying from 0.15 (SHR = 6.67:1) to 0.16 (SHR = 6.25:1), with the lower limit of the 95 % CI varying from 0.12 (SHR = 8.33:1) to 0.13 (SHR = 7.69:1), and the upper limit from 0.17 (SHR = 5.88:1) to 0.19 (SHR = 5.26:1).

Scapular internal-external rotation in healthy individuals

For scapular internal-external rotation, the meta-regressions showed some differences between AA and AC coordinate systems, with a linear-like pattern within the AA coordinate system and a non-linear pattern within the AC coordinate system during arm raising (FIG. 4). The use of RCS models seemed to induce a small improvement in the performance within the AC coordinate system (Supplementary Material 4).

Based on RCS models, the estimated mean scapular internal-external rotation at rest position (intercept) were 26.84° for scapular plane and 28.83° for coronal plane (AA coordinate systems), and 38.44° for sagittal plane and 39.05° for scapular plane (AC coordinate systems). At 150° of arm elevation, the estimated internal-external rotation values were 23.57° for scapular plane and 23.38° for coronal plane (AA coordinate systems), and 31.45° for scapular plane and 39.25° for sagittal plane (AC coordinate systems). The widths of the 95 % prediction intervals were 59.21° (AA, scapular plane), 3.21° (AA, coronal plane), 27.74° (AC, scapular plane), and 19.90° (AC, sagittal plane) (Supplementary Material 6).

The relationship between scapular internal-external rotation and arm elevation was not as clear as for upward rotation and posterior tilt movements. Overall, it seems to be a trend toward increasing scapular external rotation at higher degrees of arm elevation, but a non-consistent pattern was found at lower angles of elevation. The coefficients of the linear models within AA coordinate system were -0.02 (95 % CI, -0.04, -0.001) for scapular plane, and -0.08 (95 % CI, -0.13, -0.02) for coronal plane. Within the AC coordinate system, the first and second (quadratic term within the first and second knots) regression coefficients of the RCS model in scapular plane were 0.01 (95 % CI, -0.06, 0.07), and -0.10 (95 % CI, -0.18, -0.01); and in coronal plane they were 0.12 (95 % CI, 0.05, 0.19), and -0.21 (95 % CI, -0.31, -0.12) (Supplementary Material 6). There was no meta-analysis data for arm lowering.

Differences between individuals with and without rotator cuff related shoulder pain

Only two studies[24,46] using the AC coordinate system in scapular plane elevation could be meta-analyzed for the comparison of individuals with (n = 40) and without (n = 42) RCRSP. A linear model was selected for scapular upward rotation and anterior-posterior tilt, and an RCS model for internal-external rotation. The full model coefficients, performance measures, and line plots for predicted values are presented in Supplementary Material 8. The certainty of evidence was rated as very low according to GRADE recommendations.

Individuals with RCRSP showed less scapular upward rotation at rest (mean difference
-6.11°; 95 % CI, -7.36°, -4.86°). Furthermore, the RCRSP group showed a slightly greater slope (mean difference, 0.03; 95 % CI, 0.01 to 0.04), meaning that those without RCRSP had a greater scapulohumeral rhythm (slope = 0.35, SHR = 2.86:1), than the RCRSP group (slope = 0.38, SHR = 2.63:1). The 95 % prediction interval had a mean width of 10.54° for both groups over all the range of arm elevation.

For scapular anterior-posterior tilt, there was no difference between groups in rest position (mean difference, 0.16°; 95 % CI, -1.15°, 1.47°), and in the slope values (mean difference, -0.01; 95 % CI, -0.03, 0.01), with a mean 95 % prediction interval width of 6.39 for both groups over

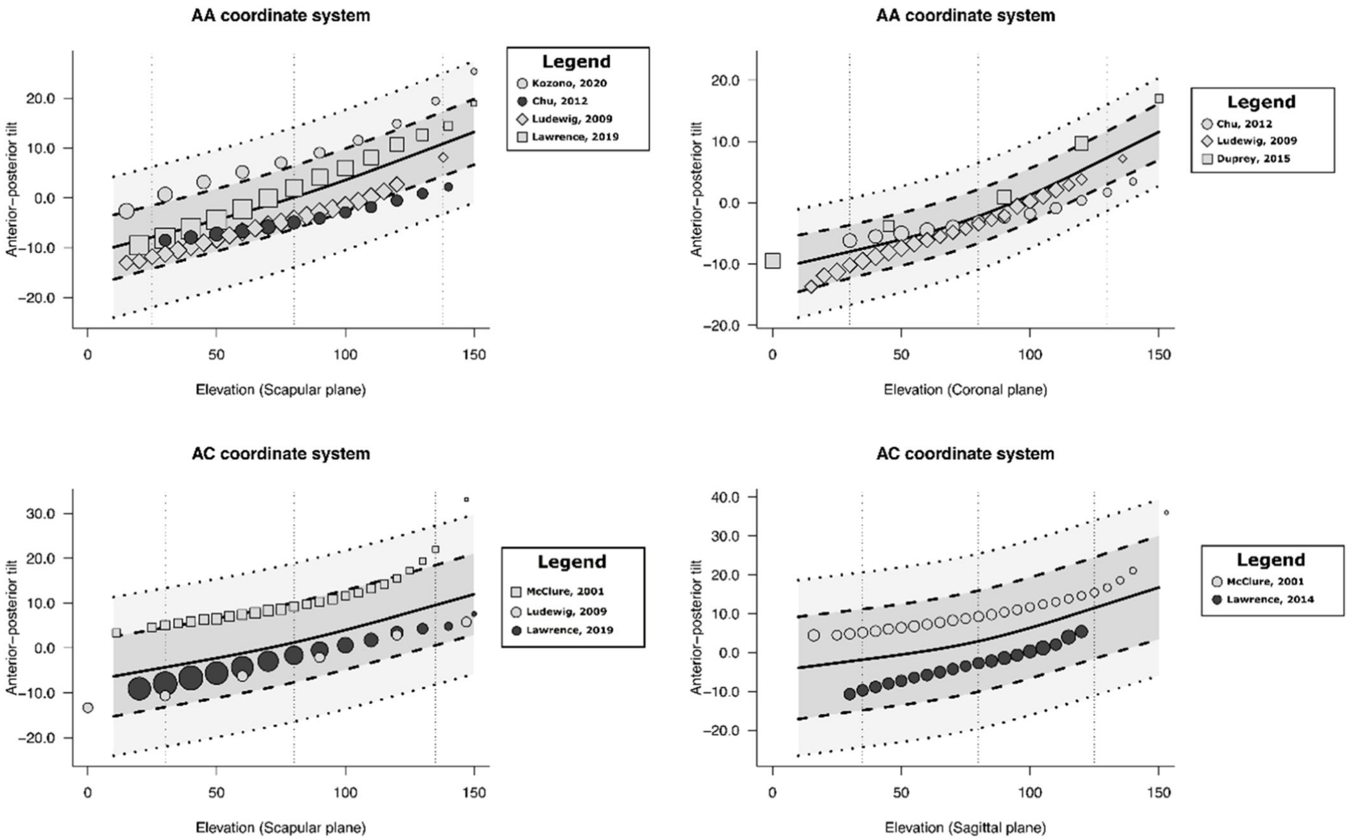

Fig. 3. Meta-analytic scatter plots of scapular anterior-posterior tilt in asymptomatic individuals during arm elevation, based on restricted cubic spline multilevel meta-regression analyses. Abbreviations: AA, angulus acromialis; AC, posterior acromioclavicular joint. Legend: Solid line, regression line; dashed line, 95 % confidence interval; dotted line, 95 % prediction interval. Positive values.

all the range of arm elevation. Finally, for scapular internal-external rotation, the RCRSP group showed greater scapular internal rotation at rest (mean difference, 4.21°; 95 % CI, 0.68°, 7.74°), but no between-group differences on slope values for any of the two terms of the RCS model. The 95 % prediction intervals had a mean width of 5.74° for both groups over all the range of arm elevation.

The studies comparing healthy individuals and those with rotator cuff tears showed a trend towards a slightly greater amount of upward rotation in injured individuals at higher degrees of arm elevation,[47,49,50] and no clear evidence for differences in posterior tilt and internal-external rotation.[47–50]

Factors associated with scapular kinematics in healthy individuals

Due to the small number of studies, incomplete reported data, and methodological heterogeneity, the association between protocol-predefined moderators and scapular kinematics could not be meta-analyzed.

Two studies evaluated the relationship between age and scapular kinematics.[51,52] Kolz et al.[51] compared scapular kinematics during scapular plane elevation, between individuals younger than 35 years and individuals older than 45 years. They found that the young group had more scapular external rotation throughout the entire scapular plane elevation, as well as greater posterior tilt at higher degrees of scapular plane elevation, but no differences in upward rotation. On the other hand, Kwon et al.[52] compared young men between 20-30 years, with older men in their 50-60. They found an increase in scapular upward rotation in the old men group, at 130° and maximum degrees of scapular plane elevation. Furthermore, they observed an increase in scapular posterior tilt in the older men group above 120° of scapular plane elevation.

Regarding the effect of added weights on scapular kinematics, Kon et al.[54] found a decrease in scapular upward rotation between 35° to 45° of scapular plane elevation, and between 40° to 70° of arm abduction, with the addition of a 3-kg dumbbell.

The influence of arm dominance on scapular kinematics was analyzed in one study.[57] The authors found less scapular upward rotation in the dominant side throughout the entire range of scapular plane elevation.

Finally, Lee et al.[25] compared the scapular kinematics between active and passive arm elevation in the scapular plane. They observed greater scapular upward rotation at 45°, 60°, 75° and 90° of elevation, and less scapular posterior tilt at 90°, 105°, and 120° of elevation when the movement was performed actively.

Discussion

This systematic review with meta-regression summarizes the evidence of 20 studies measuring scapular kinematics using three-dimensional non-surface tracking systems in individuals with and without RCRSP. There was a great variability in estimated scapular kinematic patterns, and limited evidence to draw conclusions about the existence of a difference between individuals with and without RCRSP.

Scapular kinematics in healthy individuals

The estimated mean scapular position at rest showed considerable variability in upward rotation, internal-external rotation, and posterior tilt (see Supplementary Material 6). Furthermore, the width of the 95 % prediction intervals showed even more variability in estimated scapular rest position. These results are similar to those obtained in studies using non-surface tracking devices or where scapular position at rest was just

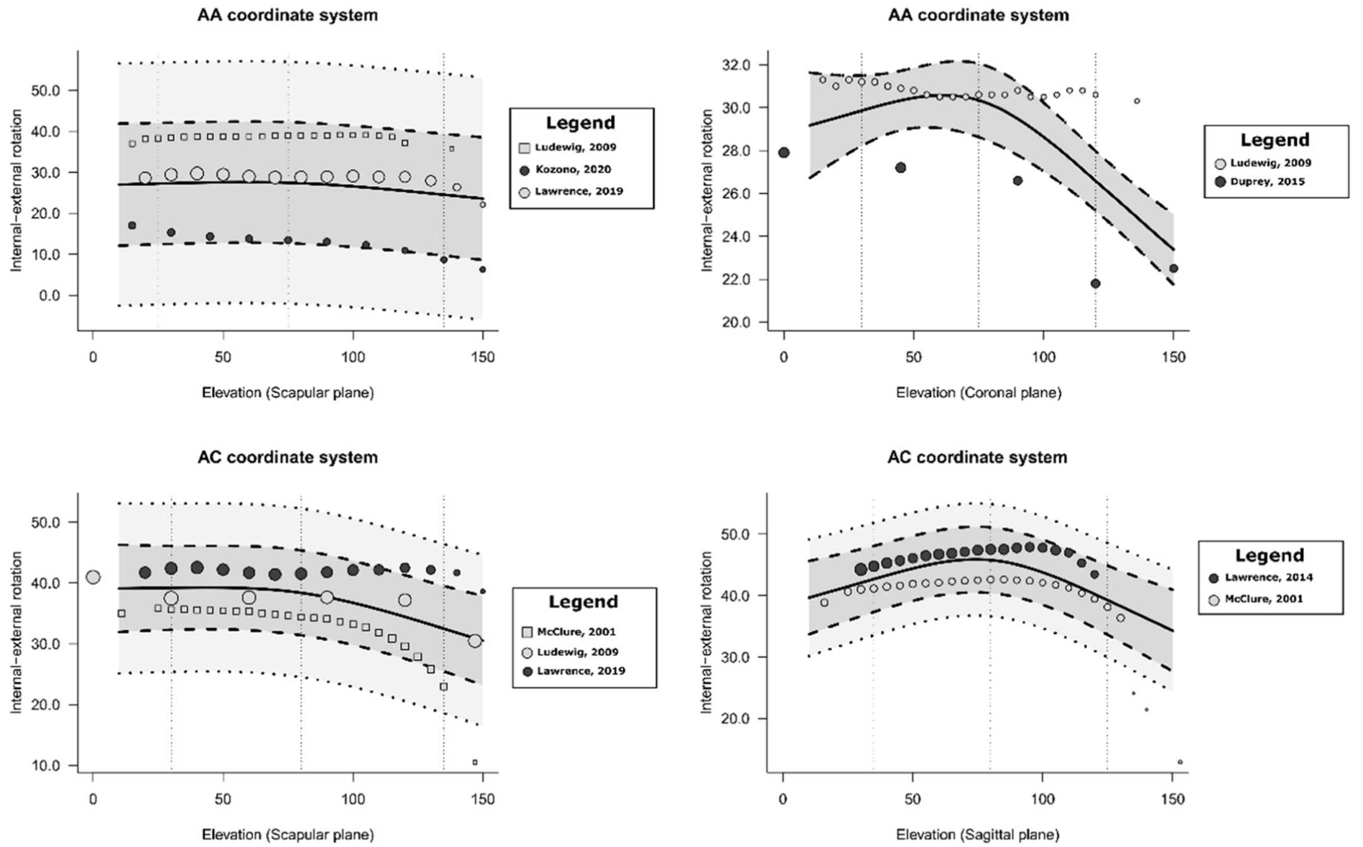

Fig. 4. . Meta-analytic scatter plots of scapular internal-external rotation in asymptomatic individuals during arm elevation, based on restricted cubic spline multilevel meta-regression analyses. Abbreviations: AA, angulus acromialis; AC, posterior acromioclavicular joint. Legend: Solid line, regression line; dashed line, 95 % confidence interval; dotted line, 95 % prediction interval. Positive values indicate internal rotation. Dot size is proportional to the inverse of the standard error.

measured.[64]

The topic of normal posture of the scapula at rest has been a matter of interest for decades, focusing on measures of central tendency.[10,64–66] However, there has been little attention upon measures of dispersion when interpreting research findings.[10,65] Altogether, results of this study shows that with the existing breadth of methodologies, there is a great variability (i.e., dispersion) in scapular position at rest within healthy individuals that, when considered alone, precludes the identification of an abnormal scapular posture at rest in clinical practice. Large scale studies with a single methodology and considering covariates of body anthropometrics are needed to fully address this point. Despite this large variation, significant differences between populations with and without RCRSP were noted.

During arm raising, the meta-regressions of asymptomatic individuals showed that the scapula moved into upward rotation and posterior tilt, and a trend was shown towards external rotation at higher degrees of elevation. All these results are in agreement with those obtained in studies using surface tracking systems.[15,64] The discrepancies observed between scapular upward rotation and posterior tilt, and scapular internal/external rotation patterns, might be explained by the biomechanical factors contributing to those movements.[2] Scapulothoracic upward rotation is produced as a result of sternoclavicular posterior rotation and elevation, and acromioclavicular upward rotation;[2,24] whereas scapulothoracic posterior tilt is produced as a consequence of sternoclavicular posterior rotation, and acromioclavicular posterior tilt.[2] The sternoclavicular and acromioclavicular movements occur during arm raising due to ligament constraints[11,12,67] and the moment arm of scapulothoracic muscles.[67–69] Scapulothoracic internal/external rotation results from sternoclavicular retraction and acromioclavicular internal/external rotation[2] that are not as much constrained by ligaments and muscles' line of action.[11,12,67] Internal/external rotation is highly influenced by the plane of arm elevation and the shape of the thoracic rib cage.[11,67,70]

Most studies investigating scapular kinematics controlled the plane of arm elevation during measurement procedures.[53] These constraints may limit the degrees of freedom of scapulothoracic internal/external rotation movement, leading to an horizontal-line look alike pattern during the low and medium degrees of arm elevation.[4,11] In this scenario, the expected changes on internal/external rotation will be mostly on intercept values, as can be observed within included studies. Finally, the tendency towards scapulothoracic external rotation at higher degrees of shoulder elevation may be explained by the changes produced in the angle of plane of elevation as the arm raises overhead, moving towards a more coronal plane[11] and thus inducing an increase in scapulothoracic external rotation movement.[70]

Another issue observed is that all included studies analyzed kinematic data by calculating average scapular angles at multiple cut-off points of arm raising and lowering, instead of using proper multilevel regression analyses. In addition, most of the studies eliminated the kinematic pattern over 150-180 degrees instead of including the full data in the analyses, that hinders the evaluation of scapular kinematic patterns at higher degrees of arm elevation.

In 1944, Inman et al.[12] observed a lack of scapular upward rotation movement within the first 30° of shoulder abduction and 60° of shoulder flexion, the so called "*setting phase*". Following that study, multiple researchers started to use this concept as a basis for the assessment of pathological scapular kinematic patterns.[71–73] The results of our meta-regression analyses do not support the existence of such a "*setting phase*", neither for upward rotation nor posterior tilt (FIG.S 2 and 3). Indeed, the scapula moves from the very beginning of arm elevation. Thus, clinicians should stop labelling scapular dysfunction based merely on the presence of early movement of the scapula during arm elevation, since it is just the normal scapular kinematic pattern.

Inman et al.[12] were also the first ones to measure the SHR, reporting a value of 3:1 for humerothoracic elevation, and a value of 2:1 for glenohumeral elevation, and scapular upward rotation. Despite not being clear if they measured more than one individual in their study and subsequent research showing other data for SHR,[18,22] the Inman et al.[12] value has been widely used in research and clinical practice to differentiate between normal and pathological scapular kinematic patterns. The results of our meta-regression analyses do not support this constant value (Supplementary Material 6).

The SHR is usually calculated as a ratio variable.[18,22] This procedure assumes a linear heteroskedastic relationship between arm elevation and scapular movement,[34] and can lead to imprecise normative reference values.[32,33] A more accurate approach for estimating the SHR is by using multilevel regression models.[32–34] However, only a few studies have used regression models,[16–21] and most of them have not considered the multilevel nature of the data.[30] The estimated value of the SHR derived from the meta-regression analyses for scapular upward rotation ranged from 2.63:1 to 3.33:1 (Supplementary Material 6). These results are similar to the ones obtained by Xu et al.[21] (SHR = 3.11:1), and Groot and Brand[30] (SHR = 2.53:1). Therefore, the current meta-analysis does not support the classical constant value of the SHR (3:1) for humerothoracic elevation reported by Inman et al.,[12] although some individuals may present this value as showed by confidence and prediction intervals.

The RCS models did not seem to perform better than the linear ones (Supplementary Material 5). Previous research using regression models found evidence of a non-linear kinematic pattern for scapular upward rotation[16,18,21] and posterior tilt[38] during arm elevation. These discrepancies may be explained by the fact that means instead of individual participant data (that were not available) were analyzed, thus decreasing scapular kinematic patterns' variability, and leading to a linear-like relationship.

Differences between individuals with rotator cuff disorders and healthy controls

Only two studies from the same research group were found comparing scapular kinematics between individuals without (n = 42) and those with RCRSP (n = 40).[24,46] Multiple researchers have stated that altered scapular kinematics could lead to the development of shoulder disorders[6,73,74] or the perpetuation of shoulder pain,[6,73] thus recommending the assessment and treatment of scapular dysfunction.[5,6,73] Despite some significant differences in scapular kinematics found in meta-regression analyses (Supplementary Material 8), the width of the prediction intervals was large, precluding any definitive conclusion about the existence of differences between people with and without RCRSP. Research using surface tracking systems have also failed to find consistent evidence of scapular kinematic differences between those with and without RCRSP.[29,75] There is also some evidence showing that scapular dyskinesis is not an isolated risk factor for the development of shoulder injuries.[9] Nevertheless, most of the conducted studies comparing individuals with and without rotator cuff disorders have small sample sizes and lack of adequate control for confounding factors such as age, type of tears and implied mechanisms by age, precluding extrapolation of their results to a general population.

These data as a whole suggest that there is not enough evidence to ascertain if scapular kinematic patterns are different in individuals with RCRSP when compared to ones without RCRSP. A better understanding of individual interactions of motion and anatomy is needed to determine if aberrant motions may contribute to the development or progression of rotator cuff disease.

Limitations

This is the first systematic review with meta-regression evaluating scapular kinematics variability in individuals with and without RCRSP. One strength is the inclusion of studies using only non-surface measurement procedures, thus avoiding skin-surface artifacts. Furthermore, the multilevel and the possible non-linear nature of scapular kinematics' data during arm elevation were considered to strengthen the precision of the estimates.

Some limitations should also be highlighted. First, all the included studies had small sample sizes, maybe due to the complexity and potential risks of the measurement procedures. Second, meta-analysis of individual participant data could not be performed due to the impossibility of accessing individual data from included studies. This fact may have decreased estimated kinematic variability, precluding evaluating moderators and obscuring possible non-linear patterns. Finally, most of the included studies eliminated data above 150-180 degrees of arm raising which prevents drawing firm conclusions about scapular kinematics at higher degrees of shoulder elevation.

Clinical implications

In summary, this study provides data regarding normal scapular kinematic patterns, and differences between individuals with and without RCRSP, that could help clinicians and researchers to better understand shoulder complex movement. There is great variability in scapular kinematics that stands against previous assumptions such as the constant 3:1 scapulohumeral rhythm for humerothoracic elevation, or the setting phase. Furthermore, there is not enough evidence to conclude about the existence of scapular kinematics' alterations in individuals with RCRSP compared to those without RCRSP. These data may serve as a first step to guide future research regarding scapular kinematics and rotator cuff pathology. Finally, future studies should improve content reporting of the methods employed to measure scapular kinematics, such as arm dominance or speed of movement, in order to evaluate whether those factors may influence the kinematic patterns in both asymptomatic individuals and people with shoulder pain.

Conclusion

The results of this review show that the scapula moves towards upward rotation and posterior tilt during all the range of arm elevation, and towards external rotation at higher degrees of arm elevation, with a large range of normal variability in healthy individuals. These findings suggest that it is difficult to detect an abnormal kinematic pattern within clinical practice. Furthermore, current data do not support the existence of the setting phase of the scapula and challenge the classical fixed scapulohumeral rhythm magnitude of 3:1 for humerothoracic elevation. Future studies should improve sample size and consider using non-linear multilevel models for a better estimation of scapular kinematics.

Patient involvement statement

Not applicable.

Data sharing statement

All data relevant to the study are included in the article or are available as supplementary files.

Declaration of competing interest

The authors declare that they have no competing interests.

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Supplementary materials

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