



Subacromial impingement anatomy and its association with rotator cuff pathology in women: radiograph and MRI correlation, a retrospective evaluation

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Abstract

Objective To evaluate the relationships between acromial anatomy and developmental alterations with rotator cuff tears in female patients and compare these parameters on radiographs and corresponding MRIs along with inter-reader performance.

Materials and methods Patient demographics, symptoms, and acromial characteristics on radiograph (acromial index, lateral acromion angle, subacromial space on AP and Y- views, acromial anterior and lateral downsloping) and MRI (shape, slope, spur, osteoarthritis, os acromiale) were recorded. Radiographic and MRI findings were compared and correlated with rotator cuff pathology on MRI. Inter-reader analysis was performed.

Results A total of 140 MRIs from 137 female patients were included. No significant correlation ($p > 0.05$) existed between acromial parameters and rotator cuff tears, except for a smaller subacromial space on the Y view and spurs correlated with subscapularis tendon tear ($p = 0.02$, $p = 0.04$). The presence of lateral downsloping on MRI correlated with a smaller lateral acromion angle ($p = 0.0002$) and the presence of lateral downsloping on radiography ($p = 0.0015$). Inter-reader agreements were good to excellent (ICC: 0.65–0.89).

Conclusion Subacromial impingement anatomy characteristics have no significant associations with supraspinatus or infraspinatus tears in symptomatic women. Among different measures, supine MRI can be reliably used to identify lateral downsloping of the acromion.

Keywords Subacromial impingement · Subacromial spur · Rotator cuff · Acromial slope · MRI

Introduction

Rotator cuff tear (RCT) is a common cause of shoulder pain, a condition responsible for 4.5 million doctor's office visits annually in the USA [1]. With a lifetime incidence of rotator cuff tear of 20–40% in USA, as many as 250,000 of these patients

require surgical repair of the rotator cuff [2], resulting in a significant societal and economic burden. Despite the significant impact of rotator cuff disorders on society, the etiology of RCT—beyond acute tear in the setting of trauma—is unclear and is often debated. In the 1930s, Codman and Akerson proposed an intrinsic “fatigue-failure” theory where the cumulative effect of repetitive chronic micro-trauma leads to the degeneration of rotator cuff tendons [3]. In contrast, Neer in the 1970s proposed the “impingement syndrome” theory where the anterior third of the acromion causes extrinsic compression and degeneration of the rotator cuff, which can be addressed by carrying out anterior acromioplasty [4]. Although some studies supported Codman's claim [5, 6], others validated Neer's findings [7–13]—though without much of a final consensus. It is also known that shoulder biomechanics differ significantly between males and females, with males having more strength and females exhibiting more endurance [14]. RCTs are likely more common in women

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[15], a group with higher pre- and post-operative disability than their respective male counterparts [16, 17]. Therefore, in our current study we have decided to focus on RCT in women. Imaging studies are often recommended in the work-up of patients with suspected RCT. Although radiographs detect humeral head migration in large RCTs and rule out other shoulder pathology [18], ultrasound and MRI are the preferred methods for the diagnosis and characterization of RCT [19]. Ultrasound studies have many pitfalls, including operator dependency, lack of adequate bony evaluation, and skill availability [20]. It is unclear whether anatomy associated with subacromial impingement (SIA), i.e., acromial characteristics, such as lateral extension, lateral slope, anterior slope, subacromial spur, and subacromial space on radiographs correlate with the findings, such as acromial shape, lateral/anterior slope, and spur on MRI.

To further explore the role of the acromial anatomy in rotator cuff pathogenesis, the aim of our study was to evaluate the relationships between acromial anatomy and developmental alterations with RCTs and compare these parameters on radiographs and corresponding MRIs along with inter-reader performance. We hypothesized that acromial slope and spur might positively correlate with RCT, whereas acromial shape and acromioclavicular osteoarthritis (ACOA) do not.

Materials and methods

For this Health Insurance Portability and Accountability Act-compliant retrospective cross-sectional evaluation, Institutional Review Board approval was obtained, and informed consent was waived.

Subjects

A search was conducted in the university hospital electronic health records for patients who had an MRI from January 2015 through May 2016 using the terms “shoulder MRI” and “female.” Exclusion criteria included nonroutine shoulder MRI (shoulder MR arthrogram, upper extremity MRI for tumor), presence of metal, previous surgery, trauma within 2 weeks, tumor, infection, myositis or neurogenic disorder, and lack of corresponding radiographs within 3 months of MRI (flow chart in Fig. 1). A detailed chart review was performed to obtain patient age, body mass index (BMI), height, occupation, and presenting symptoms.

Data collection

Magnetic resonance imaging was performed on 1.5-T and 3-T scanners, using conventional intermediate-weighted, fat-suppressed, and nonfat-suppressed imaging sequences in axial, coronal and sagittal planes using 3.5- to 4-mm slices. The

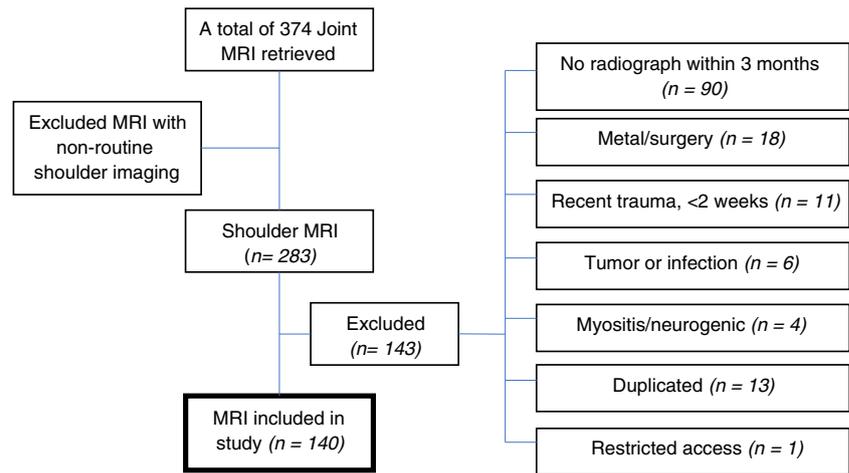
coronal and sagittal plane images were obtained parallel and perpendicular to the scapular body as identified on the scout images. All MRI examinations were non-MR arthrogram evaluations. All MRI reports contained a paragraph regarding SIA with elements of acromial shape, slope (lateral/anterior), acromioclavicular osteoarthritis, and acromial spur. The information was extracted by a medical student from various sections of the report, i.e., SIA, rotator cuff (supraspinatus, infraspinatus, subscapularis), and glenohumeral cartilage, and recorded on an Excel (Microsoft 2016) spreadsheet.

Data evaluation and repeat reads

A musculoskeletal fellowship-trained attending radiologist with more than 5 years of experience evaluated the 140 MRIs again and re-checked the information extracted by the medical student. The slice through the mid-acromion, as identified on nonfat-suppressed images, was chosen for the characterization of the acromial slope. Lateral and anterior downsloping of the acromion was qualitatively suggested based on the lack of parallelism in coronal and sagittal planes with the medial and lateral margins and anterior and posterior margins of the top of the humeral head respectively. Mild ACOA was designated if there was capsular thickening and/or small osteophytes. Moderate ACOA was designated if there were cartilage loss, subchondral cysts, and/or edema, and moderate osteophytes with/without some indentation of the rotator cuff. Severe ACOA was designated if there were large osteophytes indenting the rotator cuff, large areas of full-thickness or high-grade cartilage defects, and extensive subchondral cysts. The subacromial spurs were assessed as traction (enthesophytes at the deltoid attachment), keel (enthesophytes at the coracoacromial ligament attachment), bird beak (inferiorly projecting enthesophytes with undersurface remodeling of the acromion), and heel spur (acetabularization of the acromion), similar to the reported descriptions [7, 21, 22] on nonfat-suppressed MRI (Fig. 2). The disagreements regarding any of the findings were identified and recorded. To resolve these discrepancies, a second musculoskeletal fellowship-trained faculty member evaluated the discrepant MRIs and provided the final record of the cases where there were disagreements between the original report and the first faculty reader.

Radiographic evaluation

From the corresponding radiographic images obtained within 3 months of all MRIs, blinded to the MRI findings, a medical student and a radiology research fellow independently measured the acromial index [10], the lateral acromial angle [12], and the smallest subacromial space in anteroposterior (AP) and scapular Y views in the vertical planes (Fig. 3). The radiographs were obtained as the standard series with images in

Fig. 1 Flow chart of inclusion and exclusion criteria

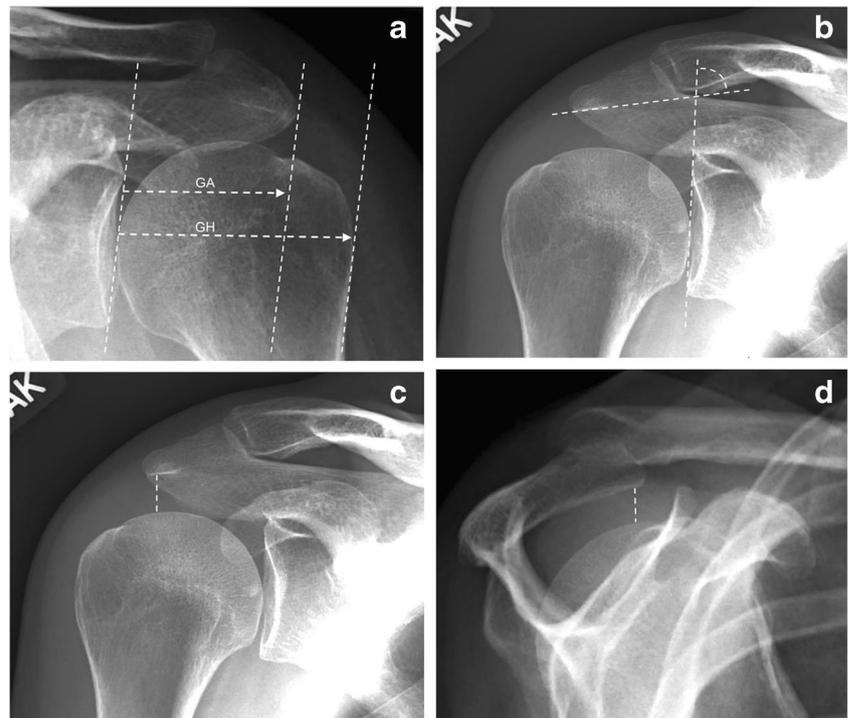
AP internal rotation, external rotation, scapular Y view, and axillary views. The readers chose AP internal rotation and scapular Y views. The study has the limitation of retrospective evaluation. Therefore, we could not standardize the perfect beam angle in every case. To train the readers and standardize the measurements, 10 scans were evaluated and measured together before the independent measurements were made on all scans blinded to each other's measurements and the MRI findings. All measurements were made directly onto the picture archiving and communication system (PACS; Isite; Philips) using distance and angle measurement tools. In addition, the readers independently qualitatively recorded the presence or absence of acromial lateral downsloping.

Statistical analysis

Descriptive and analytical statistics were performed on the data recorded from MRI and radiographic readings. The inter-reader agreement was assessed by intra-class correlation (ICC) and kappa statistics, for the continuous and categorical data respectively. The associations between radiographic and MRI measurements were tested using analysis of covariance and logistic regression when appropriate and adjusted for age and BMI at the same time. Multiple comparisons with Tukey adjustment were done when the factor had more than two levels. Groups of fewer than 5 were excluded from the analysis. SAS 9.4 (SAS Institute, Cary,

Fig. 2 Acromial spur classification: **a** traction, **b** heel, **c** keel, **d** bird beak

Fig. 3 Subacromial impingement (SLA) parameters measured on radiography. **a** Acromial index: lines parallel to the glenoid plane, the lateral margins of the acromion, and the lateral humeral shaft border were drawn. The ratio of the distance between the glenoid plane and the acromion (*GA*) and the distance between the glenoid plane and the humeral head (*GH*) determined the acromial index. **b** Lateral acromial angle: the angle of intersection between the line along the undersurface of the acromion and glenoid plane determined the lateral acromial angle. **c** Subacromial space, AP view and **d** Y view. The subacromial space is the measurement of the smallest vertical space between the undersurface of the acromion and the humeral head



NC, USA) was used for analysis. A *p* value less than 0.05 was considered statistically significant.

Results

Patient demographics

Among the 140 studies of 137 female patients, the mean age was 59 years (range 36–88 years). The average BMI was 31 (range 18–62). The average height was 163 cm (range 147–188 cm). The most common presenting symptom was pain, followed by a limited range of motion (ROM) and weakness (Table 1).

Acromial anatomy on radiographs

Of the 140 radiographic measurements, the acromial index was 0.73 ± 0.12 (mean \pm SD). The lateral acromial angle and subacromial space on AP and Y views were $77.44 \pm 8.68^\circ$, $8.74 \text{ mm} \pm 2.65 \text{ mm}$, and $8.15 \pm 3.49 \text{ mm}$ respectively. Qualitatively, 69 (49%) of the acromions exhibited lateral downsloping. The radiographic measurements showed excellent inter-reader agreement ($\text{ICC} > 0.8$) for acromial index, lateral acromial angle, and subacromial space in both AP and Y views. The inter-reader agreement was good (0.6–0.8) for the presence or absence of lateral downsloping (Table 2).

MRI findings

Subacromial impingement

Most of shoulders imaged in the study exhibited moderate ACOA (76, 54%), with a smaller number with mild ACOA (35, 25%) and severe ACOA (25, 18%). Anterior downsloping was present in 9% (13), whereas lateral sloping was more commonly seen in 30% (42). The most common acromial shape was curved, at 72% (101), whereas the least common shape was hooked, at only 2% (3). The acromial spurs were seen in 49% of shoulders and the majority were traction type (37, 26%), followed by heel (20, 14%), keel (10, 7%), and bird-beak (1, 1%) respectively. Os acromiale was present in 4% (6).

Table 1 Patient demographics and clinical characteristics

Patient demographics	Data
Age, mean \pm SD	59 \pm 12
BMI, mean \pm SD	31 \pm 8
Height (cm), mean \pm SD	163 \pm 8
Pain, frequency (%)	137 (100)
Limited ROM, frequency (%)	45 (33)
Weakness, frequency (%)	20 (15)

Table 2 Inter-reader agreement on radiographs

	ICC	95% CI	
Acromial index	0.89	0.85	0.92
Lateral acromial angle	0.87	0.82	0.91
Subacromial space AP	0.86	0.81	0.90
Subacromial space Y	0.82	0.75	0.87
Lateral downslope ^a	0.65	0.52	0.78

^akappa was used for the categorical data

Rotator cuff tear

Among the 140 MRI scans, 80 (57%) were performed on 1.5 T and 60 (43%) were performed on 3 T scanners. RCTs were most often seen in the supraspinatus tendon (128, 91%), followed by the infraspinatus (108, 77%) and subscapularis (51, 36%) tendons respectively. Of the 91% (128) of supraspinatus tendon tears, 43% (55) were full-thickness tears. The infraspinatus tendon was torn 77% of the time (108 cases), with 12% (13) being full-thickness tears. The subscapularis tendon tears were least common, seen 36% of the time (51 cases), with only 6% (3) being full-thickness tears. Forty-five percent of the gleno-humeral cartilage cases were pathological (61), most of which (51, 84%) involved partial loss of cartilage.

Discrepancies on repeat MRI reads

There were disagreements between the original MRI report and reader 1 interpretations, most often with respect to spurs in 23% and shapes in 17% with minimal disagreements regarding lateral slope, anterior slope, and acromioclavicular osteoarthritis (Table 3). Reader 2 agreed with reader 1 more frequently than with the original structured MRI report.

Radiography and MRI correlations

In characterizing the acromion on radiography and MRI, a smaller lateral acromial angle on radiography was associated with the presence of lateral downsloping on MRI ($p = 0.0002$; Fig. 4). The presence of lateral downsloping qualitatively on radiography was also significantly associated with the presence of lateral downsloping on MRI ($p = 0.0015$). Lateral acromion angle and the presence of lateral downsloping on radiography were not associated with ACOA, anterior slope, shape or spur as described on MRI. Acromial index and subacromial space (AP view and Y view) did not show a relationship with any of the radiological parameters describing the acromion on MRI either.

SIA anatomy and rotator cuff pathology

Lower subacromial space (Y view) on radiography was associated with subscapularis tears—full and partial—on MRI ($p = 0.02$; Fig. 5). The presence of a subacromial spur on MRI was associated with subscapularis tears—full and partial—on MRI ($p = 0.04$). There was no other significant difference in radiological parameters characterizing the acromion between the patients with and those without rotator cuff pathology (Table 4). Although the trend did not reach significance, patients with spurs almost always had supraspinatus tears. Patients with heel-type spur had zero (0%) intact supraspinatus (Fig. 6), 5 (31%) intact infraspinatus, and 8 (50%) intact subscapularis.

Discussion

There are many treatment options for RCT, a common cause of shoulder pain, ranging from NSAIDs and physical therapy to acromioplasty—the surgical reshaping of the acromion, Mumford procedure (distal clavicle resection), and acromioclavicular joint plasty. Despite the availability of many conservative options and the questionable therapeutic value of SIA correction, there has been an increasing incidence of acromioplasty in the last couple of decades [23]. In addition to designing parameters to characterize the acromion, many studies have utilized these parameters in isolation and have been inconclusive in determining the acromion's role in the etiology of rotator cuff disease. Our current study comprehensively evaluated acromial index, lateral acromial angle or lateral slope, subacromial space, acromial shape, anterior slope, and acromial spur on both radiography and MRI to identify their association with RCT and did not find any significant associations with supraspinatus or infraspinatus tendon tears.

The acromial index, a measure of the lateral projection of the acromion, was found to be larger in patients with RCT than in those with healthy shoulders by Nyffeler et al. [10]. Although some studies support this claim [13, 24], others were unable to confirm this trend [8]. Despite our excellent inter-observer reliability, we did not find a statistically significant difference in acromial index between patients with and those without RCT, partial- or full-thickness tears. Our findings are directly supported by a study published by Balke et al. [11] showing no significant difference in the acromial index between the impingement and RCT groups. Another study found that the acromial index cannot predict the recurrence of RCT after primary arthroscopic repair [25].

Lateral acromial angle introduced by Banas et al. in 1995 [12] describes the lateral downward sloping of the acromion. A smaller angle indicates a smaller space housing the rotator cuff tendons. Banas et al. [12], supported by other studies [11,

Table 3 Disagreement between the initial report and study readers

Variable	Initial disagreement with structured report (1st reader)		Final disagreement with structured report (2nd reader)	
	Frequency (<i>n</i>)	Percentage (%)	Frequency (<i>n</i>)	Percentage (%)
Shape	24	17	19	14
Anterior slope	3	2	3	2
Lateral slope	7	5	6	4
Spur	32	23	24	17
ACOA	2	1	1	1

ACOA acromioclavicular osteoarthritis

13], have shown correlation between smaller lateral acromial angle and RCT. One study in particular showed a difference in the lateral acromial angle between the impingement group

with intact rotator cuff and the RCT group [11]. However, we did not find a statistically significant difference in lateral acromial angle between the intact rotator cuff and RCT groups

Fig. 4 **a** Lateral acromion angle on radiography, **b** lateral downsloping on MRI, **c** smaller lateral acromion angle on radiography associated with the presence of lateral downsloping on MRI

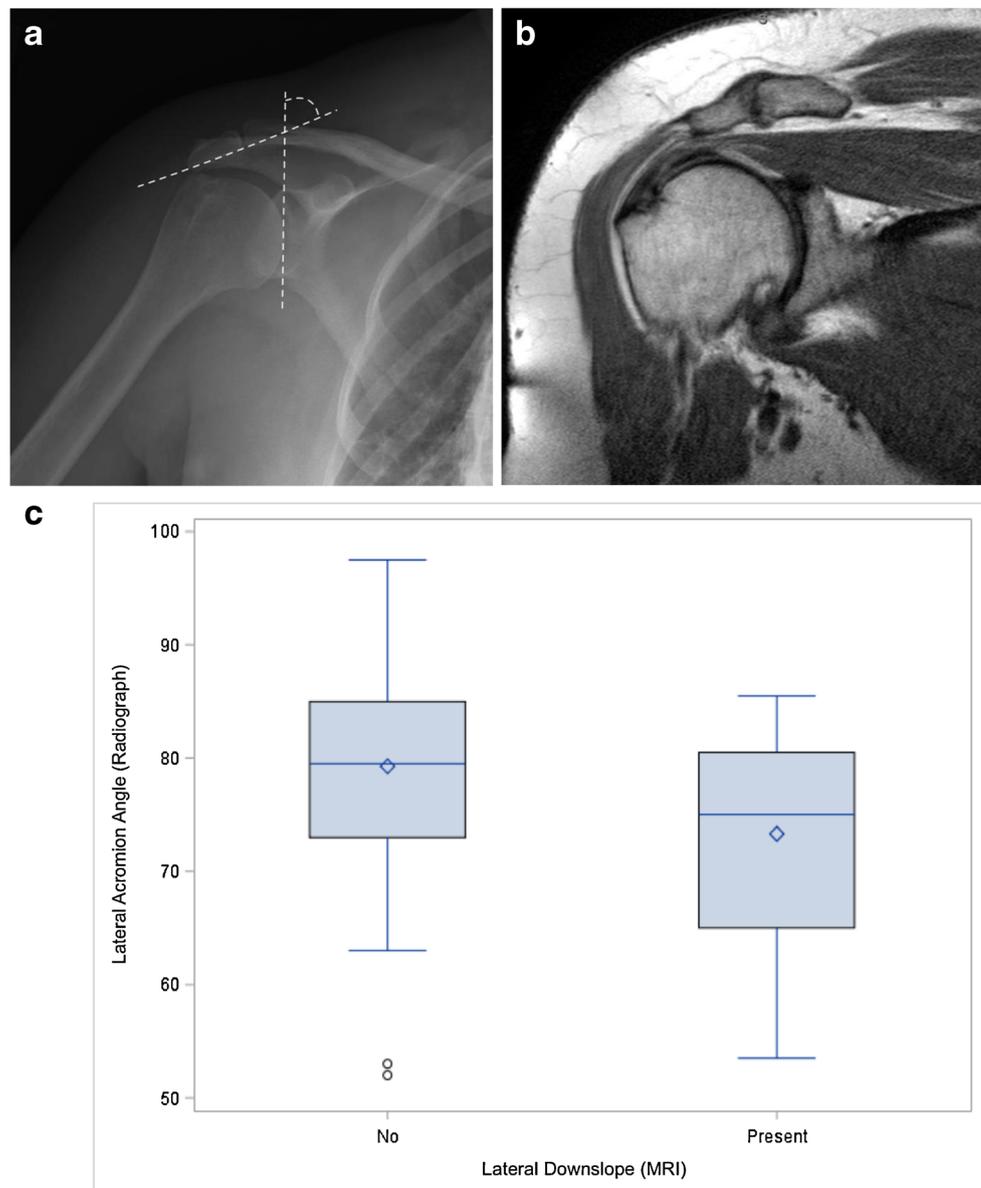
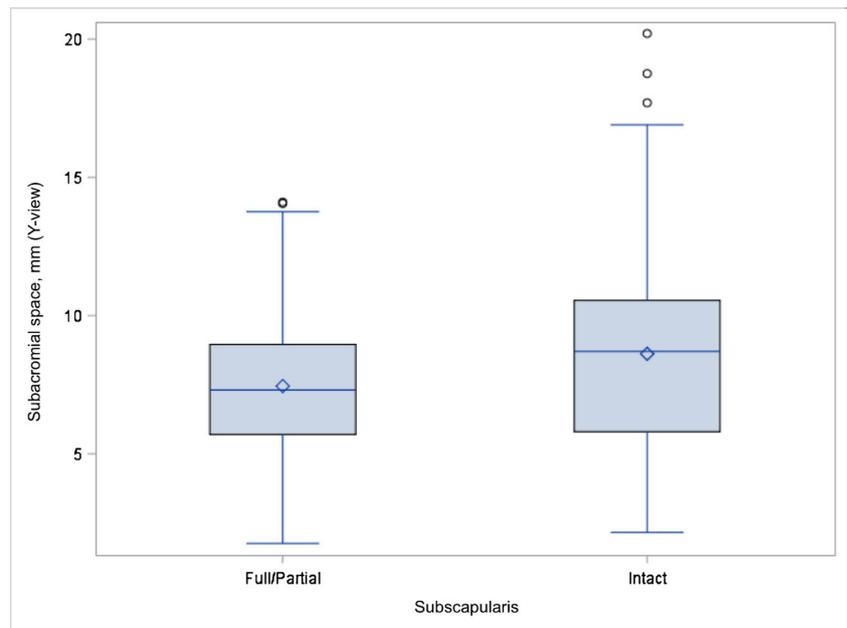


Fig. 5 Lower subacromial space (Y view) associated with subscapularis muscle tendon tear



with the limitation that we did not have asymptomatic patients in our study. Again, the inter-observer reliability here was excellent. Correlation between a smaller lateral acromial angle on radiograph and the presence of lateral downsloping on MRI suggests that evaluation of lateral downsloping of the acromion might be performed in a similar manner on the supine MRI to that on the radiographs [26].

Based on a previous study [27], we chose to define anterior sloping of the acromion as the overall impression of the slope of the acromion subtracting out the spur in contrast to the commonly used acromial tilt, which does not take into account the added consequence of acromion spurs. Our study found no association between the presence of anterior sloping and RCT, a similar finding to a study [27] that used 3D reconstructions and subtracted out the acromial spurs. Other studies [28–30] that found an association between anterior sloping and RCT defined

anterior sloping through the measurement of the acromial tilt angle, which, as stated before, does take into consideration the presence of acromial spurs.

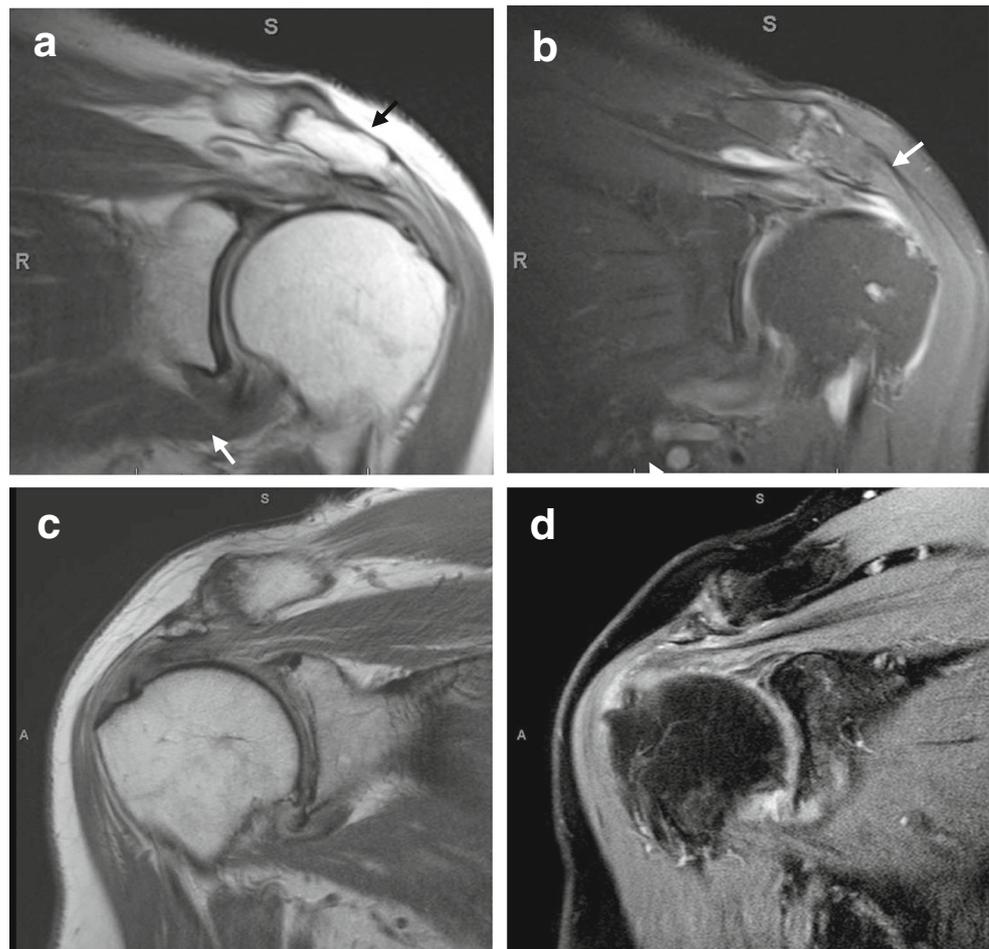
Bigliani classified acromial shape into flat (type I), curved (type II) or hooked (type III) and reported an association between hooked acromion (type III) and RCT [9]. Our study showed no correlation between acromial shape and RCT, although there were only a small number of hooked acromions. Other studies comparing symptomatic patients with an intact rotator cuff and symptomatic patients with RCT support our finding that acromial shape is not associated with RCT [11, 31]. Although classification of acromial shape is difficult to standardize [32], the discrepancy between the standard report and our final read was a mere 14%—second only to spurs. This suggests that a standard read of shoulder MRI by musculoskeletally trained radiologists might be satisfactory for clinical purposes.

Table 4 Correlation of acromial parameters with rotator cuff tears and glenohumeral cartilage degeneration

	Supraspinatus tears	Infraspinatus tears	Subscapularis tears	Glenohumeral cartilage degeneration
Acromial index	0.5735	0.6693	0.1866	0.179
Subacromial space AP	0.1652	0.5425	0.4761	0.8463
Subacromial space Y	0.8045	0.8477	0.0246	0.3761
Lateral acromial angle	0.0686	0.2873	0.4105	0.1933
Lateral downsloping (radiography)	0.1149	0.0807	0.1970	0.2711
Lateral slope (MRI)	1.00	0.19	0.85	0.19
Anterior slope	1.00	0.49	0.77	1.00
Shape ^a	1.00	0.82	0.69	0.23
Spur ^a	0.22	0.092	0.035	0.26

^a Bird-beak spur and “hooked” shape morphologies were excluded from analysis owing to the small sample size

Fig. 6 **a, b** Coronal MRI images show a heel spur and a full-thickness supraspinatus tear (*arrows*). **c, d** Coronal MRI images show a keel spur and a partial-thickness supraspinatus tear (*arrows*)



Many studies have shown that subacromial spurs, especially the heel spur, are associated with RCT [4, 7, 8]. However, our study found an association only between subacromial spurs and subscapularis tears—a minority of cases. For most tears—supraspinatus and infraspinatus—there was no relationship between subacromial spurs and RCT. Also, we found no association between the subacromial space (AP and Y view) and RCT, except between the subacromial space Y view and subscapularis tear. The association found may not be a true representation and most likely occurred as a result of the difficulty in standardizing Y view radiographs and the variability of arm positions during image acquisition, which could not be controlled owing to the retrospective nature of the study. On AP view radiographs, the subacromial space of 8.7 ± 2.6 mm is comparable with those previously reported in women (9.2 ± 1.4 mm) [33]. A recent study also reported no difference in the subacromial space between healthy controls and an RCT group at 0° elevation [34]. There are numerous surgical studies [35–37] that support the non-association of RCT with the anatomical factors of subacromial impingement. These studies show that arthroscopic decompression surgery or acromioplasty does not provide any added benefit over placebo or investigational arthroscopy only.

There are certain limitations to this retrospective study. First, all of our patients—those with and those without RCT—were symptomatic, and there was no control group of asymptomatic individuals with intact rotator cuffs. Because all patients were symptomatic, we had a limited number of patients without RCT, as detected on MRI. The study had a limited number of patients with bird-beak spur and hooked shape acromion. Also, we did not have arthroscopic or surgical confirmation of acromion characteristic or rotator cuff condition. In addition, our cross-sectional study can only investigate associations between acromial parameters and RCT; the cause-and-effect relationship between the acromion and RCT cannot be inferred. As our study focuses on women, our findings may not be generalizable to the entire population; however, RCT may be both more common and more disabling before and after surgery in women compared with men. Finally, subcoracoid impingement—a common condition in women—was not assessed and may have contributed to some associations found between acromial parameters and subscapularis tear in this study [38]. In addition, we did not measure clavicle malposition and it may play a role in rotator cuff pathology as distal clavicle resection with subacromial decompression has been shown to produce favorable results [39].

Contrary to the subacromial impingement theory, our study shows that anatomical characteristics of subacromial impingement have no significant associations with supraspinatus or infraspinatus tears in symptomatic women.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interest.

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