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Radiographic shoulder parameters and their relationship to outcomes following rotator cuff repair: a systematic review

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Abstract

Background: Anatomic parameters, such as the critical shoulder angle and acromion index, have emerged as methods to quantify scapular anatomy and may contribute to rotator cuff pathology. The purpose of this paper is to investigate the published literature on influences of scapular morphology on the development of re-tears and patient-reported outcomes following rotator cuff repair.

Methods: A systematic review of the Embase and PubMed databases was performed to identify published studies on the potential influence of scapular bony morphology and re-tear rates and patient-reported outcomes after rotator cuff repair. Studies were reviewed by two authors.

Results: A total of 615 unique titles and 49 potentially relevant abstracts were reviewed, with eight published manuscripts identified for inclusion. Two of three papers reported no relationship between these acromion index and rotator cuff re-tear rate, while one paper found an increased re-tear rate. All three studies on critical shoulder angle found a significant association between critical shoulder angle and cuff re-tear rate. There was no clear relationship between any bony morphologic measurement and patient-reported outcomes after rotator cuff repair.

Conclusions: Rotator cuff re-tear rate appears to be significantly associated with the critical shoulder angle and glenoid inclination, while not clearly associated with acromial morphologic measurements.

Keywords

anatomic should parameters, critical shoulder angle, acromial index, rotator cuff outcomes

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Introduction

With an aging population, rotator cuff tears are becoming increasingly more common[1] and carry significant disability and impact on activities of daily living.[2] Despite recent advancement in surgical technique and fixation methods, the outcomes following rotator cuff repair remain unpredictable.[3] It has been demonstrated that the rate of re-tear following rotator cuff repair can range from 24% to as high as 94%; however, it remains unclear how this impacts patient-reported outcomes.[4–6] Recently, there has been a push to identify risk factors that are associated with rotator cuff re-tears and inferior post-operative patient-reported outcomes.

The risk of rotator cuff re-tear has been hypothesized to be multifactorial in nature with contributors including patient age, initial tear size, muscle quality, and repair type utilized.[7–9] Intrinsic anatomic factors, such as bony morphology, have been proposed to play a role in the development of rotator cuff tears and poor outcomes following surgery. For example, varying acromial morphology leading to direct impingement on the rotator cuff was first proposed by Neer,[10] and the relationship between acromial morphology and rotator cuff tear development was further explored by

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Nicholson et al.[11] Since then, numerous authors have explored the interplay between scapular morphology and development of rotator cuff tears.[12–17]

In recent literature, anatomic parameters as measured from plain radiographs, such as the critical shoulder angle (CSA) and the acromion index (AI), have emerged as possible methods to quantify scapular anatomy that may contribute to the development of rotator cuff tears as well as poor outcomes following surgery. The CSA and AI are unique as both are quantitative measures of scapular morphology versus a subjective and descriptive measure such as acromial type.

The CSA, as first described by Moor et al.,[18] is defined as the angle between a line connecting the superior and inferior border of the glenoid and a line connecting the inferior glenoid to the most inferolateral point on the acromion as measured on a perfect anteroposterior (AP) radiograph of the shoulder (Figure 1(a)).[19] Moor et al.[18] have demonstrated that an elevated CSA is associated with the presence of a rotator cuff tear. The AI, as described by Nyffeler et al.,[20] is calculated by dividing the distance from the glenoid plane to the lateral tip of the acromion by the distance from the glenoid plane to the lateral aspect of the humeral head (Figure 1(b)). As with the CSA, an increased AI has been associated with the development of rotator cuff tears.[20] Additional methods to quantify scapular morphology include the lateral acromial angle (LAA)[21,22] and glenoid inclination (GI).[22] The LAA is measured on anterior posterior radiographs or a coronal MRI and is defined as the angle between the undersurface of the acromion and the glenoid plane. GI can be measured as the angle between the intersection of the line connecting the superior and inferior points of the glenoid and a line formed by the supraspinatus fossa.

The primary purpose of this paper is to investigate the influence of scapular bony morphology on the

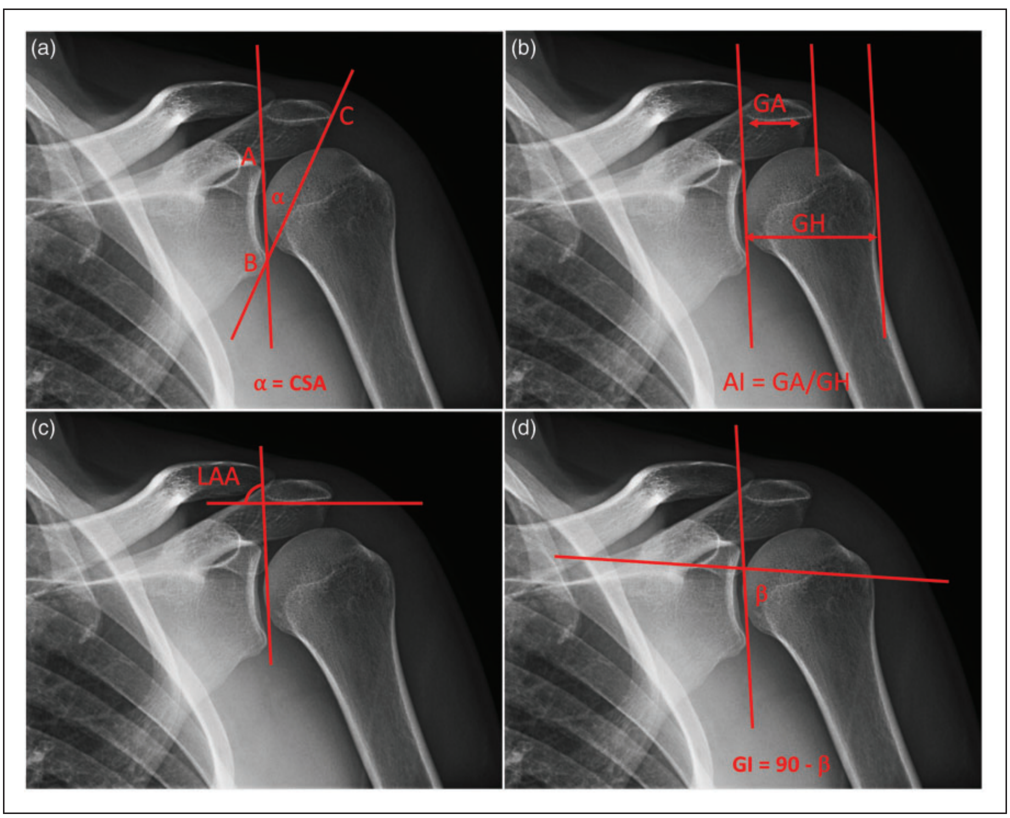

Figure 1. Shoulder radiographs demonstrating measurement of the (a) CSA, (b) AI, (c) LAA, and (d) GI. (a)—CSA: the angle (α) subtended by the line connecting the points between the inferior-lateral edge of the glenoid to the lateral tip of the acromion (B to C) and a line parallel to the glenoid (A to B) on an AP radiograph. (b)—Acromial index: the ratio of distance from the lateral glenoid plane to the lateral edge of the acromion (glenoid-acromial) and the distance from the lateral glenoid plane to the lateral border of the proximal humerus (glenoid-humeral) on an AP radiograph. (c)—LAA: the angle subtended by the line drawn along the glenoid plane and the line drawn along the undersurface of the acromion on an AP radiograph. (d)—GI: the GI is calculated by subtracting 90° from the beta angle (β) which is the angle subtended by the line drawn along the glenoid plane and a line parallel to the supraspinatus fossa. AI: acromion index; CSA: critical shoulder angle; GA: glenoid-acromial; GH: glenoid-humeral; GI: glenoid inclination; LAA: lateral acromial angle.

development of re-tears and patient-reported outcomes following rotator cuff repair. To answer this question, we conducted a systematic review of the literature addressing the relationship between acromial morphology and how this affects patient-reported outcomes and rates of rotator cuff re-tears following rotator cuff repair.

Methods

Standard systematic review protocols were used for this review.[23] Prior to conducting a search of the literature, the search criteria and objectives of the review were defined. Per the protocol, a search of the English language literature spanning 1 January 1995 to 1 January 2018 was completed. A search of the literature was conducted using Embase and PubMed with the following search terms and strategies: (''rotator cuff'' and ''acromion index'') or (''critical shoulder angle'' and ''rotator cuff'') or (''rotator cuff'' and ''inclination'') or (''rotator cuff'' and ''version'') or (''rotator cuff'' and ''scapular shape'') or (''rotator cuff'' and ''glenoid shape'') or (''rotator cuff'' and ''shoulder shape'') or (''critical shoulder'' and ''repair'') or (''acromion index'' and ''repair'') or (''inclination'' and ''repair''). This study was registered on PROSPERO prior to data abstraction.

For studies to be included in the systematic review, authors must have reported an association between radiographic measurements of the bony anatomy of the shoulder, including CSA, AI, lateral AI, or GI, and the development of rotator cuff re-tears and/or patient-reported outcomes following rotator cuff repair. Studies were excluded if they did not include measurements of bony morphology or if they did not evaluate patients after rotator cuff repair. Two reviewers (MBZ and DAL) examined each title first, and abstracts were reviewed for all titles that were selected by at least one of the reviewers. Abstracts were reviewed by both reviewers, and then the complete manuscript was reviewed for any abstract identified by at least one reviewer. All study designs including prospective and retrospective analyses were included. Specific data elements from each included paper were extracted by one reviewer (MBZ) into a data extraction spreadsheet which was reviewed and confirmed by the second reviewer (DAL).

Variables included in the data abstraction sheet included author, number of subjects, average age, AI, CSA, and patient-reported outcomes. All variables were agreed upon prior to data collection.

Results

Our literature search as outlined above resulted in a total of 468 items from PubMed and 426 items from Embase. There were a total of 615 unique results between the two databases. Thirty-six publications were excluded for not being in English. A total of 579 titles were screened by the two authors, and a total of 49 abstracts were included reviewed for study inclusion. Eight papers met our inclusion criteria and were included in the final analysis[21,22,24–29] (Figure 2). All papers were published after 2012. Seven of the eight manuscripts were retrospective cohort studies,[21,22,24,26–29] and one was a prospective cohort study.[25]

Seven of eight papers reported on AI,[21,22,24,26–29] five of eight reported on the CSA,[22,25–27,29] two of eight reported on the LAA,[21,22] and two reported on GI[22,29] (Table 1). In regards to patient-reported outcomes, five of eight reported the American Shoulder Elbow Surgeon (ASES) score,[22,24,25,27,29] six reported the visual analog scale (VAS),[21,22,25–27,29] two reported the Western Ontario Rotator Cuff (WORC) score,[25,29] two reported the University of California Los Angeles (UCLA) shoulder score,[26,27] one reported the Oxford Shoulder Score (OSS),[26] two reported the Constant Shoulder Score (CSS),[27,29] and one reported the SF12.[24] Five studies[22,24,27,28] reported on imaging-based re-tear rates after rotator cuff repair, four of which used MRI[24,27–29] and one of which used ultrasound.[22]

AI

Three studies reported on the relationship between AI and the rates of rotator cuff re-tear following arthroscopic repair. Two studies found no significant relationship between an elevated AI and the development of a re-tear.[22,28] One study found that the mean AI was increased in the re-tear group as compared to the intact group at follow-up (AI of 0.73 for the re-tear group and 0.70 in the intact group $p = 0.049$).[29]

Four studies examined the relationship between patient-reported outcomes and the AI following rotator cuff repair with conflicting results.[21,24,26,29] One of the three studies showed worse patient satisfaction scores (8.9 versus 9.5, $p = 0.055$), SF-12 (49.1 versus 55.2, $p = 0.04$) and qDASH (12.9 versus 7.4, $p = 0.042$) scores after rotator cuff repair in patients with an elevated AI.[24] The three other studies demonstrated no relationship between the AI and the UCLA shoulder score, VAS, Flex SF, ASES, or WORC score following rotator cuff repair.[21,26,29]

CSA

Three studies reported on CSA and the development of re-tears following rotator cuff repair,[22,27,29]

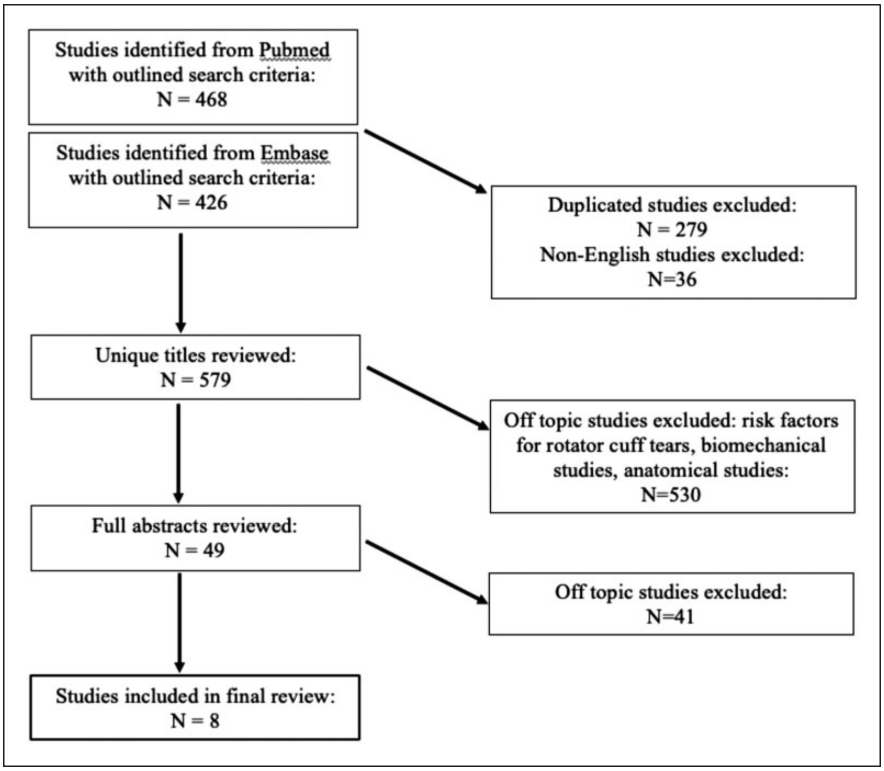

Figure 2. Flowchart of included studies.

Table 1. List of included studies and measured parameters.

Study	Design	Level of evidence	No. of patients	Avg. age	CSA	AI	LAA	GI	PROs	Cuff status
Ames et al.[24]	RCS	III	115	63	NR	+	NR	NR	+	+
Garcia et al.[22]	RCS	III	76	61.9	+	+	+	+	+	+
Kirsch et al.[25]	PCS	II	53	61	+	NR	NR	NR	+	NR
Lee et al.[26]	RCS	III	147	61	+	+	NR	NR	+	NR
Li et al.[27]	RCS	III	90	55	+	+	NR	NR	+	+
Melean et al.[28]	RCS	III	103	59.5	NR	+	NR	NR	NR	+
Scheiderer et al.[29]	RCS	III	57	54.7	+	+	NR	+	+	+
Singleton et al.[21]	RCS	III	107	63	NR	+	+	NR	+	NR

AI: acromion index; CSA: critical shoulder angle; GI: glenoid inclination; LAA: lateral acromial angle; NR: not reported, PRO: patient reported outcome; RCS: Randomized controlled study; +: measurement included in the source.

with all three finding that an elevated CSA was associated with increased rates of rotator cuff re-tear. In one study, the CSA in full-thickness re-tear was 38.6°, while the CSA in patients with no re-tear was 34.3° ($p < 0.01$).[22] In the other, an elevated CSA was associated with increased cuff signal to noise quotient (SNQ) as measured on MRI suggestive of re-tear (elevated CSA rotator cuff SNQ of 2.6 versus normal CSA rotator cuff SNQ of 1.9, $p = 0.03$).[22,27] The final study demonstrated that the mean CSA in the re-tear group was $37 \pm 4°$ as compared to $35 \pm 3°$ in the intact group ($p = 0.014$).

Five studies reported on the relationship between the CSA and patient-reported outcomes following rotator cuff repair[22,25–27,29] (Table 2). One study showed that an elevated CSA correlated to worse patient-reported outcomes following rotator cuff repair.[22] The four other studies showed no relationship between an elevated CSA and patient-reported outcome scores as measured by ASES, WORC, VAS, OSS, UCLA, and CSSs.[25–27,29]

LAA

Two studies measured the LAA.[21,22] One of the two studies found no significant difference in LAA between patients with no rotator cuff re-tear, partial re-tear, or full-thickness re-tear.[22] The other study found no difference in patient-reported outcomes as measured by the VAS or Flex SF scores following rotator cuff repair.[21]

GI

Two studies measured GI. One paper found that the average GI was significantly higher in patients who suffered a full-thickness rotator cuff re-tear compared to patients who did not suffer a re-tear (17.3° versus 12.3°, $p < 0.01$)[22]; however, the other did not find a significant difference between the groups.[29] There was no significant difference in the GI between patients with a partial tear compared to patients without a tear (14.8° versus 12.3°, $p = 0.53$).[22]

One study examined the relationship between GI and patient-reported outcomes.[29] There was no significant relationship between the degree of GI and patient-reported outcomes as measured by the ASES, WORC, VAS, or SANE scores.[29]

Discussion

The relationship between anatomic shoulder morphology and rotator cuff pathology is rapidly becoming an area of interest in modern orthopaedic surgery. While there are a number of anatomic properties that can be used to quantify shoulder morphology, the two most commonly used methods in the literature are the CSA and AI. Among the variety of anatomic measures used, bony morphology measurements were consistently associated with elevated risk of post-operative re-tear. There was no clear relationship between these bony measurements and patient-reported outcome measures.

Elevated CSA and GI measurements were associated with increased risks of post-operative re-tear. The acromial-based measurements, including the AI and the LAA, did not show a consistent effect on re-tear rates. These findings suggest that the re-tear rate may be influenced by the glenoid orientation, specifically with a superiorly tilted glenoid associated with increased re-tear risk. In a biomechanical study, Moor et al.[30] found that the superior tilt of the glenoid contributed more than lateral extent of the acromion to shear stress at the rotator cuff and superior instability at the glenohumeral joint. While the AI is independently associated with the probability of sustaining a rotator cuff tear, this measurement was not identified as a significant predictor of failure of rotator cuff repair in the majority of studies.[22,28] The GI and CSA may therefore hold the most potential for clinically relevant radiographic measurements to evaluate likelihood for repair failure.

There was no clear consensus on the influence of these bony morphologic measurements and patient-reported outcomes after rotator cuff repair. Outcomes after rotator cuff repair are dependent on multiple factors, including patient age, muscle quality, tear size, repair technique, and others.[3,31] Subjective outcomes may also improve even with a re-tear or failure of repair healing, though functional results are often inferior in the setting of a re-tear.[9] The sample sizes and study design of the included studies may not be adequate to isolate any effects from these bony morphology differences. Alternatively, patient outcomes after rotator cuff repair may be independent of these measurements. The sensitivity for radiographic measurement of complex scapular geometry may also not be high enough to precisely measure the parameters that are associated with patient outcomes after rotator cuff surgery.

Both the CSA and AI are quantitative measures that are calculated on plain radiographs.[18] They are dependent on the quality of the image that is being used for the measurements and highly susceptible to malposition on the radiograph. Suter et al.[32] demonstrated that the CSA is highly susceptible to malposition in anteversion and retroversion with deviations as small as 5° resulting in a false elevation of the CSA by 2° as compared to a measurement on a true AP view of the shoulder. Given the small difference in the CSA between controls and rotator cuff patients, an error of 2° is significant and may lead to altered results. Furthermore, the AI, just like the CSA, is intended to be measured off a true AP radiograph and is likely susceptible to variations in image acquisition; however, there are no studies that have examined this relationship. Three-dimensional shape modeling may offer an improved means of detecting the true shape differences that may impact clinical outcomes.

Moving forward, one must consider how to best integrate the data from these studies into practice. With patients with elevated CSA and increased GI at

Table 2. Summary of studies which included the critical shoulder angle.

Study	Critical shoulder angle				
Study	N	Average age	Average CSA (°)	Reported outcome measures	Key findings
Garcia et al.[22]	76	61.9 (45.3–74.9)	All patients: 34.9 ± 3.3 No re-tear: 34.3 ± 2.9 Partial re-tear: 35.6 ± 3.2 Full re-tear: 38.6 ± 3.5 No re-tear versus full $p < 0.01$ Partial re-tear versus full $p < 0.05$	Increasing CSA inversely correlated to post-operative ASES scores ($p < 0.03$)	At short term follow-up, a higher critical shoulder angle was associated with an increased risk of a full-thickness rotator cuff re-tear after repair as measured by ultrasound. Increasing CSA correlated with worse post-operative ASES scores.
Li et al.[27]	Control: 30 Large CSA: 60	55.8 (49.5–62.1) 55.0 (47.7–62.3)	Control: 36 ± 2 Large CSA: 45 ± 5	Large CSA group had a 15% re-tear rate compared to 0% in the control group. Increased CSA correlated to increased cuff SNQ ($r = 0.53$, $p < 0.001$). **ASES:** Large CSA: 88.0 ± 9.7 Control: 87.3 ± 11 $p = 0.772$ **UCLA:** Large CSA: 30.9 ± 2.9 Control: 31 ± 3.2 $p = 0.921$ **Constant:** Large CSA: 74.3 ± 8 Control: 77.0 ± 7 $p = 0.124$ **VAS:** Large CSA: 1.4 ± 1.4 Control: 1.5 ± 1.4 $p = 0.833$ **Strength:** Large CSA 8.1 ± 3.6 Control: 7.6 ± 3.1 $p = 0.507$	Higher rate of rotator cuff re-tear in the large CSA group as compared to controls as measured by MRI. No significant difference in ASES, UCLA, Constant scores between large CSA and control groups. No significant differences in strength between large CSA and control groups.

(continued)

Table 2. Continued.

	Critical shoulder angle				
Study	N	Average age	Average CSA (°)	Reported outcome measures	Key findings
Lee et al.	Control: 30 Increased CSA: 117	61 (9)	All: 39 ± 5	**Constant:** Control CSA: 70 (12) Large CSA: 70 (12) p = 0.874 **Oxford:** Control CSA: 16 (5) Large CSA: 16 (7) p = 0.937 **UCLA:** Control CSA: 29 (6) Large CSA: 30 (5) p = 0.577	The critical shoulder angle did not correlate with patient-reported outcomes as measured by the Constant, Oxford, or UCLA scores.
Kirsch et al.[25]	Increased CSA: 18 Normal CSA: 35	Increased CSA: 56.8 (7.8) Normal CSA: 62.7 (8.4)	Elevated CSA: 39.9 Normal CSA: 32.9	**VAS:** Large CSA: 10.9 (13.5) Small CSA: 10.0 (10.06) p = 0.788 **ASES:** Large CSA: 82.7 (19.8) Small CSA: 87.5 (14.3) p = 0.321 **WORC:** Large CSA: 226.7 (357) Small CSA: 348.9 (284.9) p = 0.184	The critical shoulder angle is not a significant predictor of patient-reported outcomes after arthroscopic repair of atraumatic rotator cuff tears.
Scheiderer et al.[29]	57	54.7 (47–64)	All: 36 ± 3 No re-tear: 35 ± 3 Re-tear: 37 ± 4 P = 0.014	**WORC:** Correlation rs = 0.09 P = 0.533 **ASES:** Correlation rs = −0.09 P = 0.530 **Constant:** Correlation rs = −0.10 P = 0.475 **SANE:** Correlation rs = −0.09 P = 0.488 **VAS:** Correlation = 0.08 P = 0.566	The critical shoulder angle was significantly elevated in patients who developed a re-tear; however, it does not correlate to patient-reported outcomes.

ASES: American Shoulder Elbow Surgeon; CSA: critical shoulder angle; MRI: magnetic resonsance imaging; SANE: single assessment numeric evaluation; SNQ: signal to noise quotient; UCLA: University of California Los Angeles; VAS: visual analog scale; WORC: Western Ontario Rotator Cuff.

higher risk of post-operative re-tear, future interventions may be targeted to these groups to improve overall outcomes after rotator cuff repair. Given these changes in scapular morphology cannot be changed without an osteotomy, providers must consider alternative strategies to mitigate the bony shape. Patients with at-risk morphology for re-tear may benefit more from stronger repair configurations. Future studies may also consider repair augmentation or targeted biologic treatments in patients with altered morphology. Data from these studies can be used during preoperative counseling when discussing the likelihood of success or failure of the rotator cuff repair or even factor into a risk stratification system for success after repair.

This review comes with its strengths and weaknesses. It is the first of its kind to review the currently available literature regarding the relationship of anatomic shoulder parameters and outcomes following rotator cuff repair. It is worth mentioning that currently available literature regarding this topic is limited as it is a relatively novel idea. Furthermore, it is important to acknowledge that the current literature may be underpowered to truly detect the impact of altered scapular morphology on patient-reported outcomes and function. Additionally, there was heterogeneity in the anatomic shoulder parameters that were measured; however, the CSA and AI were well represented in the papers analyzed. In addition to the heterogeneity in the anatomic parameters, there was a significant difference in which patient-reported outcome measures were utilized making it difficult to directly compare studies at times. This study was also unable to control for other variables including muscle quality, comorbidities, and smoking status that may affect the outcome measures.

Conclusions

Rotator cuff re-tear rate appears to be significantly associated with the CSA and GI, while not as clearly associated with acromial morphologic measurements. This review highlights the need for further investigations into how individual shoulder anatomy may play a role in the outcomes following rotator cuff repair. It has been highlighted that care must be taken when acquiring imaging as the accuracy of these measurements is highly dependent on the image that is being used for measurements. Furthermore, future studies should consider the use of cross-sectional imaging such as CT scans or bone specific MRI sequences to accurately quantify shoulder morphology as these modalities are not significantly impacted by patient position at the time of acquisition.

Contributorship

DAL and MBZ researched literature and conceived the study. VP, BTF, NMY, and CBM provided guidance on study design and reviewed and edited the manuscript and approved the final version of the manuscript.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: C Benjamin Ma reports that he has received grants from Zimmer Biomet during the conduct of the study; grants from Anika, Samumed, and Zimmer; personal fees from ConMed Linvatec, Medacta, SLACK, and Stryker; and grants and personal fees from Histogenics for work related to the subject of this article. Drew A Lansdown reports that he has received grants from Arthrex and Smith & Nephew for work related to the subject of this article. The other authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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Ethical Review and Patient Consent

As this study is a systematic review that did not rely on direct patient contact or review of patient records, no IRB approval was sought.

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