Article Title: Scapular Kinematics and Subacromial Impingement Syndrome: A Meta-Analysis

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Scapular Kinematics and Shoulder Impingement Syndrome: A Meta-Analysis

Context: The literature does not present a consistent pattern of altered scapular kinematics in patients with shoulder impingement syndrome (SIS).

Objectives: The objective of study is to perform meta-analyses of published comparative studies to determine the consistent differences in scapular kinematics between subjects with SIS and controls. Additionally, the purpose is to analyze factors of the data collection methods to explain the inconsistencies in reported kinematics. The results of this study will help guide future research and enable our understanding of the relationship between scapular kinematics and SIS.

Evidence Acquisition: A search identified 65 studies; 9 papers met inclusion criteria. Sample sizes, means and standard deviations of 5 scapular kinematic variables were extracted or obtained from the paper's lead author. Standard difference in the mean between SIS and controls was calculated. Moderator variables were plane of arm elevation (PLANE), level of arm elevation (ARM) and population (POP).

Evidence Synthesis: Overall the SIS group had less scapular upward rotation (UR) and external rotation (ER), and greater clavicular elevation (ELE) and retraction (RET), but no differences in scapular posterior tilt (PT). In the frontal PLANE, SIS subjects showed greater PT and ER, and in the scapular PLANE less UR and ER, and greater ELE and RET. There was also greater ELE and RET in the sagittal PLANE. There was less UR at the low ARM, and greater ELE and RET at the high ARM with SIS. Athletes and overhead workers showed less UR, while athletes showed greater PT and workers showed less PT and ER. The general population with SIS had greater ELE and RET only.

Conclusions: Subjects with SIS demonstrated altered scapular kinematics and these differences are influenced by the PLANE, ARM and POP. Athletes and overhead workers have a different pattern of scapular kinematics than the general population. The scapular plane is most likely to demonstrate altered kinematics. These factors should be considered when designing futures studies to assess the impact of altered kinematics in patients with SIS.

Keywords: Scapular kinematics, Shoulder Impingement, Rotator Cuff Disease

CONTEXT

Proper position and orientation of the scapula with respect to the humerus is needed to facilitate shoulder strength, stability and range of motion needed for daily activities.[1-3] Altered scapular kinematics have been reported in patients with rotator cuff disease, specifically subacromial impingement syndrome[3-15] and internal rotator cuff impingement.[16] The reported altered scapular kinematic might contribute to the development of the pathology or result from adaptions to the rotator cuff pathology. During arm elevation the subacromial space decreases in dimension.[17-19] Hypothetically, a loss in scapular posterior tilt(PT), external rotation(ER) and upward rotation(UR) reduces subacromial space volume leading to rotator cuff tendon compression.[20] A literature review[21] revealed inconsistencies in the reported scapular kinematics alterations in patients with shoulder impingement syndrome (SIS). Specifically, four studies[10, 22-24] reported less scapular UR while one study[12] reported greater UR, and five studies[6, 8, 11, 12, 16, 22, 25] reported no differences in scapular UR in subjects with SIS. Seven studies measuring scapular PT have inconsistent findings; four [10, 11, 22, 26] reported decreased scapular PT, two[12, 16] reported increased PT, while one[8] reported no difference in PT in subjects with SIS as compared to controls. Seven studies examined scapular ER; five studies reported no differences between controls and SIS[11, 12, 16, 26, 27], while two papers reported decreased ER in SIS.[8, 10] Consistent findings were reported only for clavicular elevation (ELE); four studies reported increased ELE with SIS.[11, 12, 16, 26] Two papers examining clavicular retraction (RET) reported inconsistent findings; one[12] reporting an increase in RET, and the other[16] no differences in RET in subjects with SIS. This literature review[21] used a narrative method to synthesize results of the individual studies. The increased rigor of the meta-analysis procedure which uses the original data rather than just the reported means from prior studies, allows for the identification of a consistent scapular kinematic pattern associated with SIS. Moreover, synthesizing the data from published studies through meta-analysis will allow us to explore how data collection methods of each study affected the outcomes of the study. Specifically, the dissimilarities between studies with respect to plane of arm elevation, arm elevation angle, and the sample of subjects with SIS studied may contribute to the inconsistencies in reported scapular kinematics.

OBJECTIVES

The purpose of this investigation was to examine published studies of scapular kinematics in subjects with SIS using meta-analysis. Specifically, we collapsed the published data to identify a consistent pattern of scapular kinematics associated with SIS, and to explore the influence of the data collection methods and the subject population had on scapular kinematics. We hypothesized that patients with SIS when compared to controls will have less scapular UR, PT, ER, RET and greater ELE during arm elevation. We also hypothesized that plane of arm elevation, angle of arm elevation and the population studied would have an effect on the consistency of the reported kinematics. The information gained by this exploration and analysis of published research will rigorously determine if there are consistent patterns of scapular kinematics in patients with SIS. This will lead to an increased understanding and serve as a guide for future studies which examine mechanisms and treatment of SIS.

EVIDENCE ACQUISTION

Literature Search

A search for published literature was performed in March, 2010 in PubMed, Science Direct and Ovid databases, search terms included shoulder, human, kinematics (motion), scapula and rotator cuff impingement (pathology, disease) identified 64 published papers, 3 additional papers were identified by examining the references. Abstracts were reviewed by 2 authors to determine if the paper: 1) compared subjects with SIS to those without SIS, 2) presented scapular kinematic variables, and 3) the paper was not a review article. From the abstract review 14 papers met the three defined criteria for full text review. Titles of these 14 papers were entered into Science Citation Index (Thomson Corporation, New York, NY), and this forward search identified no additional papers.

Literature Review

Papers were randomly assigned to 2 authors for full review to determine if the paper met the inclusion criteria for analysis. If the 2 reviewers did not agree, a third author was randomly assigned to review the paper in order to break the tie. Inclusion criteria were developed to assure shoulder pain was clinically diagnosed as SIS (either subacromial or internal impingement), and to assure consistency of kinematic methods so that differences between SIS and controls would not be attributed to the kinematic motion capture methods. To be included, papers needed to meet all inclusion criteria:

1. The paper provides a clear description of the inclusion/exclusion criteria (Table 1); subjects with a shoulder surgery, dislocation, and shoulder girdle fracture or shoulder pain produced by neck motion were excluded.
2. A healthcare professional diagnosed SIS and should be confirmed by various clinical exam methods described in the paper.
3. Each chosen paper must have presented a clear detailed description of the techniques used to measure kinematics of the shoulder girdle including (Figure 1)
   a. Description of scapular motion coordinate systems
   b. Definition of the scapular motions, a minimum of one of the five kinematic variables must be presented in the paper
   c. If an Euler sequence of coordinate system rotations is used to calculate scapular rotation then the sequence of rotation must be consistent with the ISB recommendations**.**[28]
4. Scapular kinematic variables must be collected during open chain arm elevation

Nine papers met all inclusion criteria, and were included for full text review (Tables 1 and 2). The 5 papers that were excluded and the reason for the exclusion are listed in Table 3. Each of the 9 papers included in the full text review were randomly assigned to 2 authors to determine quality of the research using the quality assessment tool described below, and the average used for the final quality score. Figure 2 depicts the flow chart of the literature search and review steps, and Table 1 and 2 present the summary of the 9 included papers.

Quality Assessment

A research quality assessment tool[29] used for a meta-analysis of ankle kinematics was adapted for the shoulder. This tool was developed to assess the threats to internal, external and construct validity described by Cooke and Campbell[30] specific for kinematic studies. Questions concerning the diagnosis of SIS were added to the internal validity section, and questions about the method of motion capture and description of shoulder motions were added to the external validity section (Figure 3). Each paper was scored on the 22-point quality scale by 2 authors, the score was recorded as a percentage, and the average reported (Table 4). Some authors of this meta-analysis were authors of papers entered into the systematic review phase; no author of this meta-analysis reviewed a paper in the systematic review or the quality assessment phases that they had authored.

The quality review was conducted in order to determine the effects of study design on the studies reported outcomes. A minimum quality assessment score was not established for inclusion of the paper into the meta-analysis as there is not an established cutoff score. To determine if study quality affected the outcomes, we conducted a meta-regression with the effect size regressed on the quality score. Similar to bias assessment the five outcome variables were analyzed separately. When multiple levels of an outcome occurred within a study (e.g. multiple planes of motion) the levels were averaged to create a mean effect size for the study. Bias is more appropriately related to studies, not outcomes, and because bias can have multiple causes (e.g., study quality) that would be expected to affect all of a study's outcomes.[31]

Data Extraction

The scapular and clavicular kinematic (UR, PT, ER, ELE and RET) mean and standard deviation data were identified in each paper by 1 of the authors and entered into the meta-analysis spreadsheet; the entered data were verified for correctness by a second author. If the kinematic data could not be directly extracted from the paper, the authors were contacted and they provided the data.

Data collection methods may impact the effects of SIS on the scapular kinematic variables; therefore we created moderator variables to assess for these confounding effects. Moderator variables were population (overhead workers, athletes or general population), level of arm elevation (below 90°, above 90°), and plane of arm motion (frontal, scapular or sagittal). Outcomes were categorized by moderator variables after thorough evaluation of the methods section of each paper (Table 5).

Statistical Methods

Statistical analysis was performed using Comprehensive Meta-Analysis (version 2.2.034; BioStat International, Inc, Tampa, FL). Intraclass correlation coefficients [ICC(3,1)] were calculated to determine the inter-rater reliability of the quality assessment scores. Data were entered as means and standard deviations of angular measures in degrees for all studies (n=9) for the five scapular rotation and position variables, except for a single study[11] where the scapular position variables were entered in centimeters. For each variable we coded the effect as positive or negative, where a positive effect was coded as the scapular rotations or positions theorized to increase risk of SIS[21, 32] of less PT, less UR, less ER, greater ELE, and less RET as compared to controls.

To analyze the overall differences for each of the 5 scapular variables between SIS and control subjects, we used the Z statistic to test whether individual and standard difference of the means (SDM) was different from zero.[33] To determine if the fixed or random effects model should be used to assess differences, we first assessed heterogeneity of the effects sizes among the studies using the Q statistic. A significant Q statistic, which approximates the χ^2 statistic for meta-analysis, indicates that the between study variance was greater than chance. If the Q value was significant ($P<0.05$), we computed the Z statistic using the random-effects model, if $P>0.05$ the fixed-effects model was used**.**[34] The standardized residual was used to identify outcomes that were outliers. Studies with residuals greater than or equal to 3.0 would be deleted from the analysis.[34, 35]

To analyze the effects of the moderator variables, we performed analyses using the grouping variables of arm angle, plane of arm elevation, and population. For arm angle, we collapsed the angles into two categories; arm angles from rest to 80° were classified as low angles, and data collected at arm angles from 90° to maximum were high arm angles. Arm angles were collapsed because the large number of arm angles studied (n=11), the low number of outcomes (1–3) for most individual arm angles. To compare between grouping variables, we used a mixed effects analyses, using the Q statistic to determine if there were differences between the grouping variable.

To assess for bias, each of the five kinematic variables were analyzed separately. When multiple levels of an outcome occurred within a study (e.g. multiple planes of motion) the levels were averaged to create a mean effect size for the study. Bias is more appropriately related to studies and not outcomes, and bias can have multiple causes (e.g., study quality)[31] that would be expected to affect all of a study's outcomes. Mean effects sizes were analyzed using the Egger regression intercept method[36] and the Duvall and Tweedie[37] trim-and-fill procedure.

EVIDENCE SYNTHESIS

Quality assessment

Results of the quality review assessment are reported in Table 4. The quality assessment scores from two reviewers had excellent reliability [ICC(3,1)=0.91;95%CI:0.44-0.96]. The mean quality score was 70.8% ±14.0%, range 42.9–90.0%. Study quality was not found to be related to effect size for any of the outcome variables: PT(slope=0.02,P=0.07); UR(slope=0.006, P=0.39); ER(slope=0.001,P=0.91); ELE(slope=-0.02,P=0.31); and RET(slope=-0.006,P=0.79).

Bias results

There was no bias detected for PT (intercept=1.3,P=0.75), ER (intercept=1.94,P=0.53), or ELE (intercept=1.25,P=0.80). The trim and fill confirmed these results with no studies trimmed for these outcomes. Bias was detected for UR (intercept=4.4,P=0.06) and RET (intercept=0.57, P=0.01). For UR the trim and fill procedure trimmed three studies and yielded a corrected effect size of 0.007. For RET two studies were trimmed yielding a corrected effect size of -0.27, suggesting the bias was minimal.

Meta-Analysis

Study participant characteristics, inclusion and exclusion criteria are reported in Table 1 and 2. There was inconsistency in participant characteristics with respect to population; therefore study populations were categorized as athletes, overhead workers, or a general population according to the authors' description.

Main Effects - Overall

Testing for heterogeneity of the outcomes was significant for PT ($P \leq 0.001$), UR ($P \leq 0.001$), ER ($P \leq 0.001$), and ELE ($P=0.006$). Meanwhile, the test for heterogeneity of the RET was not significant ($P<0.05$). Using a fixed-effects model, there was significantly greater RET ($z=-4.09$, $ES=0.26$, $P \leq 0.001$). Using the random-effects model, there were no significant difference between SIS and controls for PT ($z=1.38$, $P=0.17$). The random-effects model revealed significantly less scapular UR ($z=3.08$, $ES=0.26$, $P=0.002$) and less ER ($z=2.33$, $ES=0.21$, $P=0.020$), and significantly greater ELE ($z=3.93$, $ES=0.31$, $P \leq 0.001$) in subjects with SIS as compared to controls. The Forrest plots are presented in figures 4-8.

Moderator Variables Effects

Plane of Elevation

Comparing across planes of arm elevation, there were significant differences in PT ($P=0.002$), UR ($P<0.001$), and ER ($P=0.003$); but no differences in RET ($P=0.473$) and ELE ($P=0.683$). In the frontal plane there was significantly greater PT ($z=3.04$, $P=0.002$) and greater ER ($z=-2.11$, $P=0.035$) in patients with SIS than controls. There were no differences between groups in the frontal plane in UR ($P=0.623$). There were no outcomes for the frontal plane for ELE or RET. In the scapular plane, there was significantly less UR ($z=4.12$, $ES=0.47$, $P \leq 0.001$) and ER ($z=2.68$, $ES=0.39$, $P=0.007$) and greater ELE ($z=2.65$, $ES=0.29$, $P=0.008$) and RET ($z=-3.08$, $ES=-0.28$, $P=0.002$) in patients with SIS as compared to controls. There were no differences in PT ($P=0.076$) between patients with SIS and controls in scapular plane elevation. In the sagittal plane there was significantly greater ELE ($z=3.44$, $ES=0.35$, $P \leq 0.001$) and RET ($z=-1.96$, $ES=0.19$, $P=0.050$), but no differences PT ($P=0.726$), UR ($P=0.264$), or ER ($P=0.429$) in the sagittal plane.

Angle of arm elevation

There were significant differences between high and low arm angles for UR (P=0.013) ELE (P=0.020), but no significant differences between high and low arm angles for PT (P=0.728), ER (P=0.982) and RET (P=0.296). At the low arm angles, there was significantly less UR (z=3.36, ES=-0.50, P=0.001) in the patients with SIS versus controls. There were no differences between groups in PT (P=0.352), ER (P=0.126), ELE (P=0.211) and RET (P=0.152) at the low arm angles. At high arm angles there was significantly greater ELE (z=4.03,ES=-0,40,P≤ 0.001) and RET (z=-3.853,ES=-0.36, P≤0.001) for the patients with SIS as compared to controls, no differences in PT (P=0.249), ER (p=0.088) and UR (p=0.471).

Population

There were significant differences between populations for PT (P≤0.001), UR (P≤0.001) and ER (P=0.002). There were no differences between populations for ELE (P=0.189) and RET (P=0.658). Within the general population, patients with SIS versus controls displayed greater ELE (z= 3.83,P≤ 0.001) and RET (z=-4.06,P≤0.001), there were no significant differences in PT (P=0.866), UR (P=0.554) and ER (P=0.957) for the general population. Athletes with SIS displayed greater PT (z=-3.37,ES=-0.66, P=0.001) and less UR (z=3.99,ES=0.70,P≤0.001) compared to controls, but there were no significant differences in scapular ER (P=0.351), ELE (P=0.693) and RET (P=0.562) for athletes. Overhead workers with SIS displayed less PT (z=3.51, ES=0.83,P≤ 0.001), UR (z=3.36,ES=0.64,P=0.001) and ER (z=3.59,ES=1.05,P≤0.001) versus control subjects.

DISCUSSION

The purpose of this meta-analysis was to identify consistent differences in scapular kinematics in patients with SIS. These differences in scapular motion might lead to the development of SIS or represent adaptations in scapular motion due to the SIS. When the data from prior studies[4, 6, 8, 10-12, 14, 16, 24] was collapsed using meta-analysis, patients with SIS displayed a consistent pattern of less UR, less ER, greater ELE and greater RET as compared to healthy controls. These results concurred with our hypotheses of less scapular UR and ER, and greater ELE in SIS, but conflicted with our hypotheses of less RET and less PT. Abnormal scapular and clavicular kinematics are commonly cited biomechanical extrinsic mechanisms associated with a reduction of the subacromial space and compression of the rotator cuff tendon.[21, 32, 38] Specifically, decreased scapular UR, PT and ER are theorized to reduce subacromial space and thus contribute to SIS etiology. Clavicular protraction (less retraction) is theorized to accompany scapular internal rotation, while ELE is theorized to accompany scapular anterior tilt. Thus, less RET and greater ELE may diminish subacromial space and contribute to the impingement. Our meta-analysis results (Table 6) indicate the majority of scapular kinematic differences between patients with SIS and controls are those theoretically related to a decrease in subacromial space and SIS. The meta-analysis also explored the influence of data collection methods, revealing that the plane of arm elevation, the angle of arm elevation and the type of activity of the population studied have an effect on the scapular kinematic differences between subjects with SIS and controls.

Plane of Arm Elevation

Sub-analyses indicated an effect of plane of arm elevation on 3D kinematics. During frontal plane elevation SIS patients showed greater PT and ER. During scapular plane elevation, SIS patients showed less UR and ER and increased ELE and RET than controls. The same pattern was seen in the sagittal plane of increased ELE and RET in SIS patients. The results between planes of elevation for ER are conflicting, with decreased ER in the scapular plane and increased ER in the frontal plane. This is may in part due to the posterior shoulder tightness associated with SIS, because with the arm in a more anterior position the tight posterior soft tissue would pull the scapula into a more internally rotated position. In the scapular and sagittal plane, there was an increase in ELE and RET, with small to medium effects sizes in both planes.

Three studies examined scapular kinematics in more than one plane of motion, McClure et.,al.[12] explored arm motion in the sagittal and scapular planes, while Hebert et.,al.[9] and Roy et.,al[14] looked at arm motions in the sagittal and frontal planes. The greatest differences between those with SIS and controls are seen in scapular plane arm elevation, possibly due to the decrease constraints to scapular motion. The difference in kinematics seen between planes of motion might be an adaptation in scapular motion in order to reduce pain during arm elevation or due to more pronounced pain in one plane versus another.

Angle of Arm Elevation

Although there is limited evidence to support the impact that scapular and clavicle alterations have on subacromial space, the results of this meta-analysis suggest those with SIS are likely to display less scapular UR. Furthermore, less scapular UR appears to be a factor that is present at lower angles of arm elevation (below 90°) and in the scapular plane. In vivo biomechanical data[39] suggests that humeral elevation up to 90° but not beyond are positions where the rotator cuff tendons lie directly beneath the anterior acromion and, therefore, are susceptible to extrinsic impingement. After 90° of humeral elevation the rotator cuff tendons move medially and posterior and are no longer susceptible to mechanical impingement by the acromion. Thus, further research to determine whether rehabilitation for individuals with SIS should focus on the timing and motor control of UR below shoulder height, instead of increasing scapular total motion is warranted. In contrast, results of this meta-analysis suggest greater ELE is present in SIS, particularly in higher positions of arm elevation (greater than 90°). This finding is supported in a treatment study[40] that focused on motor control and quality of motion to minimize excessive clavicular elevation at higher elevation angles is effective in the treatment of SIS.

Population

Analysis of the population moderator variable produced results that further illustrate the complexity in the mechanisms of SIS. Athletes and overhead workers with SIS showed different patterns of PT; athletes displayed increased PT and overhead workers had decreased PT. This may be due to the underlying pathology seen in athletes (throwers) from Laudner et.,al.,[16] which is driving this finding. Throwers were diagnosed with internal impingement suggesting that their primary pathology was the result of articular-sided posterior-superior rotator cuff pain, theorized to be due to a loss of glenohumeral joint mobility of the posterior shoulder. Overhead athletes diagnosed with internal impingement have demonstrated a loss of posterior shoulder flexibility.[41-45] Posterior shoulder tightness has been shown to influence scapular position during humeral rotation[41], by pulling the scapula into more PT when the humerus is internally rotating with the arm in 90 degrees of abduction. This position may also be a compensation to unload the posterior superior structures of the shoulder. Increased scapular PT would likely decrease the contact forces between the posterior superior labrum and rotator cuff. The increase in PT in throwing athletes may also be the result of repetitive effects of throwing.[42] Laudner et al[16] included only subjects with internal impingement and exclude those with subacromial impingement. Inclusion criteria from the other papers of this meta-analysis did not clearly indicate if overhead throwing athletes were included in the samples. Moreover, the studies that classified subjects as 'general' population may have included subjects that could have been classified as either overhead athletes or workers. Our results of increased PT in athletes and decreased PT in overhead workers suggest the occupation of the patient is an important consideration when assessing scapular kinematics.

Five papers identified in the literature review did not meet all inclusion criteria for the meta-analysis (Table 4). Inclusion of these five papers may have affected the results of this meta-analysis. The results of some of these papers are contrary to the results of this meta-analysis; specifically Endo et al[22] reported less UR and greater PT in patients with SIS, while Finley et al[46] and Hallstrom et al[7, 47] reported patients with SIS had greater UR at lower arm elevation angles, and the Mell et al[25] reported no effect of SIS on UR. None of the excluded papers reported clavicular kinematic outcomes. The populations studied in the excluded papers would have been classified as general population so no further information concerning the population modifier variable would have been gained by including these papers.

The limitations of this meta-analysis need to be considered. The variability of the data collection methods and reporting of outcomes required us to use the random effects model. The random effects model is used when there is not a single effect size being estimated. Rather, a family of effect sizes is being estimated. Thus, the overall effect size is the average of this family, not a single point value. Because of this we were not able to calculate the mean differences in the kinematic variables associated with SIS. The small number of studies at specific arm elevation angles did not allow for further arm angle analysis. We addressed this limitation by collapsing outcomes as high and low arm elevation angles. There was also several different motion capture techniques used to measure the kinematic outcomes. Without information on how the different motion capture techniques compare it is difficult to control for this limitation. Studies included in this meta-analysis needed to state the motion description and coordinate systems used so that we could assure the collapse of similar data. Many of the studies did not state the duration or the intensity of the subject's pain, thus making it difficult to determine if pain affected the kinematics. Pain may explain the magnitude of the scapular kinematic alterations or be related to a specific kinematic alteration found in patient with SIS. Finally, the different patterns of scapular motion found in the overhead workers and the athletic population may be due to the specific diagnosis of internal impingement. Rotator cuff disease is a complex condition with multi-factorial etiology. These causative factors may present singularly and in combination in any given patient with the diagnosis of SIS, thus potentially leading to a variety of altered scapular motion patterns and compensations during arm elevation. This meta-analysis was performed to identify consistencies in scapula kinematics in subjects with SIS. This meta-analysis collapsed the data from case-control studies, and these results can aid in the development of future mechanistic studies of the role of scapular kinematics in SIS, and in clinical studies aimed at changing the altered scapular kinematic patterns in SIS.

CONCLUSION

Overall, a pattern of decreased scapular UR and ER, increased ELE and RET was found in subjects with SIS, but no alterations in scapular PT. This is in contrast to our hypothesis, which is likely related to the non-homogenous population of SIS subjects within the studies. The general population showed only greater ELE and RET, while athletes displayed greater PT and less UR, and overhead workers showed less PT, UR and ER versus control subjects. Analysis of the moderator variable of arm elevation angle revealed less UR at low (below degrees) arm angle. Because UR is hypothesized to decrease subacromial space, a focus on scapular control at low arm angles may be advantageous. The plane of humeral elevation affects scapular kinematics, and the greatest differences of less UR and ER along with greater ELE and RET were seen during scapula plane arm elevation. Therapeutic exercise programs designed to improve scapular control might be more effective if exercises are performed in the plane of the scapula. Further investigation of scapular kinematics within subgroups of SIS, controlling for arm angle and elevation angle is warranted.

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Figure 1. Description of scapular and clavicular motions, A) scapular posterior tilt, B) scapular upward rotation, C) scapular external rotation, D) clavicular elevation and E) clavicular retraction. Reprinted with permission from, McClure, et.,al,. 2006, "Shoulder function and 3-dimensional scapular kinematics in people with and without shoulder impingement syndrome", *Phys.Ther.*, vol. 86, no. 8, pp. 1075-1090. (Permission granted from Physical Therapy March 15, 2011)

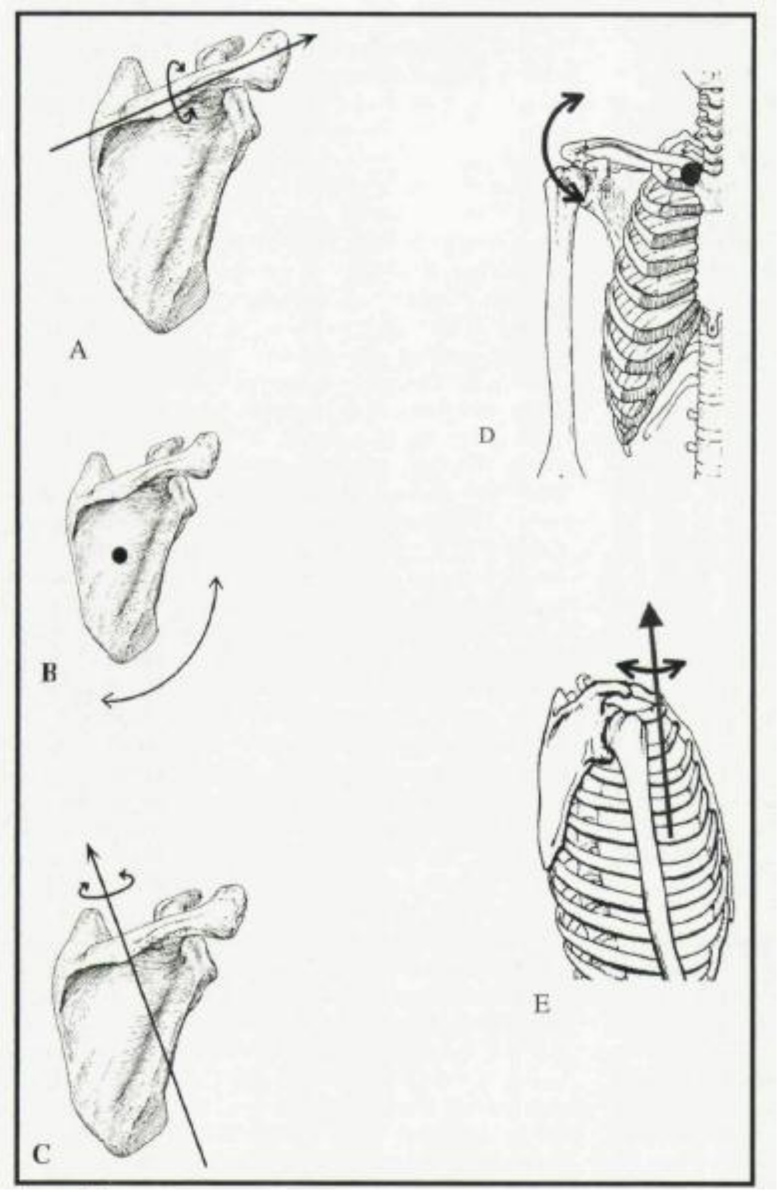


Figure 2. Summary of the literature search and review of methods sections.

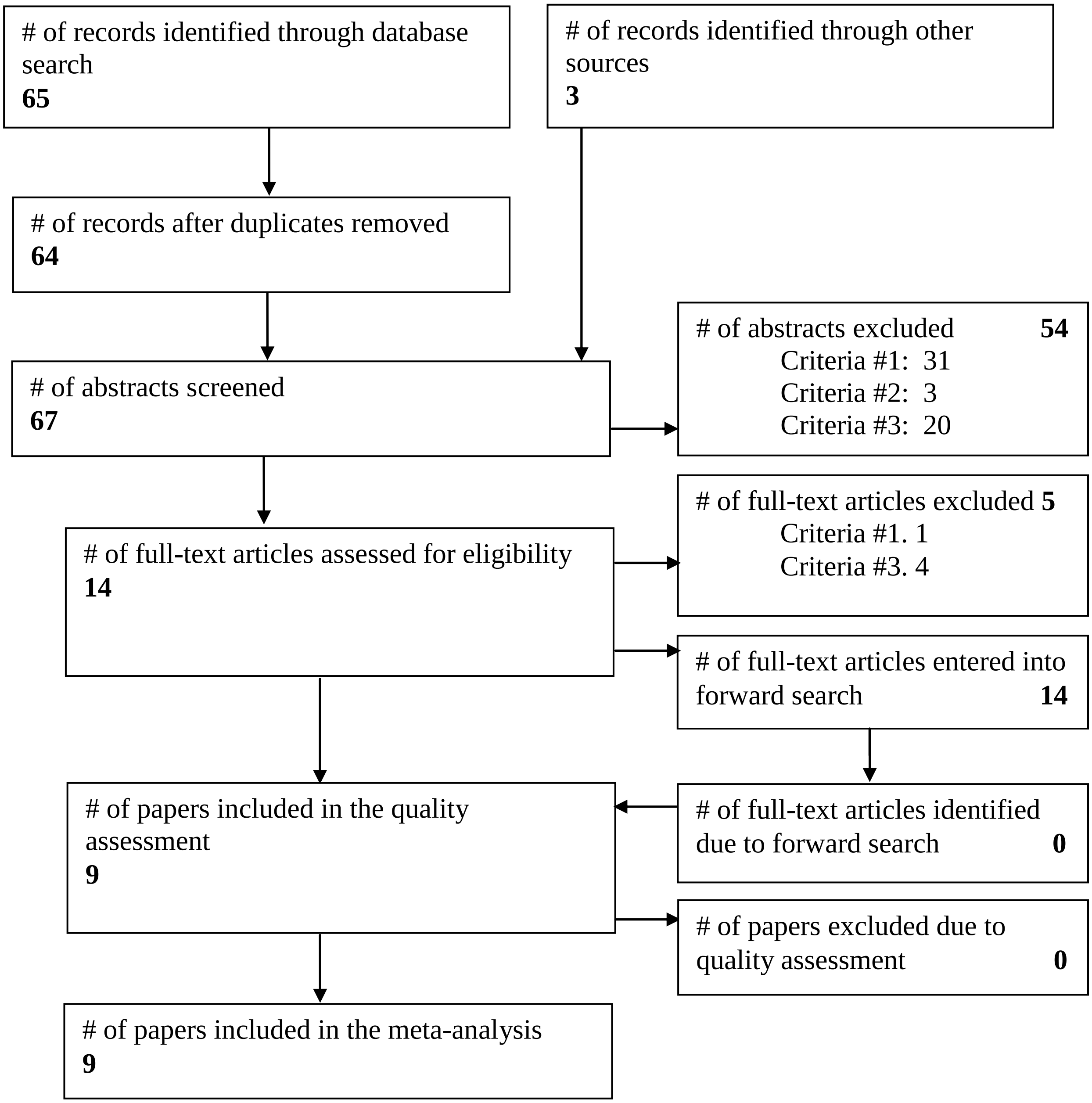
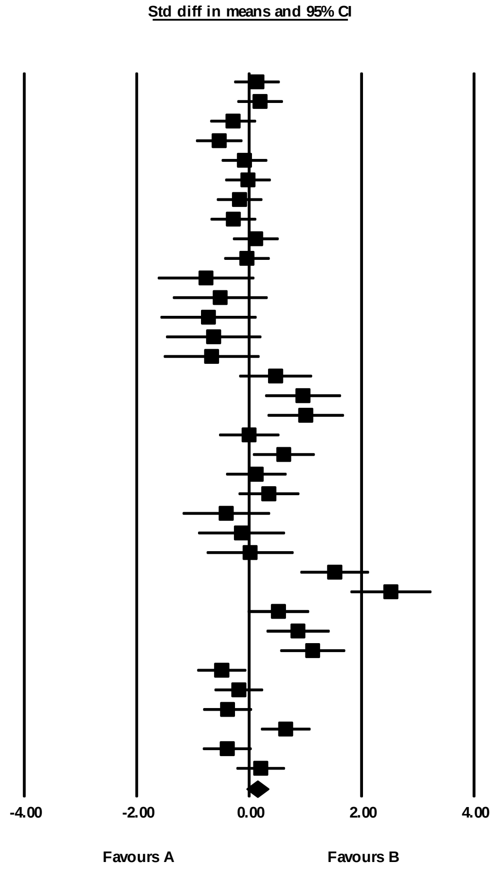


Figure 3. Scapular Posterior Tilt (PT) Forrest Plot, overall. Favors A, SIS patients showed greater PT than controls; Favors B, controls had greater PT than SIS patients.

Meta Analysis

Study name	Outcome	Statistics for each study						
		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
McClure	Scapular Tilt, 0 sagittal elevation	0.139	0.211	0.045	-0.275	0.553	0.659	0.510
McClure	Scapular Tilt, 0 scapular elevation	0.195	0.211	0.045	-0.219	0.609	0.921	0.357
McClure	Scapular Tilt, 120 sagittal elevation	-0.286	0.212	0.045	-0.701	0.130	-1.348	0.178
McClure	Scapular Tilt, 120 scapular elevation	-0.532	0.215	0.046	-0.952	-0.111	-2.478	0.013
McClure	Scapular Tilt, 60 sagittal elevation	-0.083	0.211	0.044	-0.497	0.330	-0.395	0.693
McClure	Scapular Tilt, 60 scapular elevation	-0.020	0.211	0.044	-0.433	0.393	-0.095	0.924
McClure	Scapular Tilt, 90 sagittal elevation	-0.170	0.211	0.045	-0.584	0.244	-0.804	0.421
McClure	Scapular Tilt, 90 scapular elevation	-0.280	0.212	0.045	-0.695	0.135	-1.321	0.186
McClure	Scapular Tilt, max sagittal elevation	0.118	0.211	0.045	-0.295	0.532	0.560	0.575
McClure	Scapular Tilt, max scapular elevation	-0.040	0.211	0.044	-0.453	0.374	-0.188	0.851
Laudner	Scapular Tilt, 0 scapular elevation	-0.766	0.442	0.195	-1.632	0.099	-1.735	0.083
Laudner	Scapular Tilt, 120 scapular elevation	-0.514	0.433	0.188	-1.363	0.335	-1.186	0.236
Laudner	Scapular Tilt, 30 scapular elevation	-0.723	0.440	0.194	-1.585	0.140	-1.642	0.101
Laudner	Scapular Tilt, 60 scapular elevation	-0.631	0.437	0.191	-1.487	0.225	-1.445	0.149
Laudner	Scapular Tilt, 90 scapular elevation	-0.667	0.438	0.192	-1.526	0.192	-1.523	0.128
Lukasiewicz	Scapular Tilt, 0 scapular elevation	0.472	0.334	0.112	-0.183	1.128	1.412	0.158
Lukasiewicz	Scapular Tilt, 90 scapular elevation	0.959	0.348	0.121	0.276	1.641	2.753	0.006
Lukasiewicz	Scapular Tilt, max scapular elevation	1.007	0.350	0.123	0.321	1.693	2.878	0.004
Ludewig	Scapular Tilt, 0 scapular elevation	0.000	0.277	0.077	-0.544	0.544	0.000	1.000
Ludewig	Scapular Tilt, 120 scapular elevation	0.617	0.284	0.081	0.061	1.173	2.174	0.030
Ludewig	Scapular Tilt, 60 scapular elevation	0.128	0.278	0.077	-0.416	0.672	0.460	0.646
Ludewig	Scapular Tilt, 90 scapular elevation	0.351	0.279	0.078	-0.197	0.899	1.256	0.209
Roy	Scapular Tilt, 0 scapular elevation	-0.406	0.401	0.160	-1.191	0.379	-1.013	0.311
Roy	Scapular Tilt, 70 sagittal elevation	-0.137	0.398	0.159	-0.917	0.644	-0.343	0.731
Roy	Scapular Tilt, 90 frontal elevation	0.018	0.398	0.158	-0.762	0.798	0.045	0.964
Borstad	Scapular Tilt, 100 scapular elevation	1.522	0.315	0.099	0.904	2.139	4.832	0.000
Borstad	Scapular Tilt, 120 scapular elevation	2.522	0.372	0.138	1.793	3.250	6.787	0.000
Borstad	Scapular Tilt, 40 scapular elevation	0.522	0.282	0.080	-0.031	1.075	1.850	0.064
Borstad	Scapular Tilt, 60 scapular elevation	0.870	0.290	0.084	0.301	1.438	2.997	0.003
Borstad	Scapular Tilt, 80 scapular elevation	1.130	0.299	0.089	0.545	1.716	3.785	0.000
Hébert	Scapular Tilt, 110 frontal elevation	-0.487	0.227	0.052	-0.932	-0.042	-2.147	0.032
Hébert	Scapular Tilt, 110 sagittal elevation	-0.182	0.224	0.050	-0.622	0.257	-0.814	0.416
Hébert	Scapular Tilt, 70 frontal elevation	-0.383	0.226	0.051	-0.826	0.059	-1.698	0.089
Hébert	Scapular Tilt, 70 sagittal elevation	0.651	0.230	0.053	0.201	1.101	2.836	0.005
Hébert	Scapular Tilt, 90 frontal elevation	-0.388	0.226	0.051	-0.831	0.054	-1.720	0.085
Hébert	Scapular Tilt, 90 sagittal elevation	0.207	0.224	0.050	-0.233	0.646	0.922	0.357
		0.134	0.097	0.009	-0.057	0.324	1.378	0.168

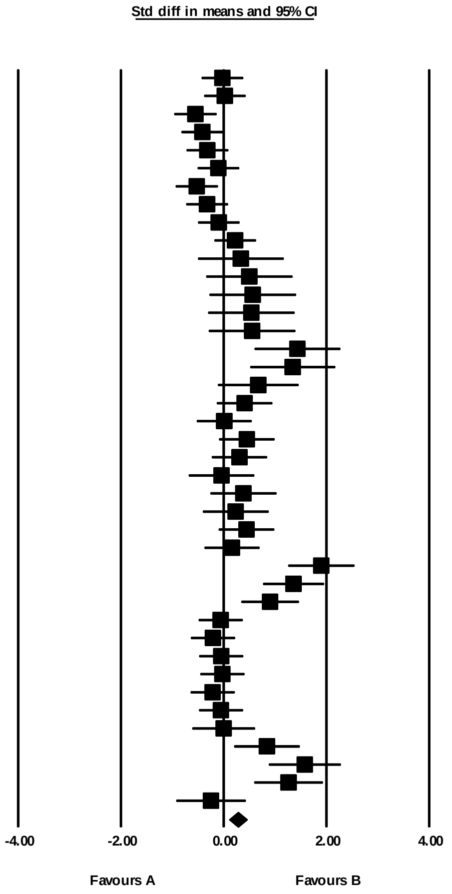


Meta Analysis

Figure 4. Scapular Upward Rotation (UR) Forrest Plot, overall. Favors A, SIS patients showed greater UR than controls; Favors B, controls had greater UR than SIS patients.

Meta Analysis

Study name	Outcome	Statistics for each study						
		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
McClure	Scapular UR, 0 sagittal elevation	-0.025	0.211	0.044	-0.438	0.389	-0.116	0.907
McClure	Scapular UR, 0 scapular elevation	0.023	0.211	0.044	-0.390	0.437	0.111	0.912
McClure	Scapular UR, 120 sagittal elevation	-0.550	0.215	0.046	-0.971	-0.129	-2.561	0.010
McClure	Scapular UR, 120 scapular elevation	-0.415	0.213	0.045	-0.833	0.002	-1.948	0.051
McClure	Scapular UR, 60 sagittal elevation	-0.317	0.212	0.045	-0.733	0.099	-1.494	0.135
McClure	Scapular UR, 60 scapular elevation	-0.103	0.211	0.045	-0.517	0.310	-0.490	0.624
McClure	Scapular UR, 90 sagittal elevation	-0.523	0.214	0.046	-0.943	-0.103	-2.438	0.015
McClure	Scapular UR, 90 scapular elevation	-0.322	0.212	0.045	-0.738	0.094	-1.518	0.129
McClure	Scapular UR, max sagittal elevation	-0.095	0.211	0.044	-0.509	0.318	-0.451	0.652
McClure	Scapular UR, max scapular elevation	0.223	0.211	0.045	-0.192	0.637	1.054	0.292
Laudner	Scapular UR, 0 scapular elevation	0.335	0.429	0.184	-0.507	1.176	0.780	0.436
Laudner	Scapular UR, 120 scapular elevation	0.500	0.433	0.187	-0.349	1.349	1.154	0.248
Laudner	Scapular UR, 30 scapular elevation	0.565	0.435	0.189	-0.287	1.418	1.300	0.194
Laudner	Scapular UR, 60 scapular elevation	0.540	0.434	0.188	-0.311	1.391	1.244	0.213
Laudner	Scapular UR, 90 scapular elevation	0.554	0.435	0.189	-0.298	1.406	1.275	0.202
Roy	Scapular UR, 0 scapular elevation	1.437	0.431	0.186	0.593	2.281	3.337	0.001
Roy	Scapular UR, 70 sagittal elevation	1.344	0.427	0.182	0.508	2.181	3.150	0.002
Roy	Scapular UR, 90 frontal elevation	0.674	0.405	0.164	-0.120	1.469	1.663	0.096
Ludewig	Scapular UR, 0 scapular elevation	0.407	0.280	0.079	-0.142	0.956	1.453	0.146
Ludewig	Scapular UR, 120 scapular elevation	0.011	0.277	0.077	-0.533	0.555	0.040	0.968
Ludewig	Scapular UR, 60 scapular elevation	0.451	0.281	0.079	-0.100	1.001	1.604	0.109
Ludewig	Scapular UR, 90 scapular elevation	0.308	0.279	0.078	-0.239	0.854	1.103	0.270
Lukasiewicz	Scapular UR, 0 scapular elevation	-0.042	0.330	0.109	-0.688	0.605	-0.126	0.900
Lukasiewicz	Scapular UR, 90 scapular elevation	0.385	0.333	0.111	-0.268	1.037	1.156	0.248
Lukasiewicz	Scapular UR, max scapular elevation	0.235	0.331	0.110	-0.414	0.883	0.709	0.478
Borstad	Scapular UR, 100 scapular elevation	0.444	0.281	0.079	-0.106	0.995	1.583	0.113
Borstad	Scapular UR, 120 scapular elevation	0.161	0.278	0.077	-0.383	0.706	0.581	0.562
Borstad	Scapular UR, 40 scapular elevation	1.900	0.334	0.112	1.245	2.555	5.687	0.000
Borstad	Scapular UR, 60 scapular elevation	1.360	0.308	0.095	0.757	1.963	4.419	0.000
Borstad	Scapular UR, 80 scapular elevation	0.903	0.291	0.085	0.333	1.474	3.102	0.002
Hébert	Scapular UR, 110 frontal elevation	-0.058	0.224	0.050	-0.496	0.381	-0.257	0.797
Hébert	Scapular UR, 110 sagittal elevation	-0.208	0.224	0.050	-0.648	0.232	-0.927	0.354
Hébert	Scapular UR, 70 frontal elevation	-0.048	0.224	0.050	-0.486	0.391	-0.213	0.832
Hébert	Scapular UR, 70 sagittal elevation	-0.025	0.224	0.050	-0.463	0.414	-0.111	0.912
Hébert	Scapular UR, 90 frontal elevation	-0.216	0.224	0.050	-0.655	0.224	-0.962	0.336
Hébert	Scapular UR, 90 sagittal elevation	-0.052	0.224	0.050	-0.491	0.386	-0.233	0.816
Su	Scapular UR, 0 scapular elevation	0.000	0.316	0.100	-0.620	0.620	0.000	1.000
Su	Scapular UR, 135 scapular elevation	0.842	0.330	0.109	0.195	1.489	2.552	0.011
Su	Scapular UR, 45 scapular elevation	1.579	0.362	0.131	0.869	2.289	4.360	0.000
Su	Scapular UR, 90 scapular elevation	1.263	0.346	0.120	0.584	1.942	3.647	0.000
Graichen	Scapular UR, 90 frontal elevation	-0.246	0.350	0.122	-0.932	0.439	-0.705	0.481
		0.264	0.086	0.007	0.096	0.432	3.083	0.002

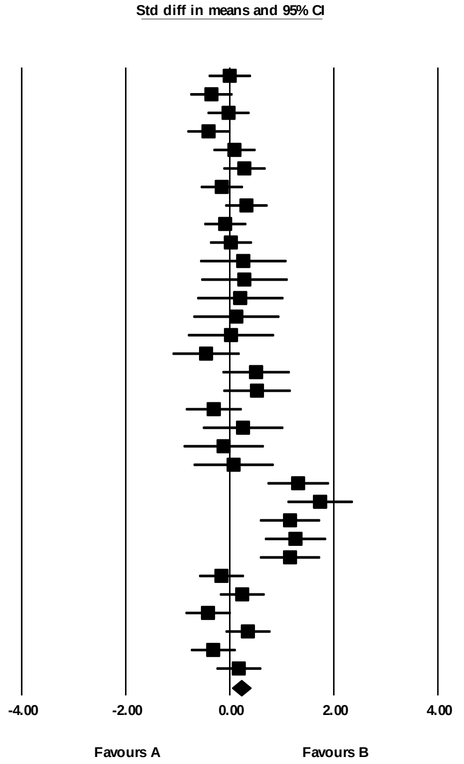


Meta Analysis

Figure 5. Scapular External Rotation (ER) Forrest Plot, overall. Favors A, SIS patients showed greater ER than controls; Favors B, controls had greater ER than SIS patients.

Meta Analysis

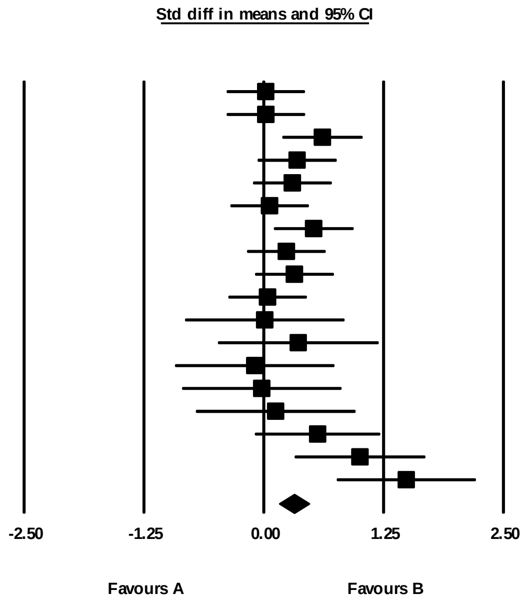
Study name	Outcome	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
		Statistics for each study						
McClure	Scapular ER, 0 sagittal elevation	0.000	0.211	0.044	-0.413	0.413	0.000	1.000
McClure	Scapular ER, 0 scapular elevation	-0.353	0.212	0.045	-0.769	0.063	-1.661	0.097
McClure	Scapular ER, 120 sagittal elevation	-0.023	0.211	0.044	-0.436	0.390	-0.108	0.914
McClure	Scapular ER, 120 scapular elevation	-0.407	0.213	0.045	-0.824	0.011	-1.909	0.056
McClure	Scapular ER, 60 sagittal elevation	0.091	0.211	0.044	-0.323	0.504	0.431	0.666
McClure	Scapular ER, 60 scapular elevation	0.281	0.212	0.045	-0.134	0.697	1.329	0.184
McClure	Scapular ER, 90 sagittal elevation	-0.152	0.211	0.045	-0.565	0.262	-0.719	0.472
McClure	Scapular ER, 90 scapular elevation	0.320	0.212	0.045	-0.096	0.736	1.508	0.132
McClure	Scapular ER, max sagittal elevation	-0.087	0.211	0.044	-0.500	0.327	-0.410	0.682
McClure	Scapular ER, max scapular elevation	0.023	0.211	0.044	-0.390	0.436	0.108	0.914
Laudner	Scapular ER, 0 scapular elevation	0.260	0.428	0.183	-0.579	1.100	0.608	0.543
Laudner	Scapular ER, 120 scapular elevation	0.281	0.428	0.184	-0.559	1.121	0.656	0.512
Laudner	Scapular ER, 30 scapular elevation	0.201	0.427	0.183	-0.637	1.039	0.471	0.638
Laudner	Scapular ER, 60 scapular elevation	0.127	0.427	0.182	-0.710	0.963	0.297	0.767
Laudner	Scapular ER, 90 scapular elevation	0.024	0.426	0.182	-0.812	0.860	0.057	0.955
Lukasiewicz	Scapular ER, 0 scapular elevation	-0.454	0.334	0.112	-1.109	0.200	-1.360	0.174
Lukasiewicz	Scapular ER, 90 scapular elevation	0.506	0.335	0.112	-0.151	1.163	1.510	0.131
Lukasiewicz	Scapular ER, max scapular elevation	0.524	0.335	0.113	-0.134	1.181	1.562	0.118
Ludewig	Scapular ER, 0 scapular elevation	-0.307	0.279	0.078	-0.854	0.240	-1.101	0.271
Roy	Scapular ER, 0 scapular elevation	0.256	0.399	0.159	-0.526	1.038	0.642	0.521
Roy	Scapular ER, 70 sagittal elevation	-0.118	0.398	0.159	-0.898	0.663	-0.296	0.767
Roy	Scapular ER, 90 frontal elevation	0.075	0.398	0.158	-0.705	0.855	0.188	0.851
Borstad	Scapular ER, 100 scapular elevation	1.316	0.306	0.094	0.716	1.915	4.301	0.000
Borstad	Scapular ER, 120 scapular elevation	1.737	0.325	0.106	1.099	2.375	5.336	0.000
Borstad	Scapular ER, 40 scapular elevation	1.158	0.300	0.090	0.571	1.745	3.864	0.000
Borstad	Scapular ER, 60 scapular elevation	1.263	0.304	0.092	0.668	1.859	4.159	0.000
Borstad	Scapular ER, 80 scapular elevation	1.158	0.300	0.090	0.571	1.745	3.864	0.000
Hébert	Scapular ER, 110 frontal elevation	-0.159	0.224	0.050	-0.598	0.280	-0.710	0.478
Hébert	Scapular ER, 110 sagittal elevation	0.239	0.224	0.050	-0.201	0.679	1.066	0.286
Hébert	Scapular ER, 70 frontal elevation	-0.417	0.226	0.051	-0.860	0.027	-1.842	0.065
Hébert	Scapular ER, 70 sagittal elevation	0.350	0.225	0.051	-0.092	0.792	1.552	0.121
Hébert	Scapular ER, 90 frontal elevation	-0.317	0.225	0.051	-0.758	0.124	-1.408	0.159
Hébert	Scapular ER, 90 sagittal elevation	0.175	0.224	0.050	-0.264	0.614	0.781	0.435
		0.208	0.089	0.008	0.033	0.382	2.327	0.020



Meta Analysis

Figure 6. Clavicular Elevation (CE) Forest Plot, overall. Favors A, SIS patients showed less CE than controls; Favors B, controls had less CE than SIS patients.

Study name	Outcome	Statistics for each study						
		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
McClure	Clavicular elevation, 0 sagittal elevation	0.022	0.211	0.044	-0.392	0.435	0.103	0.918
McClure	Clavicular elevation, 0 scapular elevation	0.023	0.211	0.044	-0.391	0.436	0.107	0.915
McClure	Clavicular elevation, 120 sagittal elevation	0.612	0.216	0.047	0.190	1.035	2.839	0.005
McClure	Clavicular elevation, 120 scapular elevation	0.348	0.212	0.045	-0.068	0.765	1.639	0.101
McClure	Clavicular elevation, 60 sagittal elevation	0.299	0.212	0.045	-0.117	0.714	1.408	0.159
McClure	Clavicular elevation, 60 scapular elevation	0.061	0.211	0.044	-0.352	0.474	0.290	0.772
McClure	Clavicular elevation, 90 sagittal elevation	0.521	0.214	0.046	0.101	0.941	2.432	0.015
McClure	Clavicular elevation, 90 scapular elevation	0.236	0.212	0.045	-0.178	0.651	1.117	0.264
McClure	Clavicular elevation, max sagittal elevation	0.320	0.212	0.045	-0.095	0.736	1.510	0.131
McClure	Clavicular elevation, max scapular elevation	0.040	0.211	0.044	-0.373	0.453	0.191	0.849
Laudner	Clavicular elevation, 0 scapular elevation	0.010	0.426	0.182	-0.825	0.846	0.025	0.980
Laudner	Clavicular elevation, 120 scapular elevation	0.360	0.430	0.185	-0.482	1.203	0.838	0.402
Laudner	Clavicular elevation, 30 scapular elevation	-0.094	0.427	0.182	-0.930	0.742	-0.220	0.826
Laudner	Clavicular elevation, 60 scapular elevation	-0.021	0.426	0.182	-0.856	0.815	-0.049	0.961
Laudner	Clavicular elevation, 90 scapular elevation	0.125	0.427	0.182	-0.712	0.961	0.293	0.770
Lukasiewicz	Clavicular elevation, 0 scapular elevation	0.563	0.336	0.113	-0.097	1.222	1.673	0.094
Lukasiewicz	Clavicular elevation, 90 scapular elevation	1.003	0.350	0.122	0.318	1.689	2.868	0.004
Lukasiewicz	Clavicular elevation, max scapular elevation	1.487	0.372	0.139	0.757	2.217	3.993	0.000
		0.308	0.078	0.006	0.155	0.461	3.933	0.000

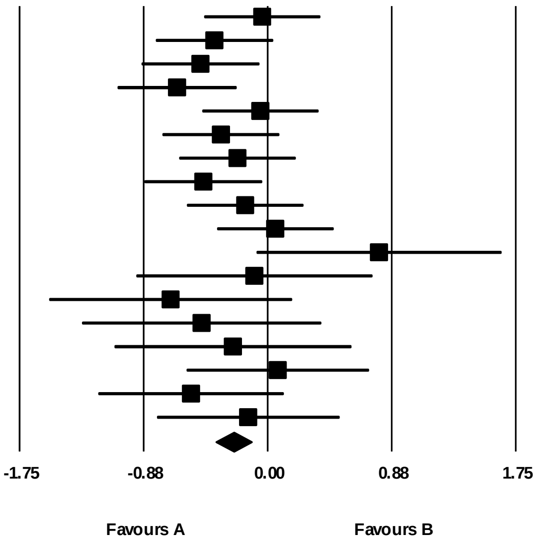


Meta Analysis

Figure 7. Clavicular Protraction (CP) Forrest Plot, overall. Favors A, SIS patients showed greater CP than controls; Favors B, controls had greater CP than SIS patients.

Study name	Outcome	Statistics for each study						
		Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
McClure	Clavicular protraction, 0 sagittal elevation	-0.038	0.211	0.044	-0.452	0.375	-0.182	0.856
McClure	Clavicular protraction, 0 scapular elevation	-0.375	0.213	0.045	-0.792	0.042	-1.764	0.078
McClure	Clavicular protraction, 120 sagittal elevation	-0.474	0.214	0.046	-0.893	-0.055	-2.217	0.027
McClure	Clavicular protraction, 120 scapular elevation	-0.638	0.216	0.047	-1.062	-0.215	-2.954	0.003
McClure	Clavicular protraction, 60 sagittal elevation	-0.051	0.211	0.044	-0.464	0.362	-0.242	0.809
McClure	Clavicular protraction, 60 scapular elevation	-0.329	0.212	0.045	-0.745	0.087	-1.552	0.121
McClure	Clavicular protraction, 90 sagittal elevation	-0.212	0.211	0.045	-0.627	0.202	-1.005	0.315
McClure	Clavicular protraction, 90 scapular elevation	-0.453	0.214	0.046	-0.872	-0.035	-2.124	0.034
McClure	Clavicular protraction, max sagittal elevation	-0.158	0.211	0.045	-0.572	0.256	-0.748	0.454
McClure	Clavicular protraction, max scapular elevation	0.054	0.211	0.044	-0.360	0.467	0.254	0.799
Laudner	Clavicular protraction, 0 scapular elevation	0.786	0.443	0.196	-0.081	1.653	1.776	0.076
Laudner	Clavicular protraction, 120 scapular elevation	-0.094	0.427	0.182	-0.930	0.742	-0.220	0.826
Laudner	Clavicular protraction, 30 scapular elevation	-0.684	0.439	0.192	-1.544	0.175	-1.560	0.119
Laudner	Clavicular protraction, 60 scapular elevation	-0.466	0.432	0.187	-1.313	0.381	-1.078	0.281
Laudner	Clavicular protraction, 90 scapular elevation	-0.245	0.428	0.183	-1.083	0.594	-0.571	0.568
Lukasiewicz	Clavicular protraction, 0 scapular elevation	0.071	0.330	0.109	-0.575	0.718	0.216	0.829
Lukasiewicz	Clavicular protraction, 90 scapular elevation	-0.540	0.336	0.113	-1.199	0.118	-1.609	0.108
Lukasiewicz	Clavicular protraction, max scapular elevation	-0.137	0.330	0.109	-0.784	0.511	-0.414	0.679
		-0.246	0.064	0.004	-0.370	-0.121	-3.858	0.000

Std diff in means and 95% CI



Meta Analysis

Table 1. List and summary of methods of papers identified through the literature search and meeting all inclusion criteria

Paper	Subjects	Inclusion and Exclusion Criteria	Motion Capture	Outcome Variables
Lukasiewicz 1999	20 controls 37 SAIS	**Inclusion Impingement**: 3 of 6 positive; Neer test, Hawkins test, Pain with active elevation, rotator cuff tendon pain on palpation, pain in C5-6 dermatome, pain with resisted external rotation **Exclusion Impingement:** Current cervical pain, positive signs of instability, acromial clavicular pain	3D electromagnetic	Static position and orientation of the scapula at 0°, 90° and maximal arm abduction in the plane of the scapula.
Ludewig 2000	26 controls 26 SIS	**Inclusion Impingement**: anterior lateral shoulder longer than 1 week, positive impingement sign, pain to palpation over the greater tuberosity, greater than 130° arm elevation **Exclusion Impingement:** Pain produced during cervical examination, positive thoracic outlet tests, numbness or tingling in arm or history of traumatic injury to the shoulder	3D electromagnetic	Scapular position and orientation during dynamic scapular plane elevation at 3 arm elevation angles of 60°, 90°, and 120°.
Graichen 2001	14 controls 20 pathology (14 SAIS, 6 FT-RCT)	**Inclusion Impingement:** Evidence of subacromial impingement on MRI. **Exclusion Impingement:** MRI evidence of full thickness rotator cuff tear	MRI 3D	Scapular orientation was determined at 30°, 90° and 120° of arm abduction.
Borstad 2002	26 controls 26 SIS	**Inclusion Impingement**: anterior lateral shoulder longer than 1 week, positive impingement sign, pain to palpation over the greater tuberosity, greater than 130° arm elevation **Exclusion Impingement**: Pain produced during cervical examination, positive thoracic outlet tests, numbness or tingling in arm or history of traumatic injury to the shoulder	3D electromagnetic	Scapular orientation was determined at 40°, 60°, 80°, 100° and 120° during concentric and eccentric dynamic arm elevation in the plane of the scapula.
Hebert 2002	39 control 41 SIS	**Inclusion Impingement:** at least one positive finding pain during active arm elevation, Neer test, Hawkins test, pain with resisted external rotation or arm elevation or Jobe test **Exclusion Impingement:** Rheumatoid, inflammatory, degenerative or neurologic disease, History of stroke, Previous surgery of the neck or shoulder, Neck pain or restricted motion of the neck, shoulder pain produced by neck motion, Trapezius myalgia syndrome or shoulder adhesive capsulitis	3D optical	Scapular orientation was determined during static arm positions of 70°, 90°, and 110° arm elevation in the sagittal and frontal planes.
Su 2004	20 controls 20 SIS	**Inclusion Impingement:** Shoulder pain which interfered with swimming, greater than 1 week, and 3 of the 6 following positive Neer test, Hawkins test, pain with active arm elevation, pain with palpation of the tendons of the rotator cuff, pain in C5-6 dermatome, pain with resisted isometric abduction **Exclusion Impingement:** history of cervical or thoracic pathology, less than 135° active humeral elevation, history of shoulder surgery, previous shoulder injury within 6 months, pain that prevented execution of any of the tests	2D inclinometer	Static scapular upward rotation during elevation of the arm in the plane of the scapula.
Laudner 2006	11 controls 11 SIS	**Inclusion Impingement:** Evidence of internal impingement on clinical examination and MRI **Exclusion Impingement:** history of neck pain, external impingement, glenohumeral laxity previous history of shoulder pain,	3D electromagnetic	Dynamic orientation and position of the scapula were measured during arm elevation in the plane of the scapula at 0°, 30°, 60°, 90°, 120° arm elevation.
McClure 2006	45 controls 45 SIS	**Inclusion Impingement**: 3 of 6 positive; Neer test, Hawkins test, Pain with active elevation, rotator cuff tendon pain on palpation, pain in C5-6 dermatome, pain with resisted external rotation **Exclusion Impingement:** Signs full thickness rotator cuff tear, Current cervical pain, positive signs of instability, acromial clavicular pain	3D electromagnetic	Dynamic scapular orientation and position during arm elevation in the plane of the scapula at arm angles of minimum, 30°, 60°, 90°, 120° and maximum arm elevation.
Roy 2007	15 controls 8 SIS	**Inclusion Impingement:** at least one positive, painful arc during active shoulder flexion or abduction, Neer test, or Hawkins, pain with resisted external rotation, abduction or Jobe test. **Exclusion Impingement:** bilateral impingement, shoulder instability, rheumatoid, inflammatory, degenerative or neurological disease, shoulder pain during cervical motion, shoulder capsulitis	3D optical	Scapular orientation was determined with the arm in 70° arm static elevation in the sagittal plane and 90° arm static elevation in the frontal plane.

Table 2. List and summary significant differences and conclusion of papers identified through the literature search and meeting all inclusion criteria.

Paper	Significant Differences	Conclusions
Lukasiewicz 1999	For scapular UR there no between group differences at all three test positions; for PT the SIS group had less PT at the 90° and maximal positions than the control group; and for ER there were no between group differences for all three test positions of 0°, 90°, and maximum arm elevation in the scapular plane. Scapular inferior-superior position: greater elevated position at 90° and maximum arm elevation. Scapular medial-lateral position: no between group differences for all 3 test positions.	Subjects with SIS showed less PT and greater superior scapular position in the 90° and maximum arm elevation positions in the scapular plane as compared to those without SIS.
Ludewig 2000	For scapular UR, subjects with SIS had less UR at 60° arm elevation as compared to controls, but no differences at 90° or 120° elevation were found. For scapular PT, subjects with SIS had less PT at 120° than controls, and for scapular ER subjects with SIS had less ER.	Subjects with SIS showed less scapular PT, less ER, and less UR than subjects without SIS.
Graichen 2001	No significant difference in UR, PT or ER was found between the groups. A subset of 5 subjects with SIS showed a significant increase in gleniod rotation.	Subjects with SIS showed no differences in scapular motion when compared to subjects without SIS.
Borstad 2002	Subjects with SIS had significantly less scapular UR at 40° and 60° arm elevation significant decrease in PT at 100° and 120°of arm elevation, during both eccentric and concentric phase. Subjects with SIS had significantly more scapular internal rotation at 120° arm elevation during the eccentric phase.	Small differences in scapular PT and ER between eccentric and concentric occur at arm elevation angles greater than 80° in subjects with and without SIS.
Hebert 2002	During elevation in the sagittal plane subjects with SIS had less UR and ER while having more PT than controls. During arm elevation in the frontal plane subjects with SIS had less UR, ER and PT than controls.	The contribution of rotations and scapular total ROM differed according to the plane of arm elevation in SIS group. Group analyses revealed no differences in 3D scapular attitudes between symptomatic and asymptomatic shoulders of subjects with unilateral SIS.
Su 2004	Significant differences were not found between the groups. Fatigue produced differences with healthy group having more UR at 45°, 90° and 135° arm elevation.	Scapular kinematics were affected following swimming activity.
Laudner 2006	SIS group showed increase PT and clavicular elevation No differences in UR, ER or clavicular retraction	Throwing athletes with internal impingement have more clavicular elevation and scapular PT.
McClure 2006	SIS subjects had increased UR, PT, clavicular elevation and retraction than controls.	SIS subjects had modest differences in scapular kinematics when compared to controls; these differences were greatest at the midrange of arm elevation.
Roy 2007	Subjects with SIS had more UR in all positions, more PT and ER at 70° flexion; SIS had less PT and ER at 90° abduction.	Scapular kinematics could be reliably determined in subjects with and without SIS, and subjects with SIS had alterations in 3D scapular kinematics.

Table 3. List of papers identified during the literature search but did not meet all inclusion criteria.

Paper	Reason for exclusion
Endo 2001	Scapular motions were not defined in a manner that would allow for comparisons to other papers and did not calculate scapular motion following ISB recommendations.
Finley 2005	Subjects in this investigation performed closed chain shoulder motions.
Mell 2005	The paper did not clearly state subject inclusion and exclusion criteria.
Hallstrom 2006	Did not present scapular kinematic data. Met inclusion criteria after abstract review because the abstract suggested that scapular kinematic data was presented.
Hallstrom 2009	Scapular motions were not defined in a manner that would allow for comparisons to other papers and did not calculate scapular motion following ISB recommendations.

Table 4. Results of the quality assessment of the papers meeting all criteria.

	Reviewer 1	Reviewer 2	Average
Paper			
Lukasiewicz 1999	77.3	61.9	69.6
Ludwig 2000	90.9	90.2	90.6
Graichen 2001	55.0	42.9	49.0
Borstad 2002	77.3	85.7	81.5
Hebert 2002	59.1	59.1	59.1
Su 2004	81.8	70.0	75.9
Laudner 2006	68.2	68.2	68.2
McClure 2006	86.4	81.8	84.1
Roy 2007	59.1	59.1	59.1

Table 5. Meta-analysis moderator variables classification for each paper.

Paper	Population	Arm Angle	Plane of Elevation
Lukasiewicz 1999	general	High, Low	Scapular
Ludwig 2000	overhead workers	High, Low	Scapular
Graichen 2001	general	High	Frontal
Borstad 2002	overhead workers	High, Low	Scapular
Hebert 2002	general	High, Low	Frontal, Sagittal
Su 2004	athletes	High, Low	Scapular
Laudner 2006	athletes	High, Low	Scapular
McClure 2006	general	High, Low	Sagittal, Scapular
Roy 2007	general	High, Low	Frontal, Sagittal, Scapular

Table 6. Summary of scapular and clavicular kinematic alterations results in individuals with SIS. Alterations in shoulder motion that are considered to be extrinsic mechanisms of SIS contributing to a reduction in Subacromial space are indicated double arrow.

	Main Effects	Moderator Effects							
	SIS vs.	Plane			Angle		Population		
Shoulder Motion	Controls	Frontal	Scapular	Sagittal	High	Low	Athletes	Overhead Workers	General
Scapular Upward Rotation	⇓	.	⇓	.	.	⇓	⇓	⇓	.
Scapular Posterior Tilt	.	↑	.	.	.	.	↑	⇓	.
Scapular External Rotation	⇓	↑	⇓	.	.	.	.	⇓	.
Clavicular Elevation	⇑	.	⇑	⇑	⇑	.	.	.	⇑
Clavicular Retraction	↑	.	↑	↑	↑	.	.	.	↑

SIS, shoulder impingement syndrome

Appendix 1. Quality assessment tool, adapted from Arnold et al(27) used to assess threats to Construct, external and internal validity.

Quality Assessment Tool

Construct Validity

1. Was more than one outcome measure used? (More than one kinematic variable measured, scapular upward rotation, scapular tilt, scapular lateral rotation) **0 1**
2. Were outcome measures (kinematic variables) determined simultaneously, if not were outcome measures randomly ordered or counterbalanced? **N/A 0 1**
3. Were there multiple levels of an independent variable, if so were levels of this independent variable applied in a random order or counterbalanced manner? (Multiple angles or planes of motion, static vs. dynamic) **N/A 0 1**
4. Were subjects blinded to the research hypothesis? **0 1**
5. Were data collectors blinded to groups? (Controls, impingement) **0 1**

External Validity

6. Was the setting described? (Laboratory or Clinic) **0 1**
7. Was the population defined? (From where as the sample recruited, e.g. all orthopedic patients, shoulder pain patients, athletes, occupation) **0 1**
8. Was the sample constructed using a representative sampling procedure? **0 1**
9. Was an established combination of clinical tests used or MRI findings used to define groups? **0 1**
10. Was the length of time that the subject had pain reported? **0 1**
11. Was a minimum length of time with shoulder pain required for inclusion? **0 1**
12. Was the intensity of shoulder pain reported? **0 1**
13. Were subjects with glenohumeral instability (apprehension, relocation, release, sulcus) identified and controlled? **0 1**
14. Were subjects with history cervical pain, shoulder surgery or shoulder fracture excluded? **0 1**
15. Were inclusion criteria for the controls comparison group subjects clearly defined? **0 1**

Internal Validity

16. Were the comparison and the impingement group equal relative to reported demographics (gender, side dominance, age, etc.)/ anthropometrics (height, weight, etc.)? This is no if not statistically tested. **0 1**
17. Were the calibration procedures (linear/angular accuracy) reported for the instrumentation used? **0 1**
18. Were ISB recommendations for sequence of scapular rotations and axis orientation followed? **0 1**
19. Was the measurement reliability of the experimental procedure reported for the variables of interest? (Acceptable to be referenced to another study) **0 1**
20. Was the measurement reliability of the variables of interest for the **current study** reported? **0 1**
21. Were multiple trials averaged (+1) or were single trials used for analysis? **0 1**
22. Was the plane (or planes) of arm elevation and the humeral angle at which data was compared clearly described? **0 1**