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The radiographic morphology of the greater tuberosity is associated with muscle degeneration in patients with symptomatic rotator cuff tears

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Background: Atrophy and fatty infiltration of the rotator cuff muscles portend poor findings in terms of postoperative function and the probability of retears. We assumed that sclerosis and spurs of the greater tuberosity (GT) on radiographs are associated with this rotator cuff muscle degeneration.
Methods: We retrospectively reviewed the preoperative radiographs and magnetic resonance (MR) images of 91 shoulders (average age of patients, 59.7 years; age range, 36-79 years) arthroscopically repaired between 2012 and 2016. The radiographic morphology of the GT was defined as normal, sclerotic, or spurring. Atrophy and fatty infiltration of the rotator cuff muscles were evaluated using the occupation ratio and Goutallier classification, respectively, via the MR images. Diagnoses of rotator cuff tears were made during arthroscopic shoulder surgery.
Results: Significant associations between the radiographic GT morphology and the severity of both supraspinatus muscle atrophy ($P = .002$) and infraspinatus muscle atrophy ($P = .047$) were found. The mean occupation ratios of both the sclerotic GT group and the spurring GT group were significantly reduced compared with the mean occupation ratio of the normal GT group. Patients with GT spurs were found to be prone to severe supraspinatus fatty degeneration ($P = .020$).
Conclusions: For patients with rotator cuff tears, the presence of GT spurs or sclerosis on radiographs predicted the occurrence of supraspinatus and infraspinatus muscle atrophy, as well as supraspinatus fatty infiltration, based on MR images. The clinical relevance is that MR imaging is suggested for patients with radiographic GT sclerosis or spurs to detect advanced rotator cuff lesions.

The study protocol was approved by the Ethics Review Board of National Cheng Kung University (No. B-ER-106-248), and the requirement for informed consent was waived considering the retrospective design of this study.

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With advances in shoulder surgery techniques and imaging modalities, associations between pathology of the rotator cuff and radiographic abnormalities of the greater tuberosity (GT) have been established. From impingement syndrome[4] to partial- or full-thickness rotator cuff tears,[4,18,34] the associated radiographic signs include GT sclerosis,[19] GT spurs,[18] a decreased acromiohumeral interval, and subacromial spurs, among others.[13] Recently, radiographic GT spurs and sclerosis were shown to be associated with the occurrence of symptomatic rotator cuff tears,[28] as well as the incidence of larger tears.[17]

The preoperative condition of the rotator cuff muscles has a profound impact on the outcomes of rotator cuff repair. Fatty infiltration has been predicted to lead to poor postoperative functional outcomes[9,12] and higher retear rates after repair.[10] Atrophy of the supraspinatus has been found to be related to higher irreparability of rotator cuff tears.[16] Some authors have called for early diagnoses and early treatment before the accumulation of adipose tissue in the rotator cuff muscles.[10]

Accordingly, we hypothesized that radiographic GT morphologic changes, such as spurs and sclerosis, are related to fatty infiltration or atrophy of the rotator cuff muscles. To our knowledge, no previous study has directly addressed the relation between radiographic abnormalities of the GT and rotator cuff muscle quality, inclusive of fatty infiltration and muscle atrophy. Hence, we aimed to retrospectively review preoperative images and arthroscopic records to confirm our hypothesis.

Materials and methods

Patient enrollment

This was a retrospective case series including images, retrospectively reviewed by 2 authors (H.-C.C. and W.-R.S.), from 105 individuals who underwent arthroscopic surgery after failure of conservative treatment with rotator cuff rehabilitation and anti-inflammatory medications for at least 3 months in the past 5 years (2012 to 2016). The inclusion criteria stipulated that all patients underwent preoperative shoulder radiography and magnetic resonance imaging (MRI) of the shoulder and underwent arthroscopic intervention on the shoulder performed by the same orthopedic surgeon (W.-R.S.). The exclusion criteria included circumstances in which image interpretation might be distorted: a lack of either radiographs (n = 7) or magnetic resonance (MR) images (n = 3), admission for revision shoulder surgery (n = 3), severe osteoarthritis affecting image interpretation (n = 1), or a history of fractures of the shoulder girdle. After consideration of the exclusion criteria, 89 subjects, 42 men and 47 women, aged between 36 and 79 years (mean age, 59.66 years), with 91 shoulders having undergone surgery, met the inclusion criteria and were enrolled in this study.

Assessment of radiographs

The morphology of the GT was graded as spurring, sclerotic, or normal on anteroposterior shoulder radiographs taken during external rotation. Spurring of the GT was documented if there was an abrupt increase in the slope of the superior GT, as depicted by Jung-Yun et al.[17] GTs without prominent spurs but showing cortical thickening and subchondral sclerosis extending from the humeral head to the lateral humeral cortex were documented as being sclerotic according to a study by Mohammad Ghandour et al[24] (Fig. 1).

Assessment of MR images

MR images of the 91 shoulders were reviewed, during which the same definition of GT spurs was applied. Measurement of the GT acromiohumeral interval, defined as the shortest distance between the dense cortical bone of the acromial undersurface and the most proximal articular cortex of the humeral head,[20] was performed on oblique coronal T1-weighted images.

Rotator cuff muscle atrophy was quantitatively assessed using the occupation ratio proposed by Thomazeau et al.[33] The cross-sectional areas of the rotator cuff muscles and the supraspinatus fossa were measured on the most lateral oblique sagittal T1-weighted image where the scapular spine formed a Y shape with the scapula. The occupation ratio was determined by dividing the cross-sectional area of the rotator cuff muscle belly by that of the supraspinatus fossa, thereby standardizing the muscle area according to individual body size.

Fatty infiltration of the rotator cuff muscles was graded according to the Goutallier classification[12] on oblique coronal T1-weighted MR images.[7] The rotator cuff muscles were graded as follows, as depicted by Gladstone et al[9]: stage 0, no fatty infiltration; stage 1, some fatty streaks; stage 2, less fat than muscle; stage 3, as much fat as muscle; and stage 4, more fat than muscle.

Arthroscopic examination of rotator cuff

All arthroscopic surgical procedures were performed by the same orthopedic surgeon (W.-R.S.). During surgery, the side and severity of the tear and the tendons involved were documented immediately after complete débridement. The Ellman classification, based on the percentage of residual tendinous

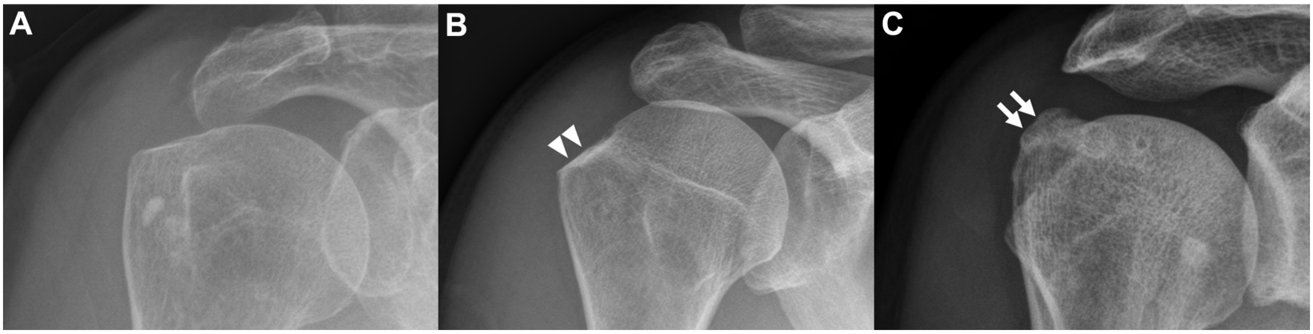

Figure 1 (**A**) Normal greater tuberosity. (**B**) Sclerotic greater tuberosity (*arrowheads*). (**C**) Greater tuberosity spur (*arrows*).

connection,[5] was applied to grade the condition of the rotator cuff as follows: no tear, 0% torn (intact, impingement, or tendinitis); grade 1, less than 25% torn; grade 2, less than 50% torn; grade 3, greater than 50% torn; and grade 4, 100% torn (ie, full-thickness rotator cuff tear).

Statistical analysis

Statistical analysis was performed using the Kruskal-Wallis test to compare the degree of muscle atrophy, degree of fatty infiltration, and arthroscopic diagnoses among patients with different GT radiographic morphologies. To analyze the specific sample pairs for stochastic dominance, the Dunn test was used in post hoc testing. For all analyses, $P < .05$ was considered statistically significant. All analyses were performed using SPSS software (version 17.0; IBM, Armonk, NY, USA).

Results

Radiographic morphology of GT

Examination of the 91 anteroposterior shoulder radiographs revealed 40 cases (44.0%) with spurs and 26 cases (28.6%) with sclerosis; the remaining 25 cases (27.5%) were normal (Table I).

Rotator cuff muscle atrophy

We found a significant correlation between radiographic GT abnormalities and the occupation ratio of the supraspinatus and infraspinatus muscles ($P = .002$ and $P = .047$, respectively). The average occupation ratio of the supraspinatus muscle was significantly lower in patients with radiographically spurring GTs and sclerotic GTs vs. their radiographically normal counterparts (0.519 and 0.55, respectively, vs. 0.67; $P = .002$ and $P = .039$, respectively). Similarly, the occupation ratio of the infraspinatus muscle was significantly different in patients with radiographically spurring GTs and sclerotic GTs vs. those with normal GTs (0.966 and 0.959, respectively, vs. 1.135; $P = .047$). On the other hand, the occupation ratios of the subscapularis and teres minor muscle were not significantly different among patients with distinct radiographic GT morphologies (Fig. 2).

Rotator cuff muscle fatty infiltration

A significant association was found between the radiographic GT morphology and the Goutallier classification of the supraspinatus muscle ($P = .020$) (Table II). Among the patients with radiographically spurring GTs, 40% (16 of

Table I Demographic data of all subgroups

Characteristic	Radiographic GT morphology			*P* value*
	Normal	Sclerotic	Spurring	
n (%)	25 (27.5)	26 (28.6)	40 (44.0)	
Mean age, yr	61.2	60.5	58.1	.312
Sex, n				.191
Male	12	9	23	
Female	13	17	17	
Involved arm, n				.851
Right	9	8	15	
Left	16	18	25	
Mean acromiohumeral interval, mm	9.28	8.66	8.57	.339

GT, greater tuberosity.
* *P* value using Kruskal-Wallis test.

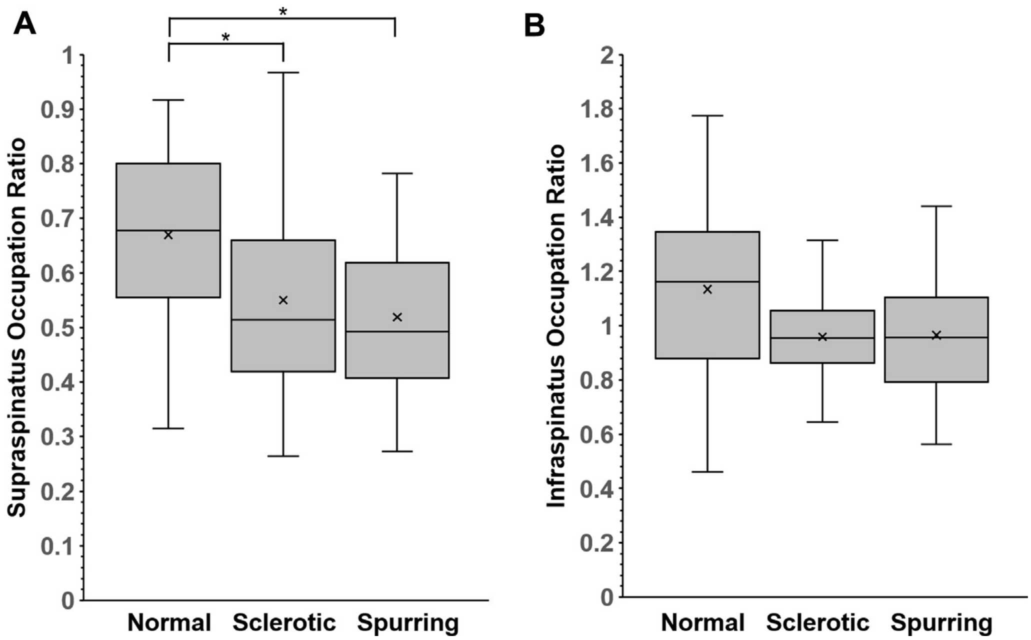

Figure 2 Occupation ratios of rotator cuff muscles in subjects with different radiographic greater tuberosity morphologies: normal group (25 cases), sclerotic group (26 cases), and spurring group (40 cases). (**A**) Supraspinatus occupation ratio (cross-sectional area of supraspinatus muscle belly divided by that of supraspinatus fossa). (**B**) Infraspinatus occupation ratio (cross-sectional area of infraspinatus muscle belly divided by that of supraspinatus fossa). Median values (*horizontal line in middle of the box*), quartile ranges (*top and bottom of the box*), and minimum and maximum (*whiskers*) are shown. The *x* near the median lines of each graph represents the average for the respective groups. *$P < .05$ using Dunn test.

40) had severe supraspinatus fatty infiltration. Among those with radiographically sclerotic GTs, 26.9% (7 of 26) showed severe supraspinatus fatty infiltration. Among those with radiographically normal GTs, only 8% (2 of 25) were found to have severe supraspinatus fatty infiltration. A post hoc analysis using the Dunn test revealed a statistically significant difference between those with spurring GTs and their normal counterparts ($P = .016$). In contrast, the radiographic GT morphology had no statistically significant association with fatty infiltration of the infraspinatus, subscapularis, and teres minor muscles ($P = .183$, $P = .241$, and $P = .483$, respectively).

Arthroscopic diagnosis

The Kruskal-Wallis test revealed a statistically significant difference in the percentage of full-thickness supraspinatus tears among patients with radiographically spurring GTs (82.5%, 33 of 40), sclerotic GTs (84.6%, 22 of 26), and normal GTs (56%, 14 of 25) ($P = .025$) (Table III). The post hoc analysis showed that a full-thickness supraspinatus tear occurred significantly more often in individuals with radiographically spurring GTs than in their normal counterparts ($P = .047$). No association was found between GT morphology and the severity of infraspinatus, subscapularis, or teres minor tears ($P = .331$, $P = .232$, and $P > .999$, respectively).

Discussion

Degenerative changes in the GT on a plain radiograph of the shoulder have been proved to be indicative of symptomatic and larger rotator cuff tears.[17,28] In this study, we extended this finding by showing that the radiographic GT morphology is associated with the degree of supraspinatus

Table II Radiographic GT degeneration and supraspinatus fatty infiltration

Radiographic GT morphology	Goutallier stage of supraspinatus muscle		*P* value*
	Mild (n = 66)	Severe (n = 25)	
Normal (n = 25)	23	2	.020†
Sclerosis (n = 26)	19	7	
Spur (n = 40)	24	16	

GT, greater tuberosity.
* *P* value using Kruskal-Wallis test.
† Significant at $P < .05$.

Table III Radiographic GT morphology and severity of supraspinatus tears

Radiographic GT morphology	Severity of supraspinatus tear		P value[*]
	Partial (n = 22)	Full (n = 69)	
Normal (n = 25)	11	14	.025[†]
Sclerosis (n = 26)	4	22	
Spur (n = 40)	7	33	

GT, greater tuberosity.
* P value using Kruskal-Wallis test.
† Significant at $P < .05$.

and infraspinatus muscle atrophy, the stage of supraspinatus fatty infiltration, and the severity of supraspinatus tears based on MR images. The clinical relevance of our findings is that in patients presenting with radiographic GT degeneration, MRI examinations should be prioritized to allow early detection of rotator cuff muscles of poor quality and to allow consideration of timely surgical intervention before the accumulation of fat and muscle atrophy.

The importance of detecting preoperative rotator cuff muscle degeneration has been increasingly stressed in recent years.[10,16,23] Fatty infiltration of the infraspinatus muscle equates negatively to postoperative functional outcomes,[7,9,11,12] and fatty infiltration of the supraspinatus muscle not only aggravates functional outcomes but also increases the retear rate after repair.[10] A direct correlation between increased muscle atrophy and postoperative retears has been reported.[8,32] Jeong et al[16] further reported that supraspinatus muscle atrophy decreases the mobility of the tendon and thus results in a high probability of an incomplete repair. Even when the rotator cuff repair was successful and remained intact, neither fatty infiltration nor muscle atrophy was reversed after surgery.[9] Therefore, some authors have advocated early diagnosis and timely treatment of rotator cuff tears lest muscle degeneration should occur.[10]

To detect muscle degeneration early and efficiently, the results of our study suggest arranging to perform preoperative MRI in patients with radiographic GT sclerosis or spurs. These degenerative changes in the GT are known to be associated with the occurrence and severity of rotator cuff tears,[17,28] and our study indicated that these changes are associated with advanced cuff muscle degeneration. To confirm and grade the cuff muscle degeneration, Okoroha et al[27] recommended the use of MRI for surgical planning in the case of large tears. Although ultrasound is as sensitive as MRI regarding the detection of a full-thickness rotator cuff tear,[21] ultrasonography has shown some disadvantages, including lower interobserver reliability, a lower detection rate for rotator cuff muscle degeneration,[27] and lower diagnostic accuracy for supraspinatus and infraspinatus fatty atrophy.[31] Computed tomography is also an effective diagnostic modality for rotator cuff tears. Nevertheless, computed tomography risks underestimating the severity of fatty infiltration and muscle atrophy in patients with glenohumeral osteoarthritis.[3,6] Hence, MRI is a superior tool for visualizing rotator cuff pathology and assessing the quality of soft tissue. However, the use of preoperative MRI on a routine basis would be economically prohibitive, as reflected by the fact that current diagnostic algorithms recommend reserving MRI for patients with suspected concomitant labroligamentous pathology or equivocal results of shoulder sonography.[26] In light of this, given the findings of our study, it is recommended that patients presenting with concomitant radiographic GT sclerosis or spurs undergo an MRI examination regardless of whether a rotator cuff tear was initially diagnosed via shoulder sonography or plain radiography.

The presence of radiographic sclerosis or spurring likely denotes chronic tensile GT overload. Chronic tensile overload and inhomogeneous strain concentrated on the articular side are two of the most crucial mechanisms leading to the development of rotator cuff tears.[15,29] In the case of chronic impingement syndrome, Burns and Whipple[1] reported that the GT stretches the coracoacromial ligament, which results in the formation of traction osteophytes on the anterior acromion. It could be inferred from this finding that the reaction force due to this repetitive stretching is applied to the GT. In the presence of increased loading, the cortical bone will initially undergo adaptive changes and resorption. Then, according to Wolff's law, sclerosis will ensue and eventually evolve into osteophyte formation if the repetitive stress persists.[2] Sclerotic cortical bone presents as increased density of the GT on a radiograph, whereas thickened cortical bone presents as a spur.

Patients with degenerative GTs on shoulder radiographs are prone to have muscle degeneration and fatty infiltration, presumably because full-thickness rotator cuff tears occur more often in this subgroup. Pearsall et al[28] first stated that radiographic GT sclerosis was associated with symptomatic rotator cuff tears. Jung-Yun et al[17] proved that more severe radiographic GT degeneration led to larger torn rotator cuffs. Furthermore, as the severity of the rotator cuff tear increases, atrophy and fatty infiltration of the supraspinatus muscle are found to be more serious on MR images.[25] Our study concurred with the previous literature, showing that patients with rotator cuff tears and radiographic sclerosis or spurs are predisposed to the development of full-thickness supraspinatus tears instead of partial ones. We also took it further to show that rotator cuff muscle degeneration, including supraspinatus muscle atrophy and fatty infiltration, is apt to develop in these patients with radiographic GT degeneration. This association could be accounted for by the theory of disuse atrophy of muscles. When individuals with supraspinatus tears underwent positron emission tomography, a significant decrease in the standardized uptake value of 2-[^{18}F]-fluoro-2-deoxy-D-glucose was found in their supraspinatus muscles.[30] The results suggested that the supraspinatus tear rendered the supraspinatus muscle belly unable to function properly and led to a decrease in the rotator cuff muscle metabolism. This prolonged disuse could lead to muscle atrophy by decreasing muscle protein synthesis, thus leaving degradation of muscle fibers unopposed.[22] Moreover, disuse of muscle induces accumulation of intramyocellular lipids, which presented as fatty infiltration on MR images.[14]

There are several limitations to this study. The first was the patient population, which was composed of operable cases. Patients at the extremes of the rotator cuff disease spectrum, with either irreparable massive tears or conservatively treated minor tears, would not have arthroscopic records available and were thus excluded from this study. However, past studies have maintained that radiographic abnormalities are more conspicuous in advanced cases.[13,34] In addition, subjects with short acromiohumeral intervals often present with prominent spurs, but those with acromiohumeral intervals of less than 7 mm are typically dissuaded from surgery because of poor postoperative outcomes[23] and therefore were excluded from the study.

Conclusion

For patients with rotator cuff tears, the presence of GT spurs or sclerosis on radiographs predicted the occurrence of supraspinatus and infraspinatus muscle atrophy, as well as supraspinatus fatty infiltration, based on MR images. The clinical relevance is that MRI is suggested for patients with radiographic GT sclerosis or spurs to detect advanced rotator cuff lesions.

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