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Anatomic shoulder parameters and their relationship to the presence of degenerative rotator cuff tears and glenohumeral osteoarthritis: a systematic review and meta-analysis

Musa B. Zaid, MD*, Nathan M. Young, PhD, Valentina Pedoia, PhD, Brian T. Feeley, MD, C. Benjamin Ma, MD, Drew A. Lansdown, MD

Department of Orthopaedic Surgery, University of California, San Francisco, San Francisco, CA, USA

Background: Scapular anatomy, as measured by the acromial index (AI), critical shoulder angle (CSA), lateral acromial angle (LAA), and glenoid inclination (GI), has emerged as a possible contributor to the development of degenerative shoulder conditions such as rotator cuff tears and glenohumeral osteoarthritis. The purpose of this study was to investigate the published literature on influences of scapular morphology on the development of degenerative shoulder conditions.

Methods: A systematic review of the Embase and PubMed databases was performed to identify published studies on the potential influence of scapular bony morphology on the development of degenerative rotator cuff tears and glenohumeral osteoarthritis. The studies were reviewed by 2 authors. The findings were summarized for various anatomic parameters. A meta-analysis was completed for parameters reported in more than 5 related publications.

Results: A total of 660 unique titles and 55 potentially relevant abstracts were reviewed with 30 published articles identified for inclusion. The AI, CSA, LAA, and GI were the most commonly reported bony measurements. Increased CSA and AI correlated with rotator cuff tears, whereas lower CSA appeared to be related to the presence of glenohumeral osteoarthritis. Decreased LAA correlated with degenerative rotator cuff tears. Five articles reported on the GI with mixed results on shoulder pathology.

Discussion: Degenerative rotator cuff tears appear to be significantly associated with the AI, CSA, and LAA. There does not appear to be a significant relationship between the included shoulder parameters and the development of osteoarthritis.

Level of evidence: Level IV; Systematic Review

Keywords: Critical shoulder angle; acromial index; glenoid inclination; acromial center-edge angle; scapular morphology; shoulder shape; scapular shape; anatomic shoulder parameters

*Reprint requests: Musa B. Zaid, MD, Department of Orthopaedic Surgery, University of California, San Francisco, 500 Parnasssus Ave, MU-320 W, San Francisco, CA 94143, USA.

E-mail address: Musa.Zaid@ucsf.edu (M.B. Zaid).

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Shoulder pain is a common complaint prompting evaluation by orthopedic surgeons and primary care physicians, with an annual estimated incidence of 14.7 per 1000 patients in primary care and a lifetime prevalence of up to 70%.[23,26,52] With an aging population, degenerative shoulder conditions such as rotator cuff tears and glenohumeral osteoarthritis are accounting for a majority of these complaints and are the source of significant pain and disability. Numerous studies have demonstrated the prevalence of rotator cuff tears to be as high as 22% to 23%,[29,47] whereas the prevalence of glenohumeral osteoarthritis has been estimated to be as high as 26%.[48] As patients desire to remain active as they age, we are beginning to see an increase in the utilization of surgical resources for rotator cuff repair and shoulder arthroplasty.[14,17]

The development of degenerative shoulder conditions such as rotator cuff tears and glenohumeral osteoarthritis is likely multifactorial in nature, with contributors such as age, sex, genetics, and trauma, although recent attention has been directed to scapular morphology as a risk factor for the development of these degenerative conditions.[37,40,53] The relationship between scapular shape and the development of rotator cuff tears was first described by Neer[33] in 1972 with his observation of varying acromial morphology leading to direct compression on the rotator cuff and resulting pathology and has since been explored by numerous other authors as well.[35] More recently, the critical shoulder angle (CSA), acromial index (AI), lateral acromial angle (LAA), and glenoid inclination (GI) (Fig. 1), as well as myriad other scapular measurements, have been introduced as potential radiographic measurements that can distinguish which patients are at risk of the development of rotator cuff tears or glenohumeral osteoarthritis.

The primary purpose of this study was to investigate the influence of scapular morphology on the presence of degenerative rotator cuff tears and glenohumeral osteoarthritis, as well as to identify the supporting literature for these conclusions. A systematic review of the literature was performed to summarize the currently available evidence on this topic, and a meta-analysis was performed to determine the influence of scapular morphologic parameters on the presence of rotator cuff tears and glenohumeral osteoarthritis.

Methods

Search strategy and inclusion terms

A systematic review of the literature was performed following the standardized PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) protocol.[42] Prior to initiation of data abstraction, this review was registered with PROSPERO (International Prospective Register of Systematic Reviews). The search criteria and objectives of the review were defined before a search of the literature was conducted. Per the protocol, a search of the English-language literature using PubMed and Embase was conducted for all studies published prior to November 1, 2018. The search terms used included the following: (rotator cuff tear and acromial index) or (rotator cuff and critical shoulder angle) or (rotator cuff and anatomic parameters) or (rotator cuff and scapular shape) or (rotator cuff and scapular morphology) or (rotator cuff and glenoid inclination) or (rotator cuff and predisposition) or (arthritis and acromial index) or (arthritis and critical shoulder angle) or (arthritis and anatomic parameters) or (arthritis and scapular shape) or (arthritis and scapular morphology) or (glenohumeral arthritis and predisposition) or (glenohumeral arthritis and predisposed).

All titles were reviewed independently by 2 reviewers (D.A.L. and M.B.Z.) to determine the appropriateness for inclusion. All identified abstracts were then reviewed by both reviewers. The complete article from any abstract was subsequently reviewed by 1 reviewer with data verification performed by a second reviewer. Studies were included if they included radiographic measurements of bony morphology at the shoulder in patients with either symptomatic rotator cuff tears or symptomatic osteoarthritis. Studies were excluded if they reported on only biomechanical data, computer modeling, or cadaveric findings.

Methodologic study assessment was performed using the National Institutes of Health Quality Assessment Tool for Cross-Sectional Studies. Each reviewer performed the study quality assessment and recorded his responses (Supplementary Table S1). Any discrepancies were reviewed by the 2 authors until a consensus was reached.

Data extraction

Data extraction was performed with items of interest identified a priori, including sample size of the study, demographic information of each cohort, radiographic measurements, and disease prevalence. The means and standard deviations of the included anatomic parameters were recorded for analysis.

Meta-analysis

Anatomic parameters reported in more than 5 independent studies were pooled in a meta-analysis using RStudio software (RStudio, Boston, MA, USA). As all anatomic parameters were reported as continuous measures, the pooled effects were presented as mean differences with confidence intervals (CIs) with an inverse-variance weighted method. Study heterogeneity was determined by calculating the I^2 value; a random-effects model was used as there was significant heterogeneity ($I^2 > 75\%$) among all studies.

Results

A search of the literature as outlined earlier resulted in a total of 427 titles from MEDLINE and 404 from Embase. A total of 660 unique titles were identified between the 2 searches. Fifty-five unique abstracts were identified for further review based on the title alone. A total of 30 unique articles were included in the final analysis[2-5,8-10,12,13,15,16,19-21,24,27,30-32,38,39,41,43-46,49-51] (Fig. 2).

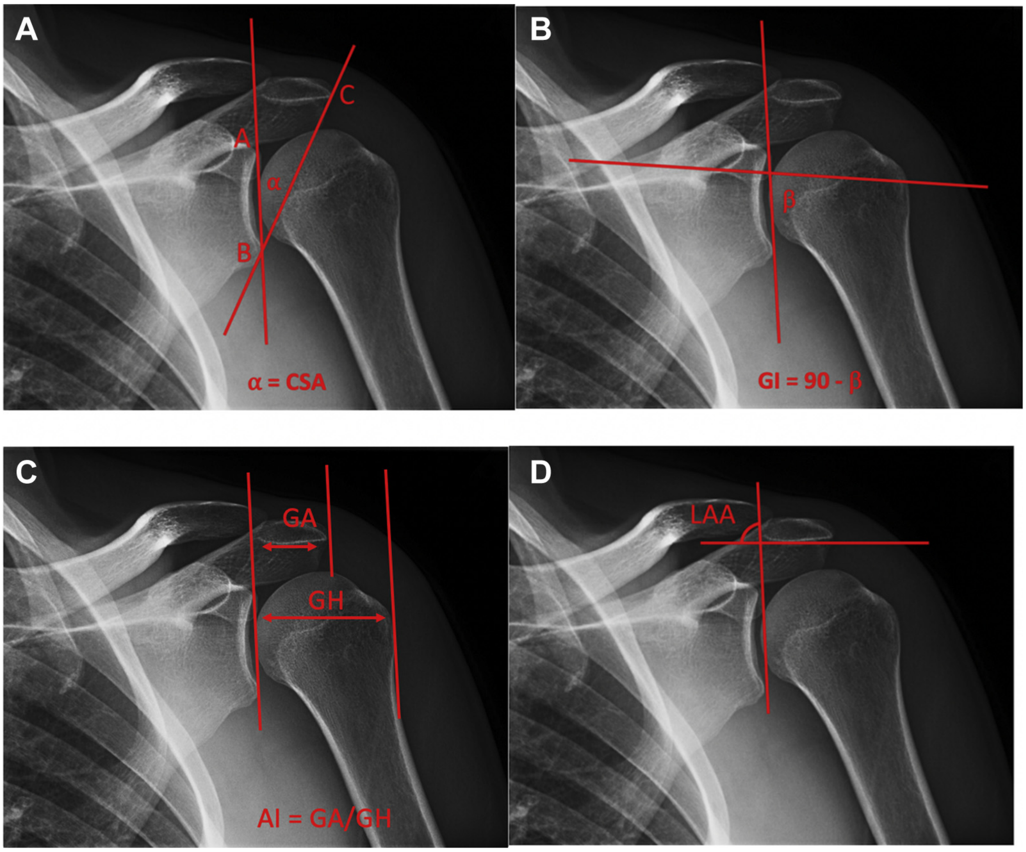

Figure 1 Radiographic measurements of selected anatomic shoulder parameters: critical shoulder angle *(CSA)* (**A**), glenoid inclination *(GI)* (β angle method of Maurer et al[28]) (**B**), acromial index *(AI)* (*GA*, glenooid-acromial distance; *GH*, glenoid-humeral distance) (**C**), and lateral acromial angle *(LAA)* (**D**).

All articles were published after 2004. One study was longitudinal in nature,[12] with the remainder being cross-sectional.

Of the studies, 19 examined the CSA,[2,4,5,9,10,11,13,16,19,21,27,30-32,38,39,44,46,51] 8 measured the AI,[2,3,20,21,24,31,38,45] 5 measured the LAA,[2,3,21,32,45] 5 examined the GI,[4,5,8,11,16] 2 measured the acromial slope,[2,3] 1 measured the acromial center-edge angle (ACEA),[45] 1 measured the acromial coverage index,[49] 1 measured the greater tuberosity angle (GTA),[15] 1 measured the coracoid cavity ratio,[41] and 1 measured the coracoid inclination.[49] All 30 studies included in this review included a rotator cuff tear group, whereas 10 of these studies included a glenohumeral osteoarthritis group as well.[4,5,9,10,16,21,27,30,44,46]

For the assessment of scapular parameters, 18 studies used radiographs alone,[2,3,9,10,11,13,15,19-21,24,27,30-32,38,41,44] 5 used plain radiographs and computed tomography (CT) scans,[4,5,8,16,45] 1 used magnetic resonance imaging and CT scans,[11] and 1 used CT scans alone.[39]

Critical shoulder angle

The CSA was significantly elevated in patients with isolated rotator cuff tears compared with healthy controls in numerous studies (Table I).[10,11,13,16,19,31,32,39,51] This finding was consistent across multiple studies. When data were pooled in a meta-analysis, the mean difference in the CSA between patients with rotator cuff tears and control patients was 1° (95% CI, 0.59°-1.44°; $P < .05$; $I^2 = 91\%$) (Fig. 3).

In the only longitudinal study identified, Chalmers et al[11] evaluated the CSA and its effect on the rotator cuff over time. Although they found that patients with rotator cuff tears had a significantly elevated CSA at the time of enrollment (34° vs. 32°, $P = .003$), the CSA did not correlate with baseline tear size nor was the CSA different in patients in whom tear enlargement occurred over time.

One study examined how the CSA differed in patients with full-thickness vs. partial-thickness tears and found that the CSA was elevated in both groups compared with healthy controls (41.01° and 38.83° vs. 37.28°; $P < .001$ and $P = .02$, respectively).[38] In addition, patients with degenerative rotator cuff tears were found to have an elevated CSA compared with those with traumatic rotator cuff tears in 1 study (36.8° vs. 35.3°, $P = .007$).[2] The CSA appeared to be significantly elevated in patients with isolated degenerative rotator cuff tears compared with those with isolated glenohumeral osteoarthritis, with the mean

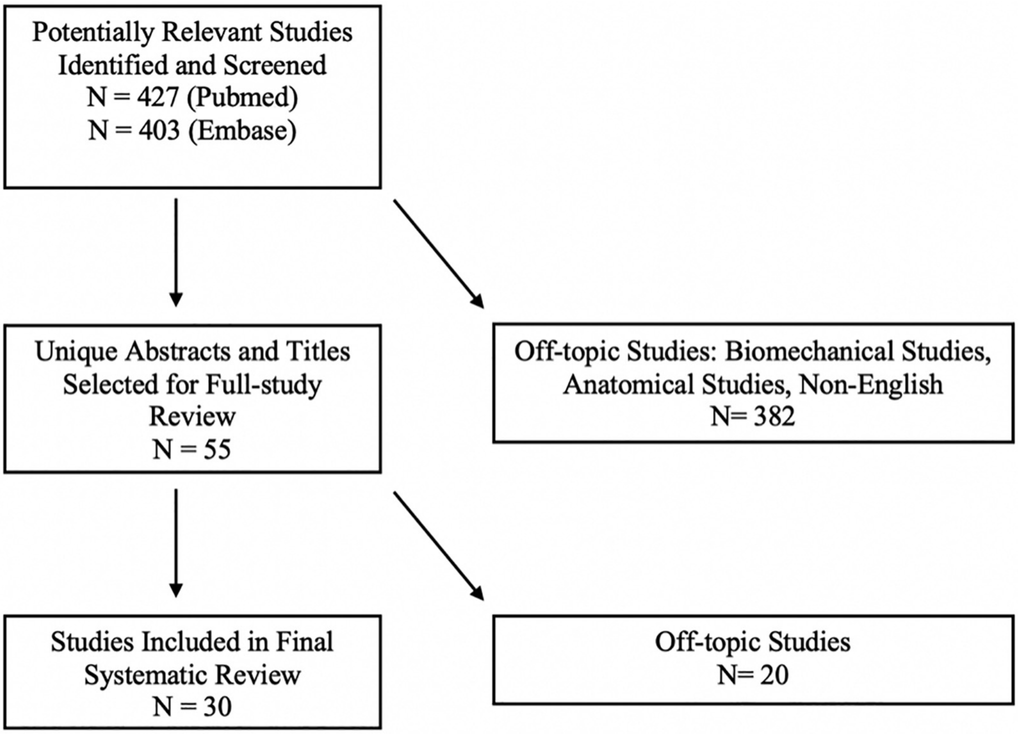

Figure 2 Flowchart of study design and included studies.

CSA ranging from 34° to 34.5° in patients with degenerative cuff tears compared with 27.2° to 28° in patients with glenohumeral osteoarthritis ($P < .001$ in all studies).[4,5,10]

When comparing patients with cuff tear arthropathy with those with isolated rotator cuff tears and those with isolated glenohumeral osteoarthritis, 1 study found that the CSA was significantly elevated in patients with isolated rotator cuff tears compared with those with cuff tear arthropathy (36.3° vs. 35.2°, $P = .006$).[21] In addition, the CSA appeared to be significantly elevated in patients with cuff tear arthropathy compared with those with isolated glenohumeral osteoarthritis (35°-35.2° vs. 27.3°-30°, $P < .001$ for both studies).[27,38]

A lower CSA appeared to be related to the presence of isolated glenohumeral osteoarthritis. Although numerous studies concluded this,[9,10,21,27,30,46] multivariate analysis completed in 1 of the included studies did not find any significant relationship between the CSA and the presence of glenohumeral osteoarthritis.[44] When data were pooled in a meta-analysis, the mean difference in the CSA in patients with glenohumeral osteoarthritis was 1.42° (95% CI, –2.50° to –0.35°; $P < .01$; $I^2 = 94\%$) less than that in controls (Fig. 4). One study did not find a significant relationship between the CSA and the presence of rotator cuff tears; however, the authors did conclude that a lower CSA is associated with glenohumeral osteoarthritis (rotator cuff tear group: 33.9° vs. 33.6°, $P = .063$; glenohumeral osteoarthritis group: 31.1° vs. 33.2°; odds ratio, 2.25; $P = .002$).[9]

Acromial index

Eight studies reported on the relationship between the AI and rotator cuff tears,[2,3,20,21,24,32,38,45] and 1 of these 8 studies examined the relationship between the AI and the presence of glenohumeral osteoarthritis.[21] The AI was consistently significantly elevated in patients with rotator cuff tears compared with healthy controls in all but 1 of the included studies (Table II).[3,20,24,32,45] In the 1 study that did not find a significant difference between groups, patients with full-thickness rotator cuff tears were compared with a composite group of patients with partial or no tears.[20]

One study examined the AI in patients with full-thickness tears vs. those with only partial-thickness tears, as well as a control group.[38] The authors did not find a significant difference in the AI between patients with full- and partial-thickness tears; however, the AI in these 2 groups was significantly elevated compared with the control group (0.76 for full thickness, 0.74 for partial thickness, and 0.70 for healthy control; $P = .006$ between full-thickness group and no-tear group). In addition, the AI was noted to be significantly elevated in patients with degenerative rotator

Table I Critical shoulder angle in rotator cuff tear patients vs. control population

	Critical shoulder angle, mean (SD), °		*P* value
	Rotator cuff tear	Control	
Blonna et al[10] (2016)	40 (3.5)	34 (3)	<.001*
Chalmers et al[12] (2017)	34 (4)	32 (4)	.013*
Cherchi et al[13] (2016)	36.4 (4.4)	33.3 (3.8)	.02*
Daggett et al[16] (2015)	37.9 (3)	27.2 (3.4)	<.001*
Gomide et al[19] (2017)	39.75 (3.37)	33.59 (5.35)	<.007*
Moor et al[31] (2014)	37.8 (3.8)	31.9 (3.8)	<.0001*
Moor et al[32] (2014)	38 (3.2)	33 (3.4)	<.001*
Peltz et al[39] (2015)	36.9 (5)	34.5 (4.7)	.03*
Watanabe et al[51] (2018)	34.4 (3.4)	32.1 (3.1)	<.001*

SD, standard deviation.
* Statistically significant ($P < .05$).

cuff tears compared with those with traumatic rotator cuff tears (0.77 vs. 0.73, $P = .0239$).[2]

When data were pooled in a meta-analysis, the mean difference in the AI for patients with rotator cuff tears compared with healthy controls was 0.75 (95% CI, 0.23-1.27; $P < .01$; $I^2 = 88\%$) (Fig. 5). One study examined the relationship between the AI and rotator cuff tears, as well as glenohumeral osteoarthritis, and found that the AI was significantly elevated in patients with rotator cuff tears compared with those with isolated glenohumeral osteoarthritis (0.74 vs. 0.63, $P < .001$).[21]

Lateral acromial angle

A total of 5 studies examined how the LAA correlates with the presence of rotator cuff tears, and 1 of these studies examined how the LAA related to the presence of glenohumeral osteoarthritis. The LAA was consistently lower in patients with rotator cuff tears compared with healthy controls in all included studies (Table III).[3,32,45]

One study found that the LAA was significantly lower in patients with degenerative rotator cuff tears compared with those with traumatic rotator cuff tears.[2] In addition, the LAA appeared to be significantly lower in patients with isolated rotator cuff tears compared with patients with glenohumeral osteoarthritis (76.7° vs. 89.5°, $P < .001$), as well as patients with cuff tear arthropathy (76.6° vs. 82°, $P < .001$).[21]

Glenoid inclination

Five studies reported on the GI with varying results regarding its relationship with rotator cuff tears. Different methods to measure the GI were used by the various authors.

Table II Acromial index in rotator cuff tear patients vs. control population

	Acromial index, mean (SD)		*P* value
	Rotator cuff tear	Control	
Balke et al[3] (2013)	0.75 (0.1)	0.67 (0.1)	<.001*
Hamid et al[20] (2012)	0.692 (NR)	0.691 (NR)	.92
Kum et al[24] (2017)	0.68 (NR)	0.63 (NR)	<.001*
Moor et al[32] (2014)	0.75 (0.06)	0.66 (0.06)	<.001*
Singleton et al[45] (2017)	0.755 (0.005)	0.69 (0.003)	<.001*

SD, standard deviation; *NR*, not reported.
* Statistically significant ($P < .05$).

Two studies concluded that the GI was significantly lower in patients with rotator cuff tears compared with patients with isolated glenohumeral osteoarthritis when measured on plain radiographs using the β angle method of Maurer et al[28] (78.7° vs. 81.5°, $P = .008$),[4] as well as when measured on CT scans (78.8° vs. 82.0°, $P = .008$).[5] Similarly, when examining patients with unilateral degenerative rotator cuff tears, one study found that the GI was significantly lower in the shoulder with the cuff tear than in the healthy contralateral shoulder using methods previously described by Hughes et al[22] to measure the GI (90.7° vs. 92.3°, $P = .04$).[8]

Two studies primarily used CT scans to measure the GI and reported opposite results to those in the aforementioned studies. Chalmers et al[11] measured the superior GI on coronal CT scans that had been corrected such that the glenoid was placed in the scapular plane. Using this method, they found that patients with rotator cuff tears had a significantly increased superior GI compared with control patients (11° vs. 9°, $P < .001$). Daggett et al[16] measured the GI on anteroposterior radiographs using the method of Maurer et al[28] in which the β angle was subtracted from 90°, as well as on coronal CT scans corrected to be in the scapular plane. When measured on CT scans, the GI was significantly elevated in the rotator cuff tear group

Table III Lateral acromial angle in rotator cuff tear patients vs. control population

	Lateral acromial angle, mean (SD), °		*P* value
	Rotator cuff tear	Control	
Balke et al[3] (2013)	77 (6)	84 (6)	<.001*
Moor et al[32] (2014)	80 (6.3)	86 (7.7)	<.001*
Singleton et al[45] (2017)	76.48 (0.37)	79.71 (0.27)	<.001*

SD, standard deviation.
* Statistically significant ($P < .05$).

Study	Rotator Cuff Tear Mean	SD	Total	Controls Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Blonna 2016	36.00	3.0000	40	34.00	3.0000	80	10.0%	0.66 [0.27; 1.05]
Bjarnison 2017	33.90	.	97	33.60	.	285	0.0%	
Chalmers 2017	34.00	4.0000	179	32.00	4.0000	50	10.4%	0.50 [0.18; 0.82]
Cherchi 2016	36.40	4.4000	28	33.30	3.8000	27	9.0%	0.74 [0.19; 1.29]
Gomide 2017	39.75	5.3500	44	33.59	3.3700	34	9.4%	1.33 [0.83; 1.82]
Heuberer 2017*	36.30	2.7000	100	30.20	2.9000	100	10.2%	2.17 [1.82; 2.52]
Miswan 2017	39.40	4.4000	85	37.40	3.8000	103	10.5%	0.49 [0.20; 0.78]
Moor 2014	37.80	3.8000	236	31.90	3.8000	130	10.8%	1.55 [1.31; 1.79]
Moor 2014	38.00	3.4000	51	33.00	3.2000	51	9.7%	1.50 [1.06; 1.94]
Peltz 2015	36.90	5.0000	36	34.50	4.7000	84	10.0%	0.50 [0.10; 0.89]
Watanabe 2018	34.40	3.5000	65	32.10	3.1000	45	10.0%	0.68 [0.29; 1.07]
Total (95% CI)			**961**			**989**	**100.0%**	**1.01 [0.59; 1.44]**

Heterogeneity: $Tau^2 = 0.3079$; $Chi^2 = 102.53$, df = 9 (P < 0.01); $I^2 = 91\%$

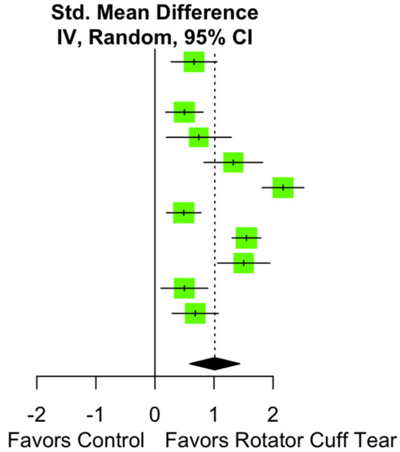

Figure 3 Forest plot of studies examining how the critical shoulder angle relates to the presence of symptomatic rotator cuff tears. The mean difference in the critical shoulder angle in patients with rotator cuff tears compared with controls was 1.01° (95% confidence interval *[CI]*, 0.59°-1.44°; $P < .05$; $I^2 = 91\%$). *Std*, standardized; *SD*, standard deviation; *IV*, inverse variance.

compared with controls (13.6° vs. 4.7°, $P < .001$); however, when measured on plain radiographs, the GI showed no significant difference in patients with rotator cuff tears compared with patients without rotator cuff tears (13.6° vs. 7.6°, $P =$ not significant).[16]

Acromial slope

Two studies examined how the acromial slope relates to the presence of rotator cuff tears, with different conclusions. One study found no difference in acromial slope in patients with rotator cuff tears compared with healthy controls (25° vs. 25°, $P = .7$),[3] whereas the other study found that the acromial slope was significantly elevated in patients with degenerative rotator cuff tears compared with those with traumatic rotator cuff tears (21.2° vs. 19.1°, $P = .026$).[2] No study examined how acromial slope related to glenohumeral osteoarthritis.

Acromial center-edge angle

One study measured the ACEA and how it relates to the presence of rotator cuff tears. Singleton et al[45] found that the ACEA was significantly higher in patients with rotator cuff tears than in controls (23.89° vs. 16.66°, $P < .001$).

Acromial coverage index

One study measured the acromial coverage index and its relationship to rotator cuff tears. Torrens et al[50] found that the acromial coverage index was significantly higher in patients with surgically treated rotator cuff tears than in healthy controls (0.687 vs. 0.591, $P < .001$). In addition, no significant difference was found between patients with rotator cuff tears treated surgically and those with tears were managed conservatively (0.687 vs. 0.725, $P = .219$).

Study	Osteoarthritis Mean	SD	Total	Controls Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bjarninson (2017)	31.10	.	87	33.30	.	258	0.0%	
Blonna (2016)	28.20	2.0000	40	34.00	3.0000	80	17.2%	-2.13 [-2.59; -1.66]
Heuberer (2017)	27.30	3.5000	100	35.90	2.7000	100	17.5%	-2.74 [-3.13; -2.35]
Mantell (2017)	30.00	4.0000	31	35.00	4.0000	62	17.2%	-1.24 [-1.71; -0.77]
Miswan (2017)	33.00	5.6000	49	37.40	3.8000	103	17.6%	-0.98 [-1.34; -0.62]
Shinagawa (2018)	33.00	5.3000	12	32.10	4.3000	133	16.6%	0.20 [-0.39; 0.80]
Spiegl (2016)	28.70	2.2000	10	32.70	2.5000	10	14.0%	-1.63 [-2.67; -0.59]
Total (95% CI)			**329**			**746**	**100.0%**	**-1.42 [-2.50; -0.35]**

Heterogeneity: $Tau^2 = 0.9536$; $Chi^2 = 87.21$, df = 5 (P < 0.01); $I^2 = 94\%$

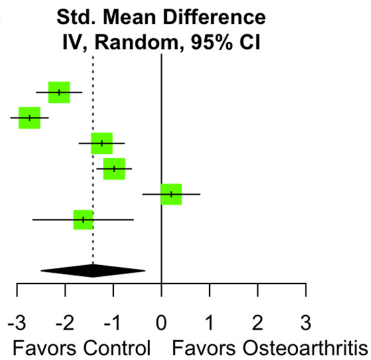

Figure 4 Forest plot of studies examining how the critical shoulder angle relates to the presence of symptomatic glenohumeral osteoarthritis. The mean difference in the critical shoulder angle in patients with glenohumeral osteoarthritis was –1.42° (95% confidence interval *[CI]*, –2.50° to –0.35°; $P < .01$; $I^2 = 94\%$) compared with controls. *Std*, standardized; *SD*, standard deviation; *IV*, inverse variance.

Study	Rotator Cuff Tear Mean	Rotator Cuff Tear SD	Rotator Cuff Tear Total	Controls Mean	Controls SD	Controls Total	Weight	Std. Mean Difference IV, Random, 95% CI
Balke 2013	0.75	0.1000	50	0.67	0.1000	50	16.0%	0.79 [0.39; 1.20]
Balke 2016	0.77	0.0700	72	0.73	0.0600	64	16.8%	0.61 [0.26; 0.95]
Heuberer 2017	0.74	0.0600	100	0.70	0.0500	100	17.5%	0.72 [0.44; 1.01]
Kum 2017	0.68	.	100	0.63	.	100	0.0%	
Hamid 2012	0.69	0.0600	123	0.69	0.0600	93	17.7%	-0.02 [-0.29; 0.25]
Moor 2014	0.75	0.0600	51	0.66	0.0600	51	15.6%	1.49 [1.05; 1.93]
Pandey 2016	0.76	0.0100	54	0.70	0.0800	61	16.3%	1.02 [0.63; 1.41]
Singleton 2017	0.76	.	107	0.69	.	200	0.0%	
Total (95% CI)			**657**			**719**	**100.0%**	**0.75 [0.23; 1.27]**

Heterogeneity: $Tau^2 = 0.2109$; $Chi^2 = 41.52$, df = 5 ($P < 0.01$); $I^2 = 88\%$

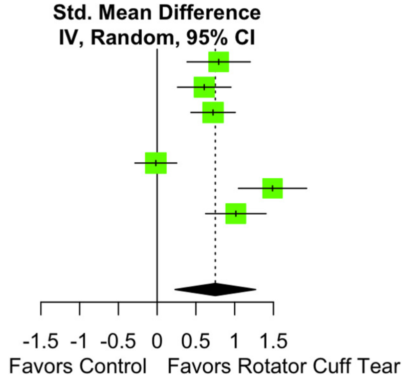

Figure 5 Forest plot of studies examining how the acromial index relates to the presence of symptomatic rotator cuff tears. The mean difference in the acromial index for patients with rotator cuff tears was 0.75 (95% confidence interval *[CI]*, 0.23-1.27; $P < .01$; $I^2 = 88\%$) compared with healthy controls. *Std*, standardized; *SD*, standard deviation; *IV*, inverse variance.

Greater tuberosity angle

One study measured the GTA and its effect on rotator cuff tears and found that the GTA was significantly elevated in patients with rotator cuff tears compared with healthy controls (72.5° vs. 65.2°, $P < .001$); in addition, a GTA of more than 70° resulted in 93-fold higher odds of detecting a rotator cuff tear ($P < .001$).[15]

Coracoid cavity ratio

One study measured the coracoid cavity ratio and its impact on the presence of rotator cuff tears and concluded that patients with an isolated supraspinatus tendon tear had a significantly elevated coracoid cavity ratio compared with healthy controls (65 vs. 43, $P = .0002$).[41]

Coracoid inclination

One study measured the coracoid inclination from CT scans by measuring the angle between the coracoid and glenoid surface (A1), the angle between the coracoid tip and glenoid surface (A2), and the angle created by the coracoid body and coracoid tip (A3).[49] The authors found that all angles (A1, A2, and A3) were significantly lower in the rotator cuff tear group compared with the control group (A1, 49.7° vs. 56.1° [$P = .011$]; A2, 76.45° vs. 93.6° [$P < .001$]; and A3, 132.33° vs. 144.34° [$P < .001$]).

Discussion

Scapular morphology as well as how it relates to the development of degenerative rotator cuff tears and glenohumeral osteoarthritis continues to be an area of interest in modern orthopedics as physicians hope to identify risk factors for these common degenerative conditions. Although numerous quantifiable anatomic parameters to characterize scapular morphology have been identified in the literature, the AI, CSA, GI, and LAA were the most commonly examined in the studies in our review.

Overall, the AI, CSA, and LAA are reliably associated with the presence of degenerative disorders of the shoulder. The results of the meta-analysis on the CSA demonstrate that an increased CSA compared with controls is associated with the development of degenerative rotator cuff tears whereas a lower CSA compared with controls is associated with the presence of glenohumeral osteoarthritis. Furthermore, the meta-analysis showed that an increased AI is associated with degenerative rotator cuff tears. The majority of studies found that an elevated AI, usually greater than 0.74, was associated with the presence of degenerative rotator cuff tears. A conclusion on how the AI relates to glenohumeral osteoarthritis is difficult to make as only 1 study looked at this and did not have a healthy control population; rather, the arthritis group was compared with a rotator cuff tear group.[21]

Similarly to the AI, the CSA was almost consistently found to be elevated in patients with degenerative rotator cuff tears compared with healthy controls, and it was decreased in patients with glenohumeral osteoarthritis in numerous studies, as well as in our meta-analysis. Because of the large variation in the measured values of the CSA between articles (range of 33.9°-37.9° for patients with rotator cuff tears and 27.2°-37.3° for patients without rotator cuff tears), it is difficult to assume an abnormal cutoff value.[8,21,27,44,46] In addition to the AI and CSA, the LAA consistently related to the presence of degenerative rotator cuff tears. A lower LAA was universally associated with the presence of degenerative rotator cuff tears in the studies included in this review, usually with a value of less than 80° correlating with cuff tears. As only a single study looked at how the LAA relates to glenohumeral osteoarthritis, it is difficult to assume a conclusion on this relationship.

The pathomechanics of how scapular morphology relates to the development of degenerative shoulder conditions remains an area of controversy. Whereas numerous authors have hypothesized that impingement of the rotator cuff by the underside of the acromion can lead to the development of rotator cuff tears,[6,7,10,18,34] others have argued that changes in acromial morphology may occur as a result of rotator cuff tears.[1,25] For example, Li et al[25] theorized that rotator cuff degeneration leads to an imbalance in forces around the shoulder, ultimately resulting in anterior-superior instability followed by the formation of bone spurs along the coracoacromial arch with a resultant deformity in the acromion. Nonetheless, there is convincing evidence[36] to suggest that increased lateral extension of the acromion may relate to the development of rotator cuff tears. Nyffeler et al[36] have hypothesized that with increasing lateral extension of the acromion, the deltoid is able to exert a larger force vector on the glenohumeral joint, leading to increased joint contraction and subacromial impingement, which in turn may lead to degenerative rotator cuff tears. This increase in the lateral extension of the acromion would manifest as an increased CSA and AI and a decrease in the LAA; these are the changes that were consistently associated with the presence of degenerative rotator cuff tears in the published literature.

Integrating the data from these studies into clinical practice may allow for the identification of patients at risk of having degenerative rotator cuff tears and possibly glenohumeral osteoarthritis. As these changes in scapular morphology are intrinsic in nature, they cannot be changed without surgical intervention, which is unlikely to be performed. In addition, clinicians should have a higher index of suspicion for a degenerative rotator cuff injury in patients with these alterations in scapular shape who may present with shoulder pain.

Although there was significant consistency in the aforementioned parameters, there were some studies that did not come to similar conclusions. The most variable findings involved the GI: 2 studies concluded that a more superior GI related to rotator cuff tears,[11,16] whereas 3 concluded the opposite.[4,5,8] These discordant results may be attributed to a difference in methods used to measure the GI, as well as the fact that some authors measured this parameter on plain radiographs whereas others used CT scans. This point may serve to highlight the importance of radiographic and measurement techniques in determining these anatomic parameters. Furthermore, differences in patient populations between studies may contribute to this discordance. As with the GI, all of the aforementioned parameters are subject to variability based on measurement techniques and the quality of the imaging used for the measurements. Numerous studies have demonstrated that these quantitative measures are highly dependent on the rotation of the image used.[11,12,20] Although some of the studies included in this review used CT scans, which are not dependent on patient rotation, the majority used plain radiographs.

This study comes with strengths and limitations. It is one of the first of its kind to review the currently available literature on how anatomic shoulder parameters affect the development of degenerative rotator cuff tears and glenohumeral osteoarthritis. As it is a systematic review, it is dependent on the quality of the studies included. The majority of studies included in this analysis were retrospective in nature but did have sufficient sample sizes and control groups. Although numerous parameters were measured in the literature, the AI, CSA, and LAA were the most highly represented. In addition, although some studies completed a multivariate analysis to control for confounding factors, this analysis was not completed in all of the included sources, possibly introducing some error.

Conclusion

The presence of degenerative rotator cuff tears appears to be associated with an increased AI and CSA and a decreased LAA. In addition, a lower CSA appears to be associated with the presence of glenohumeral osteoarthritis. It must be highlighted that these quantifiable anatomic parameters are highly dependent on the technique used to obtain the radiographs. Although a few studies used cross-sectional imaging such as CT scans and magnetic resonance imaging to more accurately quantify these parameters, future studies should continue to use these methods to perhaps look for associations between anatomic shoulder parameters and the presence of glenohumeral osteoarthritis.

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Supplementary data

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