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Sharpened lateral acromion morphology (SLAM sign) as an indicator of rotator cuff tear: a retrospective matched study

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Background: Bigliani types of acromion and critical shoulder angle (CSA) have been implicated as indicators of rotator cuff disease. A sharpened inferolateral edge of acromion (termed as Sharpened Lateral Acromion Morphology or SLAM sign) is frequently observed in anteroposterior radiographs of the glenohumeral joint in patients with rotator cuff tears (RCT). We aimed to evaluate the association of the SLAM sign with RCT in comparison to high CSA (≥35°) and Bigliani type 3 (hooked) acromion.

Methods: A cohort of 100 consecutive patients undergoing non-arthroplasty surgery for RCT and 106 patients with primary frozen shoulder were matched manually in 1:1 ratio based on age and gender to yield study population with 50 patients in each group. The 2 groups were compared for the presence of the SLAM sign, high CSA, and type 3 acromion on the radiographs.

Results: All the 3 parameters were found more prevalent in the RCT group than the frozen shoulder group (SLAM, 46% vs. 0; high CSA, 60% vs. 40%; type 3 acromion, 18% vs. 4%) ($P < .05$). The SLAM sign showed stronger correlation with RCT than high CSA and type 3 acromion ($Ps = 0.562$ vs. 0.220 vs. 0.224 respectively).

Conclusion: The SLAM sign is a simple and easily identifiable radiological predictor of rotator cuff disease.

The etiology of a degenerative rotator cuff tear (RCT) is considered multifactorial resulting from a combination of intrinsic and extrinsic factors.[5,11,12,15,21,23,24,26,30] Extrinsic impingement of the rotator cuff tendon caused by the acromion and coraco-acromial arch was first suggested by Armstrong[2] in 1949 and then popularized by Neer[21] in 1972. Later, Bigliani et al[5] described 3 types of acromion based on the shape of the anterior aspect of acromion; type-I (flat), type-II (curved), and type-III (hooked) acromion. Subsequently, many researchers believed that type III (hooked) acromion causes degeneration in rotator cuff tendon by reducing the subacromial space and thereby causing mechanical compression of the tendons.[1,3,5] However, this radiological sign has been criticized for poor interobserver reliability and poor association with RCT in a few studies.[10,27] A bony spur at the anteroinferior aspect of acromion was noted first by Neer to cause impingement on the rotator cuff tendon.[21] Since then, a variety of acromion spurs were identified as predictors of RCTs; keel, heel, hat-shaped, and irregular spurs.[13,15,25-27] Other types of spur have not been found to influence the risk of RCTs.[26]

More recently, many scapular morphometric measures focusing on the lateral extension of acromion such as acromion index[24] and lateral acromion angle[4] were developed to predict RCTs. Other measurements focused on glenoid morphology such as glenoid inclination[12] and retroversion.[29] In 2013, Moor et al[20] published the critical shoulder angle (CSA) by combining acromion index and glenoid inclination where 84% of the patients with high CSA (>35°) were diagnosed to have degenerative RCTs. According to Gerber et al,[9] high CSA alters length-tension relationship and results in the need of additional supraspinatus force to balance the instability caused by an increased superiorly directed deltoid force, increased shear force, and reduced compressive force, which causes a higher mechanical load in the supraspinatus tendon, ultimately leading to tendon failure. Subsequently, the CSA was found as a significant predictor of degenerative RCTs by many investigators.[1,10,20,27]

A recently conducted meta-analysis of 14 studies comparing 1361 RCT with 1189 non-RCT patients by Andrade et al[1] revealed significant association of type III acromion, acromion spur, acromial index, lateral acromial angle, and high CSA with degenerative rotator cuff

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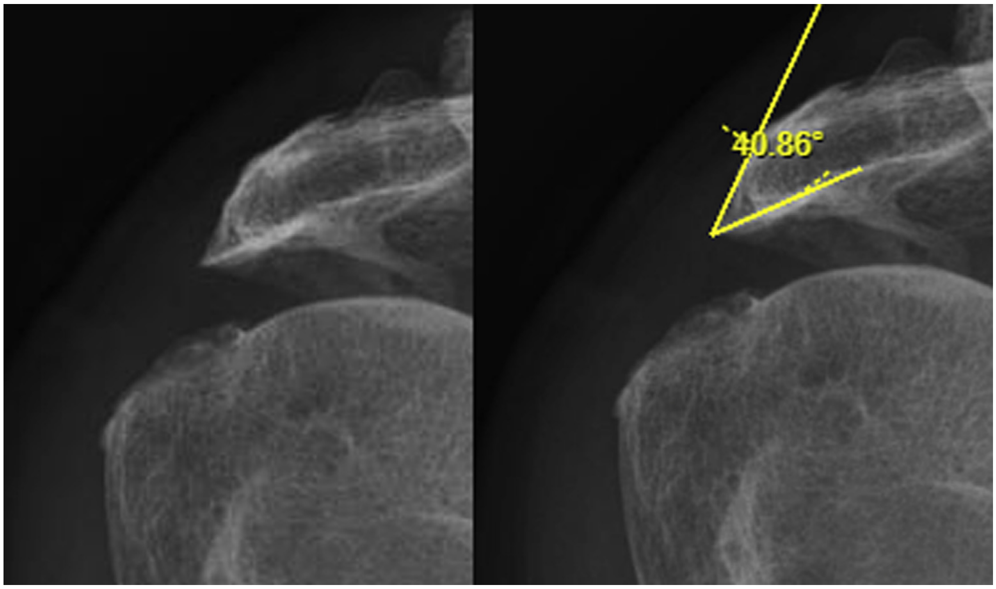

Figure 1 Radiographs of glenohumeral joint showing the assessment of infero-lateral acromion angle (ILAA) which measures 40.86°. It is measured between a line along the inferior border of acromion starting from the most inferolateral point and another line connecting the most inferolateral point to the most prominent point on lateral border of acromion.

tears. There was moderate evidence of a higher weighted mean CSA angle of 36.8° in the RCT group than 33.6° in the control group with mean difference of 4.19° ($P < .001$). It also showed moderate evidence for a significant association between type III acromion and degenerative RCT (relative risk = 1.98, $P = .001$).

In our practice, we have observed a radiological feature that encompasses all the adaptive changes of the lateral acromion associated with RCTs previously described such as acromial spurs, subacromial sclerosis, and subacromial osteophytes.[13,15,25,26,31] While in non-RCT patients, the inferolateral edge of acromion demonstrated a rounded shape; in many RCT patients, the inferolateral edge demonstrated a pointed or sharpened appearance, which is evidenced by an acute angle (<90 degrees) formed between the lateral and inferior borders of the acromion. An extensive literature search did not reveal any such description of acromion in relation to RCTs. We have named this entity the "Sharpened Lateral Acromion Morphology (SLAM) sign".

The primary objective of this study was to investigate the association between the SLAM sign and RCTs. The secondary objective was to compare its predictive ability on cuff tears with that of other valid parameters; type III acromion and CSA. We hypothesized that, first, the SLAM sign would be more common in patients with RCT than in non-RCT patients, and second, it would have a comparable predictive ability to a type III acromion and a high CSA.

Materials and methods

This retrospective review was conducted at our institution between July 2016 and December 2017 after obtaining approval from the ethics committee (NHS-HRA/HCRW IRAS 289721). A total of 100 patients with degenerative posterosuperior RCTs (RCT group) with concentrically located humeral heads (Hamada grade < 2) were selected from the operative theatre records in a consecutive manner if they had undergone nonarthroplasty rotator cuff surgery (rotator cuff repair, augmented repair, cuff debridement, or isolated long head of biceps tenotomy) after failed conservative treatment including physical therapy, injections, activity modification, and anti-inflammatory drugs. The patients with traumatic RCTs, associated fractures around shoulder joint, cuff tear arthropathy, previous shoulder surgery, and osteonecrosis were excluded.

The control group comprised 106 patients with primary frozen shoulder, selected from the outpatient record system in a consecutive manner with ultrasound demonstrating features of adhesive capsulitis (thick glenohumeral capsule and increased soft tissue in rotator interval) and intact rotator cuff tendons. The patients were excluded if frozen shoulder was secondary to surgery, trauma, or underlying rotator cuff pathology. The strict inclusion criteria for both the groups were the availability of a Grashey view[14] radiograph with 30° of caudal tilt and a supraspinatus outlet view[22] for each patient.

The radiographs were reviewed by 2 of the authors for adequate quality to be included in the study. If there was disagreement between the 2 assessors, the patient was excluded from the study. A total of 66 patients with degenerative RCTs and 84 control patients were identified with adequate imaging. Subsequently, the 2 groups were matched manually in a 1:1 model based on age and gender to yield a final study population with 50 patients in each group.

The preoperative diagnosis of RCT, earlier confirmed with ultrasound or MRI, was reconfirmed at arthroscopy. The type of tear was documented; articular-sided tear, bursal-sided tear, or full-thickness tear. The size of tear was measured with arthroscopic probe and subsequently classified as per Cofield classification[6]; small (<1 cm), medium (1-3 cm), large (3-5 cm), and massive (>5 cm).

The angle between the inferior and lateral borders of the acromion using the most inferolateral point as the apex was termed the "infero-lateral acromion angle" (ILAA) (Fig. 1). This was measured in all patients, and if less than 90 degrees, it was considered as SLAM sign. Furthermore, 2 independent assessors (junior doctors with no specialist orthopedic or shoulder experience) were given a brief but a comprehensive explanation on the radiological characteristics of a SLAM sign. They were then asked to evaluate the radiographs of the patients in both groups (while they were blinded to the groups) and identify the presence, or not, of SLAM signs. This was done on 2 different occasions at least 15 days apart. The CSA was measured on

Figure 2 Radiographs showing various presentation of SLAM signs all associated with a rotator cuff tear. *SLAM*, sharpened lateral acromial morphology.

the Grashey view.[20] It was classified as normal (<35°) or high (≥35°). The supraspinatus outlet view radiograph was assessed for acromion types as per Bigliani's classification.[5] The radiographic measurements were performed electronically on Carestream Vue Patient Archiving and Communication System (Carestream Health, Inc. 2020, Rochester, NY, USA) using an image analysis software program.

Statistical analysis

The statistical analysis was performed using SPSS 22.0 (IBM Corp, Armonk, NY, USA). Continuous variables were presented as a mean (standard deviation), and categorical values were presented as numbers or percentages. Intraobserver and interobserver reliability was calculated using Cohen kappa coefficient for agreement between the 2 assessors for positive identification of a SLAM sign. The weighted kappa (k) values were graded as excellent (0.81-1.0), substantial (0.61-0.80), moderate (0.41-0.60), fair (0.21-0.40), and slight (0-0.20) agreement.[16] The prevalence of 3 parameters between RCT and the control groups was assessed using Chi-square and Mann-Whitney tests. Spearman correlation test was used to evaluate the relationship between different variables and RCTs. One-way analysis of variance test was used to evaluate the relationship of a SLAM sign with age and tear sizes.

Results

The mean age in both groups was 51 (range, 36-66) years. There were 24 female and 26 male patients in each group. Left:right distribution was 18:32 in RCT group and 28:22 in the control group. In the RCT group, full thickness tears were most common (58%), followed by articular-sided (30%), then bursal-sided tears (12%). Nine patients had an additional tear in their subscapularis tendon. In the control group, ultrasound confirmed intact rotator cuff tendon in all the patients.

The ILAA measured was 111.9 ± 13.5° (range, 90-135°) in the control group. In the RCT group, it measured 86.9 ± 26.7° (range, 45-139°). Those with the characteristic SLAM appearance (24 patients) had a mean angle of 62.1 ± 9.9° (range, 45-82°), whereas in the RCT patients without a SLAM sign, the ILAA measured 110.6 ± 11.4° (range, 92-139°). It was logical to stipulate that an ILAA of less than 90 degrees indicated the presence of a SLAM sign.

While SLAM signs were observed in 46% of patients in the RCT group (Fig. 2), none in the control group demonstrated this sign (P < .001) (Fig. 3). The Kappa value for intrarater and interrater reliability score for SLAM sign was 0.83 and 0.76 showing excellent intrarater and substantial interrater agreement. Table I shows the distribution of the 3 parameters in the 2 groups.

The mean CSA in the RCT group (36.1° ± 4.6°) was significantly higher than that in the control group (34.3° ± 3.8°) (P = .046).

Figure 3 Radiograph of a patient with frozen shoulder showing absence of a SLAM sign. *SLAM*, sharpened lateral acromial morphology.

Table 1
Distribution of parameters in two groups

Parameters	RCT	Control	*P* value
Acromion types			
Type 1	12 (24%)	29 (58%)	.025*
Type 2	29 (58%)	19 (38%)	
Type 3	9 (18%)	2 (4%)	
CSA			
Normal (<35°)	20 (40%)	30 (60%)	.046#
High (≥35°)	30 (60%)	20 (40%)	
SLAM			
Present	24 (48%)	0	<.001#
Absent	26 (52%)	50 (100%)	

CSA, critical shoulder angle; *SLAM*, sharpened lateral acromial morphology; *RCT*, rotator cuff tear group.
*Mann-Whitney test.
#Chi-square test.

A high CSA (>35°) was seen in 60% of patients in the RCT group compared with 40% patients in the control group ($P = .046$). Type 2 acromion was the most common acromion type in the RCT group, whereas, in the control group, type 1 was most common. Type III acromion was more frequently seen in the RCT group (18%) than in the control group (4%) ($P = .025$).

All the 3 parameters correlated significantly with RCT. The SLAM sign demonstrated a stronger relationship with RCT ($Ps = .562$) than type III acromion ($Ps = .224$) and high CSA ($Ps = .220$) (Table II). SLAM sign demonstrated higher positive predictive value (100) for cuff tear than high CSA and type III acromion. However, the negative predictive value of a SLAM sign was only slightly better than a high CSA and type III acromion (Table III).

The SLAM sign significantly correlated with a high CSA, as it was seen in 34% of patients with high CSA in comparison to only 17% of patients with normal CSA. It also showed a strong relationship with acromion type, with 63.6% of patients with type III acromion exhibiting SLAM signs as compared to only 19.1% with type I/II acromion (Table II).

Among the 24 SLAM signs in the RCT group, there were 7 patients where we could clearly also identify subtypes of acromion spurs (2 lateral traction, and 5 hat-shaped spur) (Fig. 4). These spurs were not seen in the control group.

There was no significant difference in the mean age and decade-wise distribution of SLAM signs in the whole population ($P > .05$).

Table 2
Correlation of three parameters with rotator cuff tear

Parameters	SLAM	High CSA	Type III acromion	RCT
SLAM	1	*Ps* = .223 *P* = .019	*Ps* = .326 *P* < .001	*Ps* = .562 *P* < .001
High CSA	*Ps* = .223 *P* = .019	1	*Ps* = .153 *P* = .129	*Ps* = .220 *P* = .046
Type III acromion	*Ps* = .326 *P* < .001	*Ps* = 0.153 *P* = .129	1	*Ps* = .224 *P* = .025
RCT	*Ps* = .562 *P* < .001	*Ps* = .220 *P* = .046	*Ps* = .224 *P* = .025	1

SLAM, sharpened lateral acromial morphology; *CSA*, critical shoulder angle; *RCT*, rotator cuff tear group; *Ps*, spearman correlation coefficient.

Table 3
Predictive values of each parameter for rotator cuff tear

Parameters	PPV	NPV
High CSA (≥35°)	60	60
Type 3 acromion	81.8	53.9
SLAM	100	65.8

CSA, critical shoulder angle; *SLAM*, sharpened lateral acromial morphology; *PPV*, positive predictive value; *NPV*, negative predictive value.

The SLAM sign was observed in 12.5%, 28.9%, 22.5%, and 21.4% of patients in fourth, fifth, sixth, and seventh decades, respectively. It was observed more commonly in bursal tears (66.7%) and full-thickness tears (58.6%) than in articular-sided tears (13.33%). Similarly, it did not show any relation with tear size ($P = .537$) (Table IV).

Post-hoc power analysis with a sample size of 50 in each group and alpha level of 0.05 suggested that the sample size was adequately powered (1.0) to detect 48% difference in prevalence of SLAM signs between the 2 groups.

Discussion

This study has demonstrated the value of the SLAM sign as a predictor of degenerative RCTs. This sign shows correlation with cuff tears and compares well with the 2 most commonly used radiological parameters in relation to RCTs in current practice; type III acromion and high CSA.

Similar to previously published literature,[1,3,5,10,20,27] the present study also found greater incidence of a high CSA and type III acromion in the RCT group than in the control group. However, these parameters are also observed in the non-RCT patients. In the index article by Moor et al,[20] 16% of patients with high CSA had either osteoarthritis (4%) or no pathology (12%) in the glenohumeral joint. Similarly, a recent systematic review demonstrated that type III acromion was found in 11.7% of the non-RCT patients.[1] In contrast, the SLAM sign was seen specifically in the RCT patients. As a result, it demonstrated a stronger relationship with a higher correlation coefficient and predictive values for RCTs. This may be explained by the fact that a type III acromion and high CSA are believed to be predisposing factors for RCTs, while a SLAM sign, as proposed, develops secondary to the tear. This must also be the reason that the SLAM sign correlated significantly with a high CSA and type III acromion.

In our study population, around 30% of SLAM signs were also identified as a lateral traction spur[26] or a hat-shaped spur[13] because of sharpened inferolateral edge of acromion in these spurs. However, in contrast to a spur which is considered significant if it protrudes at least 2 mm beyond the lateral margin of the original acromion,[15,26] the SLAM sign was not necessarily distinguishable from the original lateral acromion, which was the case in around

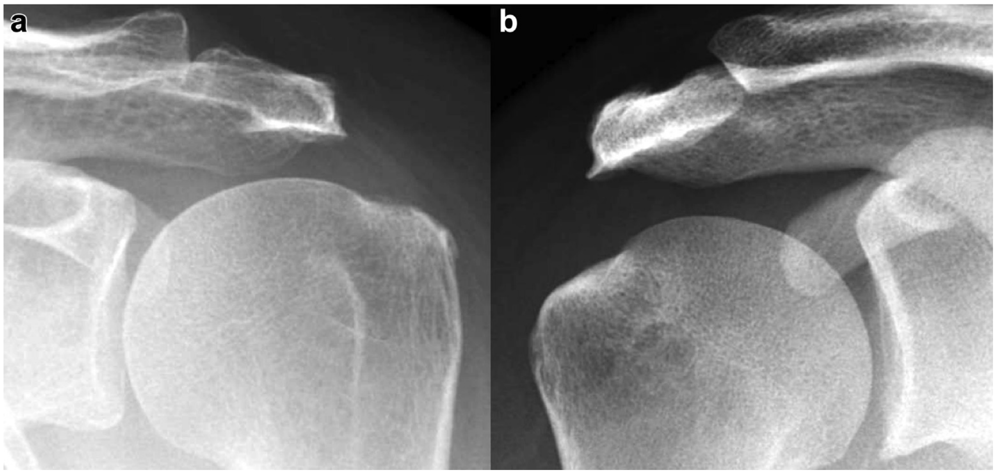

Figure 4 Radiograph showing SLAM signs also identified as (**a**) hat-shaped spur in association with bursal-sided tear and (**b**) lateral traction spur in association with full-thickness tear. *SLAM*, sharpened lateral acromial morphology.

Table 4
The distribution of SLAM sign in the study population in accordance with age, tear type, and size

Parameters	Number of patients (n = 100)	SLAM		*P* value
		Present	Absent	
Mean age (y)		51.2 ± 6.9	51.5 ± 8.1	.844*
Decades (y)				
31-40	8	1 (12.5%)	7	.793†
41-50	38	11 (28.9%)	27	
51-60	40	9 (22.5%)	31	
>60	14	3 (21.4%)	11	
Tear type				
Articular-sided	17	3 (17.6%)	14	.009‡
Bursal-sided	6	4 (66.7%)	2	
Full-thickness	27	17 (62.9%)	10	
Tear size (cm)				
<1	3	1 (33.3%)	2	.537†
1-3	16	11 (68.7%)	5	
3-5	8	5 (62.5%)	3	
>5	0	0	0	

SLAM, sharpened lateral acromial morphology.
*Unpaired t-test.
†One-way analysis of variance test.
‡Chi-square test.

70% of this series. We appreciate that previously various subtypes of lateral spurs have been described, but we believe that the broader concept of the SLAM sign, which encompasses different patterns of morphology in the lateral border, can be regarded as a more pragmatic and more easily identifiable radiological indicator of a superior RCT. Moreover, the SLAM sign did not demonstrate predilection towards advancing age, unlike anterior acromial spurs which are observed more often in the aging population but do not always indicate RCT.[10,25,26]

The cause-effect relationship of alterations in acromial morphology with RCTs has long been debated. Acromial spurs are considered by a few authors as a part of degenerative process that could cause cuff tears by mechanical compression.[17] However, others believe that the spurs form along the deltoid muscle secondary to RCTs as a result of mechanical impingement of the greater tuberosity.[7] We believe that the pathogenesis of a SLAM sign is closely related to that of an acromion spur, ie, it develops as an adaptive change of the acromion which appears as the degeneration in the tendon progresses, possibly due to increased mechanical load at the deltoid attachment on the acromion. However, this would need further investigation to be proven.

Currently, the therapeutic importance of SLAM signs is not entirely clear. The acromioplasty is performed as an adjunct procedure during rotator cuff repair to ablate the effect of type III acromion (anteroinferior acromioplasty) and high CSA (lateral acromioplasty).[8,21] However, recently, several authors have questioned the role of anteroinferior acromioplasty during rotator cuff repairs.[19,28] In our practice, we routinely aim to remove the sharpened lateral edge of acromion as a part of the acromioplasty performed during rotator cuff surgery to reduce the mechanical stress on the superior rotator cuff by medializing the force vector of the deltoid. Furthermore, the SLAM signs were observed in relation to both partial-thickness and full-thickness RCTs. Therefore, the identification of a SLAM sign should prompt the clinician to suspect a partial- or full-thickness tear. The partial-thickness tears are known to progress into full-thickness tears in 10%-50% of cases.[18] Hence, it may be assumed that this would help in early detection of partial tears, allowing prompt treatment and preventing progression onto full-thickness tear.

Our study has demonstrated the internal validity of the SLAM sign as a predictor of degenerative RCTs which is easy to identify on plain radiograph. It is evident from the fact that once the junior doctors had been given an explanation of a SLAM sign, they were accurately, consistently, and reproducibly able to identify these signs by their characteristic appearance alone, as indicated by the high kappa values. Although measurements of ILAA convincingly demonstrated that all the SLAM signs had angles of less than 90°, the interobserver and intraobserver assessments did not require the ILAA to be measured.

Other characteristics of the SLAM sign were also noted during our analysis. They were evenly distributed across different tear size groups, which might suggest that their occurrence does not relate to the size of the RCT. This feature is supported by the finding of Fujisawa et al[7] who suggested that the degree of change in acromion morphology is not affected by the degree of subacromial pressure. Moreover, the SLAM sign showed stronger association with bursal-sided and full-thickness tears than articular-sided tears.

The main limitation of this study is its retrospective nature. However, group-matching and blinded analysis were undertaken to reduce potential bias. There is also a possibility of selection bias as only operative RCTs were investigated which may limit the application of our results to the wider population including patients with asymptomatic or conservatively treated RCTs. Having said this, anecdotally, we have identified SLAM signs in many patients with RCTs who we have initially managed nonoperatively. The exclusion of the RCT patients due to inappropriate radiographs also might have led to the selection bias.

Conclusions

The SLAM sign is a common, easily identifiable and reliable radiological marker of degenerative RCTs. It was not observed in the control group. Compared to CSA and Bigliani acromion types, it is a better predictor of RCTs with a higher correlation coefficient and positive predictive value. The positive predictive value of 100 would suggest that this study indicates that SLAM signs are pathognomonic for degenerative failure of the superior rotator cuff. For patients exhibiting a SLAM sign, there should be further evaluation of the soft tissues with ultrasound or MRI.

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