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SCIENTIFIC ARTICLE

Muscle atrophy as a consequence of rotator cuff tears: should we compare the muscles of the rotator cuff with those of the deltoid?

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Abstract
Purpose The quantitative assessment of muscle atrophy has a degree of importance in prognosticating rotator cuff treatment. However, it has been conjectured that muscle fat increases with aging. Therefore, we thought that the quantitative assessment of the supraspinatous would be better if made in comparison with a standard of reference such as the deltoid. Consequently, we performed a two-part study, first evaluating supraspinatous changes compared with the deltoid in "normals" with aging, and second, determining if in patients with cuff tears the supraspinatous fat exceeds that of the deltoid.
Materials and methods In part 1, we studied 50 patients stratified by decade. In the first sitting, two blinded independent observers quantitatively graded the deltoid (with the supraspinatous obscured) and in the second sitting the same two observers quantitatively graded the supraspinatous (with the deltoid obscured). In part 2 of the study, we evaluated patients with moderate rotator cuff tears (>2 cm) and performed the same blinded, two-sitting, quantitative assessment (with the comparison muscle obscured).
Results We found that muscle atrophy increases with age in patients without tears (0.011/0.028 U/year), although to a greater degree in the deltoid ($p = 0.032$). Also, in similarly aged patients, quantitative scores of the deltoid closely matched those of the supraspinatous ($p = 0.071$). Notably, however, in patients with large tears, the supraspinatous showed significant changes disproportionate to those of the deltoid, regardless of patient age ($p = 0.044$).
Conclusion In the presence of a normal rotator cuff, fatty infiltration increases with age. Age-related changes occur more frequently in the deltoid, verifying this muscle's potential as a standard of reference. With cuff tears, supraspinatous atrophy was disproportionate to that of the deltoid. Therefore, systematic assessment of supraspinatous muscle atrophy may be more reliable using the deltoid as a control for comparison than assessing it in isolation.

Keywords MRI shoulder · Muscle atrophy · Rotator cuff tear

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Introduction

Rotator cuff tears are among the most common injuries to the shoulder [1]. As tears progress the muscles undergo retraction and fat infiltration related to atrophy [2]. Fatty infiltration of muscle may occur secondary to aging and disuse [3]. In the context of cuff tears muscle atrophy has been considered an important prognostic indicator [4, 5]. Consequently, there has been considerable investigation into quantifying this atrophy by imaging [6–8].

As discussed above, fatty infiltration of muscles may, however, occur related to aging, disuse, and diabetes [9, 10]. Therefore, absolute quantification scales may be of limited utility in a specific patient who may be debilitated, or have changes related to co-morbid conditions. We hypothesized that a better quantification schema would assess the status of the muscles of the rotator cuff in reference to the other muscles of the shoulder girdle, notably the deltoid.

To assess this hypothesis, we performed a two-part study. In the first part we systematically evaluated the degree of fatty infiltration of the supraspinatous compared with the deltoid, with the observer blinded to the comparison muscle, and correlated these findings with patient age. In the second part of this study, we assessed whether the fatty infiltration of these two muscles diverge in patients with severe cuff tears, regardless of their age.

Materials and methods

In this retrospective study, we studied two populations. The first consisted of 50 patients with an age range of 31 to 79 years, with a mean age of 56.6. These patients underwent an MRI of the shoulder after complaining of shoulder pain, but without evidence of a rotator cuff tear as determined by two observers. Since these patients did not go to surgery, we used the usual criteria established by prior papers to diagnose tears in order to exclude rotator cuff tears for this group of patients [11–16]. Exclusion criteria for this group of patients included prior surgery or MR arthrogram examinations.

The MRI findings for these patients were unremarkable MR examination in 28 patients, mild to moderate AC joint arthrosis in 17 patients, anterior or posterior degenerative labral tear in 3 cases, and biceps tendinopathy in 2 patients.

These patients were stratified by decade into five groups with 10 patients in each decade (group 1 was 30–39 years, group 2 was 40–49 years, group 3 was 50–59 years, group 4 60–69 years and group 5 was 70–79 years). This was the population utilized for quantitative comparison of the deltoid with the supraspinatous in patients without cuff tears, but with varying degrees of disuse and age.

The second group of patients included 20 patients with moderate to massive full-thickness rotator cuff tear [17]. The age of the patients of this group ranged between 36 and 78, with a mean age of 67.15, with 10 women and 10 men.

All images were performed at 1.5 T (Siemens Erlangen, Germany) with a dedicated shoulder coil. Although multiple planes and sequences were obtained, to determine fatty atrophy we only systematically evaluated the T1-weighted coronal oblique plane (TR/TE 550–680/11–15, matrix 256; slice thickness 4, inter-slice gap 1 mm, and field of view of 16 cm).

The assessment of fatty degeneration was done by two fellowship-trained musculoskeletal radiologists independently. The degree of fatty atrophy was scored for each of the three selected images according to the grading system of Goutallier [6]. This five-stage grading system consisted of: stage 0 completely normal muscle, without fatty streaks; stage 1 in which the muscle contains some fatty streaks; stage 2 in which the fatty infiltration is prominent, but with more muscle than fat; stage 3 in which there is as much fat as muscle; and stage 4 in which more fat than muscle is present.

For each muscle three representative images (anterior, mid-portion, and posterior) were selected to be formally graded and assigned a global score. To prevent potential bias when evaluating the supraspinatous muscle, the deltoid muscle was masked. In the second session when the deltoid muscle was graded, the supraspinatous muscle and cuff tendon were masked.

Statistical analysis was performed with the use of mixed model regression to assess the cross-sectional age-related yearly rate of change in the atrophy scores for each of the deltoid and supraspinatous muscles among patients with and without a rotator cuff tear. Kappa analysis was performed to evaluate interobserver variation. We used weighted Kappa, and assigned different weights, w (I), to individuals for whom the ratings differ by I rating categories; then different levels of agreement contributed to the value of Kappa. The weights are calculated as: $w(I) = 1-[i/(k-1)]$, where k is the number of distinct levels on our ordinal measurement scale.

Results

In patients without cuff tears the mean fat score for the supraspinatous was 0.50 with a range from 0 to 2, where a score of 2 was found in 2 patients in the fourth and fifth age groups. For the deltoid the mean score was 0.52, range 0–2 (Fig. 1).

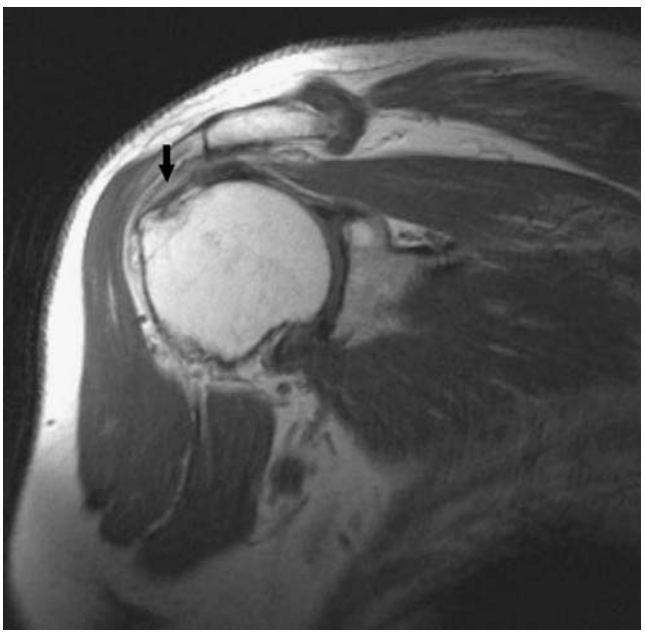

Fig. 1 A coronal T1-weighted image of the right shoulder showing a degenerative supraspinatous tendon without a distinct tear (*arrow*) with mild age-related fatty changes of the supraspinatous and the deltoid muscles in a 76-year-old male patient

When the analyses were stratified by age the mean fat score of the supraspinatous increased (first decade 0.3, second decade, 0.5, third decade, 0.3, fourth decade, 0.7, fifth decade, 0.7. The fat score for the deltoid shows the same pattern of increase with age (first decade, 0.5; second decade, 1.1; third decade, 0.5; fourth decade 1.3; fifth decade, 1.8; Table 1). This led to an estimated yearly rate of fat increase of the supraspinatous of 0.0028 units and of 0.0049 for the deltoid (Fig. 2).

The estimated increase in fat of the deltoid was nearly identical in patients with and without cuff tears (0.013 vs. 0.011).

When the fat score was compared with the presence of a cuff tear there was significant correlation for the supraspinatous ($p = 0.026$), but not the deltoid ($p = 0.791$; Fig. 3).

Analysis of the atrophy data by both observers was done to assess inter-observer agreement. For the mean score of atrophy of the deltoid muscle, the readers exhibited exact agreement on 40 out of 70 occasions and the weighted kappa was 0.316, which is considered "fair" agreement.

For the measurement of the mean score of atrophy of the supraspinatous, the readers exhibited exact agreement on 38 out of 70 occasions and the weighted kappa was 0.549, which is considered as "moderate" agreement.

Fig. 2 A coronal T1-weighted image of the right shoulder of a 82-year-old man with a degenerative supraspinatous tendon (*arrow*) and atrophy of both the supraspinatous and disproportionately of the deltoid muscles (*arrowhead*)

Discussion

Skeletal muscle fat is a non-specific response to many local or systemic insults [9, 10]. This has been colloquially termed atrophy, although this is perhaps imprecise. Causes of fatty change include muscular dystrophies [18], diabetes [9], stroke, focal denervation [19], polymyositis [20], generalized debility, and local disuse, in addition to chronic cuff tears [10].

The exact pathophysiological mechanism of this infiltration is incompletely understood [21]. In most types of muscle atrophy overall rates of protein synthesis are suppressed and rates of protein degradation are consistently elevated. This response accounts for rapid loss of muscle protein and its replacement by fat. Intramuscular fat is, however, best considered as a final common pathway of various local and systemic processes of muscle [22].

Goutallier et al. believed that fatty degeneration of the rotator cuff muscles occurs only if the rotator cuff tendon is torn and that fatty degeneration occurs only within those muscles whose tendons are torn [23].

Following rotator cuff tears fat occupies the spaces left by muscle fiber atrophy. The fatty infiltration appears on CT as low attenuation within the muscle belly. On MRI, the fat within the muscle follows the signal intensity of subcutaneous fat in all pulse sequences [24].

The re-tear rate increases up to 50% in cases of significant fatty degeneration [4]. Replacement of more than half of the muscle cross-section with fat has been

Table 1 Age and gender distribution of patients and the range and mean values of the fat scoring for both muscles in each group by both readers

Patients' group	Number of patients	Age range and mean	Gender		Fat score for the supraspinatous: reader 1	Fat score for the supraspinatous: reader 2	Fat score for the deltoid: reader 1	Fat score for the deltoid: reader 2
			Male	Female				
Group 1	10	30–39 (32.7)	4	6	0 (0)	0–1 (0.3)	0 (0)	0.5 (0–2)
Group 2	10	40–49 (44)	6	4	0–1 (0.1)	0–1 (0.4)	0.2 (0–1)	0.9 (0–3)
Group 3	10	50–59 (54.2)	6	4	0 (0)	0–1 (0.3)	0 (0)	0.5 (0–2)
Group 4	10	60–61 (62.9)	4	6	0–1 (0.2)	0–2 (0.5)	0.5 (0–2)	0.8 (0–2)
Group 5	10	70–71 (74.6)	5	5	0–1 (0.3)	0–2 (0.3)	0.4 (0–2)	1.4 (0–4)
Rotator cuff tear	20	36–78 (67.15)	10	10	0–3 (1.6)	0–4 (2.1)	1.2 (0–2)	2 (0–3)

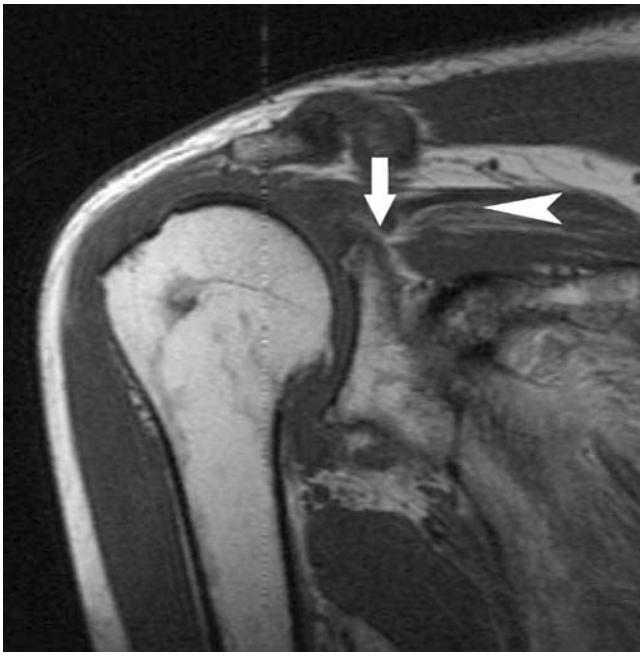

Fig. 3 Full-thickness tear with retraction of the supraspinatous tendon in a 58-year-old man (*arrow*), associated with fatty degeneration of the supraspinatous muscle (*arrowhead*), the deltoid shows mild, age-related fatty changes disproportionate to the supraspinatous fatty atrophy, seen on a coronal T1-weighted image of the right shoulder

considered to be a relative contraindication for surgical reconstruction. This raises the importance of the accurate assessment of the fatty degenerative changes of the rotator cuff prior to any attempts to repair the cuff tear [25].

Some studies have demonstrated quantitative methods for the assessment of the degree of fatty degeneration of the supraspinatous muscle. Van de Sande et al. [8] has suggested CT measurement of the mean muscle density (MMD), which showed high inter-observer agreement. However, this method has disadvantages. First, it utilizes CT scanning, which is not the method of choice for evaluation of the rotator cuff tendons. Second, it depends on software that is not readily available clinically. This disadvantage is also present in the study done by Pfirrmann et al., using proton MR spectroscopy for the assessment of supraspinatous lipid content [8, 26]. Spectroscopy is also susceptible to errors produced by field inhomogeneity, temperature differences, and patient variability. Fuchs et al. [27] correlated the cross-sectional area (CSA) of supraspinatous muscle and the grade of fatty degeneration according to Goutallier's classification [6]. We agree with them that the use of the CSA to quantify the degree of muscle fatty atrophy is suboptimal because of the possibility of differences in adipose tissue content within different muscle regions examined. To optimize this comparison, we used the coronal oblique plane rather than the oblique sagittal plane used by most of the authors in the assessment of supraspinatous atrophy or fatty degenerative changes.

We conjunctured that these staging systems should be taken one step further; that it is the relative fat in the cuff muscles other than the absolute fat score that is important. We chose the deltoid as a surrogate for general muscle health because its function is to some degree independent of the rotator cuff muscles while being in close geographic proximity [2].

Our study confirmed our hypothesis as both the deltoid and supraspinatous showed significant fatty infiltration with aging in patients without cuff tears. In fact, the fatty infiltration associated with aging was slightly greater in the deltoid than in the supraspinatous. Therefore, the use of the deltoid as a standard of reference may be conservative as it normally shows slightly more fat with aging than does the supraspinatous. We also confirmed the modest variability of Goutallier's scoring system [8, 27] as there was only fair to moderate agreement for the supraspinatous.

This finding renders the widely-established grading system for rotator cuff fatty degeneration by Goutallier [6] to be slightly suspect when used in isolation. We firmly agree with its basis, as well as that of related staging systems, but feel they should be adapted to the general health of the patient and the consequent robustness of their musculature. We confirmed this hypothesis in our group of patients with cuff tears. In these patients the fat score of the supraspinatous diverged from that of the deltoid in those with full-thickness supraspinatous tears.

Our work is preliminary, as are our conclusions, which should be viewed in relation to the limitations of the study. We stratified patients by decade rather than sequentially following them. We used the MRI assessments of two experienced musculoskeletal radiologists as evidence for rotator cuff tears. We utilized the commonly used semi-quantitative grading systems rather than using a quantitative assessment. It remains interesting that there was only fair to moderate agreement with this grading system. Lastly, for our control population we used symptomatic patients without tears. However, this population is likely closer in epidemiologic characteristics to the population usually imaged and is therefore, in some ways, preferable.

Accepting these limitations, we conclude that age-related fatty infiltration appears to occur in the supraspinatous and to a somewhat greater degree in the deltoid. Why this happens is unclear. It may be secondary to co-morbid conditions, or more likely, generalized debility. Also, it is unclear whether these age-related changes in muscle fat have a similar prognostic impact to the more localized changes in muscle fat quoted in several publications [4, 11, 28]. However, when the cuff is torn the fatty infiltration is much more severe in the supraspinatous. Therefore, in patients with cuff tears, disproportionate atrophy relative to the deltoid would be more significant. A longitudinal study to include operated patients would be useful to validate our preliminary findings.

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