J Shoulder Elbow Surg (2019) 28, 617–624

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Rotator cuff muscles fatty infiltration increases with age: retrospective review of 210 patients with intact cuff on computed tomography arthrography

Jeremy Gueniche, MD, Guillaume Bierry, MD, PhD*

Department of Radiology, University Hospital, Strasbourg, France

Hypothesis: We aimed to demonstrate that rotator cuff fatty infiltration (FI) increases physiologically with age and that a FI degree of 2 might be encountered in patients with an intact cuff.

Methods: We retrospectively evaluated the FI of 210 patients (classified in 7 age groups: <20, 20-30, 30-40, 40-50, 50-60, 60-70, and >70 years) who had an intact cuff on computed tomography (CT) arthrography. The Goutallier grading system was used to assess FI of rotator cuff muscles and of the deltoid muscle. FI was then compared between groups for each muscle, and determinants (age, sex, and body mass index) of FI were assessed.

Results: FI of all evaluated muscles progressively increased with age, but a statistically significant increase between 2 consecutive age groups was observed for all muscles only after age 40 years. For each group, intermuscle comparison showed that the FI distribution was not significantly different between each rotator cuff muscle at any age. Age was a determinant for FI for all muscles, but sex and body mass index also influenced deltoid FI. A median FI value of 2 was found in the "over 70 group" for the supraspinatus, but in the 60 to 70 group for infraspinatus and subscapularis and in the 50 to 60 group for the deltoid.

Conclusion: FI of rotator cuff muscles increased with age, with a significant acceleration after 40 years. Moreover, a FI graded 2, a common threshold for management decision, was commonly found in those aging patients with intact cuff on CT arthrography

Level of evidence: Anatomy Study; Imaging

Keywords: Rotator cuff; fatty infiltration; age; CT; CT arthrography; management

Besides volume loss, infiltration of the rotator cuff (RC) muscles with fatty tissue is a well-known feature in RC tears.[2] This fatty infiltration (FI) is generally considered as irreversible and usually progresses with time.[2,10,12,14] Preoperative FI is recognized as a major prognosis for healing, clinical outcomes, and retear rates after cuff repair, and a good chance of satisfactory anatomic repair can only be expected in muscle cuffs with minimal amount of FI. Some authors have found FI is a better predictor of outcome than tear size or recurrence.[12] Those poor outcomes in cuffs with significant FI are generally explained by a poor quality of the corresponding tendon.[3,5,6]

FI is commonly assessed using 2 different imaging-based classifications: Goutallier based on axial computed tomography (CT) images and Fuchs based on sagittal magnetic resonance images (MRIs).[9,14] The Goutallier classification

The Strasbourg Medical School Ethical Committee approved this study.

*Reprint requests: Guillaume Bierry, MD, PhD, Department of Radiology, University Hospital, 1 Avenue Molière, F-67098 Strasbourg, France.

E-mail address: guillaume.bierry@chru-strasbourg.fr (G. Bierry).

1058-2746/$ - see front matter © 2018 Journal of Shoulder and Elbow Surgery Board of Trustees. All rights reserved.
https://doi.org/10.1016/j.jse.2018.09.020

classifies FI in 4 grades of increasing severity. Some authors considered that stage 2 or higher is associated with a definitive loss of muscle function and that RC repair should be performed before this stage.[14,15,21] With the aging population and the desire to pursue an active lifestyle, RC repair can be proposed to patients aged older than 60 or even 70 years.[30]

Whether the cutoff values based on Goutallier classification suit those aging patients can be discussed. Indeed, FI is recognized as a general phenomenon in aging.[19] But, if reports of FI in patients with RC tears are widely available, data on FI in decade-stratified individuals with an intact RC remain sparse. Moreover, the direct influence of age on FI in RC muscles remains debated, and contradictory results can be found in the literature, presumably resulting from differences in the study populations.[15,16,23]

In this study, we aimed to report the range and distribution of FI in RC muscles and estimate the determinant of FI in age-stratified patients who presented with an intact RC on CT arthrography (CTA). We hypothesized that FI physiologically increases with age and that a FI graded 2 could be frequently encountered in healthy aging patients. This threshold might therefore be considered with caution when a cuff repair is discussed.

Materials and methods

Patient selection

A radiology resident (J.G.) retrospectively screened our local database for shoulder CTA (SCTA) reports. From January 2009 to January 2016, 4446 SCTAs were performed in 4367 patients. We excluded examinations that reported (1) any RC abnormalities (tear or calcifications), (2) biceps abnormality, (3) acute trauma, or (4) any internal joint disorders (osteoarthritis, arthritis, or capsulitis). We found 347 examinations in 347 patients; of those, 210 patients were randomly selected and stratified by decades into 7 groups of 30 patients: group 1 was younger than 20 (<20), group 2 was 20 to 30 (20-30 group), group 3 was 30 to 40 (30-40 group), group 4 was 40 to 50 (40-50 group), group 5 was 50 to 60 (50-60 group), group 6 was 60 to 70 (60-70 group), and group 7 was older than 70 years (>70 group; Fig. 1). There were 123 men and 87 women. A senior musculoskeletal radiologist (reader 1 [G.B.]), with 15 years of experience in musculoskeletal imaging, reviewed the SCTAs of the 210 patients to confirm the absence of exclusion criteria.

Images acquisition

The SCTA protocol was identical for all patients, with a puncture of the glenohumeral joint though an anterior approach and the injection of 10 to 15 mL of iodinated contrast media. CTA was performed on 2 different CT units (Siemens AS+, Siemens definition; Siemens, Munich, Germany) but with the same protocol (350-400 mA, 120 kV) with "bone" and "soft tissue" reconstruction kernels.

FI assessment

Fatty degeneration was assessed on CT images by a senior radiologist (reader 1, G.B.) and a radiology resident (reader 2, J.G.) on a picture archive and consultation system (General Electric, Milwaukee, WI, USA; 2013), with the 2 radiologists working in consensus.

In addition, a reliability study was conducted in which the 2 readers independently evaluated FI of the supraspinatus (SSp) muscle

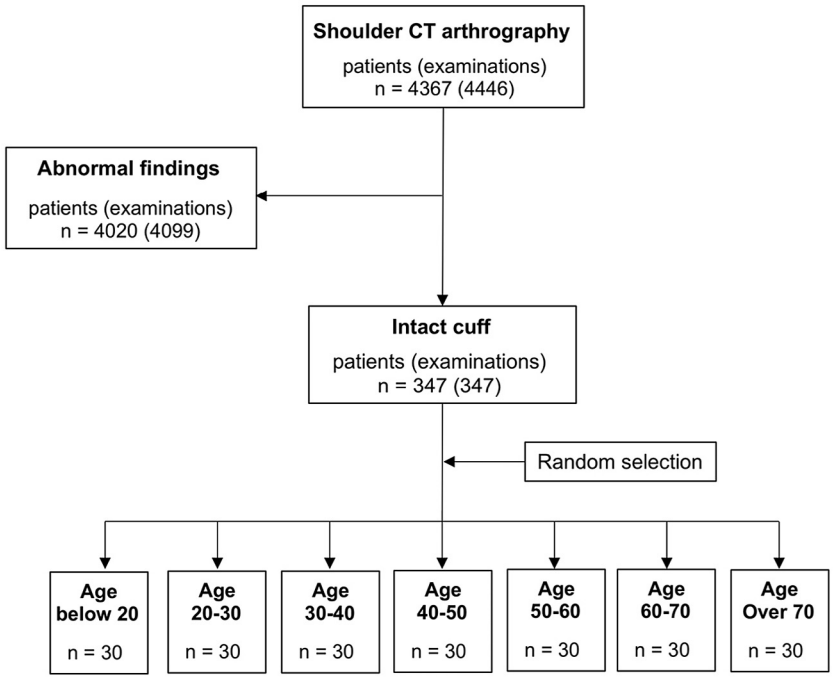

Figure 1 Flowchart of patients. *CT*, computed tomography.

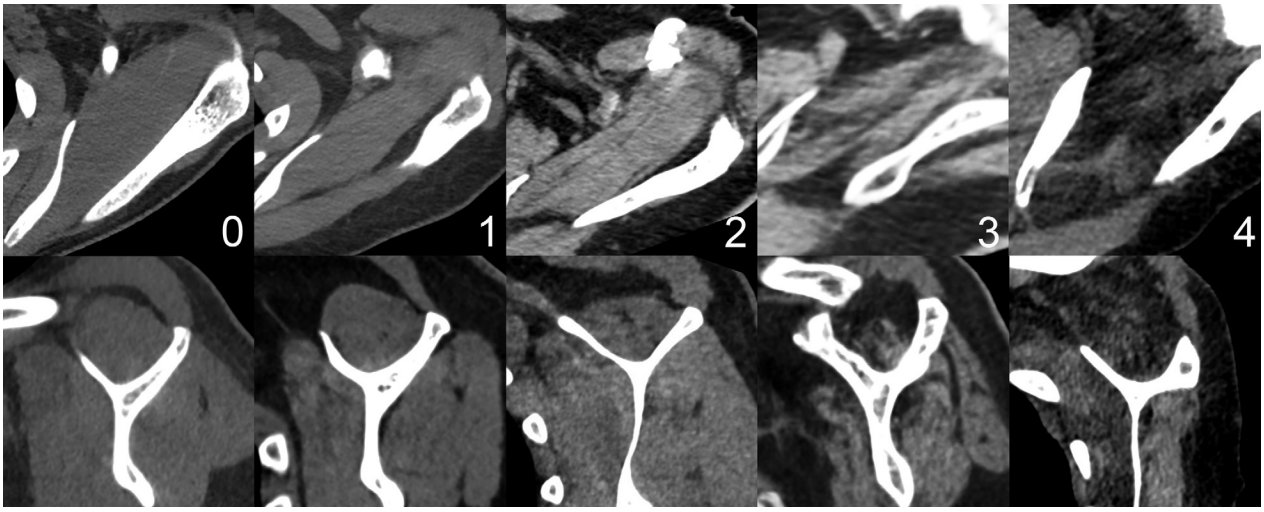

Figure 2 Degrees of fatty infiltration (Goutallier grading from 0 to 4) on axial (upper row) and sagittal (lower row) computed tomography images.

of the 120 patients. Reader 2 reviewed the data set a second time after a 1-week interval to assess intraobserver agreement.

A "soft tissue" data set was used for evaluation, with a reconstruction kernel of 30, a "soft tissue" windowing, and a 5-mm slice thickness. Because the distribution of FI through a muscle belly is random and variable, FI of SSp, infraspinatus (ISp), subscapularis (SS), and deltoid muscles was evaluated on axial and sagittal planes.

On the axial plane, the SSp was assessed at the section of the muscle with the greatest visual surface area between the scapular spine and the rest of the scapula. The ISp, SS, and deltoid muscles were assessed on 1 section at the midglenoid level. Deltoid FI was estimated in the pars spinalis of the muscle.[24] On the sagittal plane, SSp, ISp, SS, and deltoid muscles were evaluated on 1 image at the level that showed the coracoid base and where the spine and body of the scapula formed a Y shape.[9] The degree of fatty atrophy was scored according to the grading system of Goutallier: stage 0, completely normal muscle, without fatty streaks; stage 1, in which the muscle contains some fatty streaks; stage 2, in which the FI 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[14] (Fig. 2). Axial and sagittal planes FI scores were compared using the Spearman correlation. Because scores were highly correlated (see Results; Table I), a composite score was chosen by choosing for each muscle the highest degree of FI on axial or sagittal planes.

Table I Comparative analysis of fatty infiltration scores on axial and sagittal planes

Muscle	Pearson	*P*
Supraspinatus	0.980	<.0001*
Infraspinatus	0.984	<.0001*
Subscapularis	0.992	<.0001*
Deltoid	0.979	<.0001*

* Statistically significant ($P < .05$).

Statistical analysis

Analyses were performed using SPSS 23 software (IBM, Armonk, NY, USA). FI scores on axial and sagittal planes were compared using the Pearson test. Distribution of FI was compared between the different muscles for each age group using analysis of variance with the Bonferroni correction.

Determinants of FI were assessed using linear regression. Then, for each determinant, contribution was evaluated using the χ^2 test. To determine intraobserver and interobserver agreement, we calculated weighted κ index values and 95% confidence intervals (CIs). Agreement strength was inferred from κ index values: a κ value of <0 was interpreted as poor agreement; a value in the range of 0.01 to 0.20, slight agreement; a value from 0.21 to 0.40, fair agreement; a value from 0.41 to 0.60, moderate agreement; a value from 0.61 to 0.80, substantial agreement; and a value from 0.81 to 1.00, nearly perfect agreement.[18] Results with $P < .05$ were considered as statistically significant.

Results

FI scores measured on axial and sagittal planes were highly correlated (Table I), confirming that the Goutallier classification, based on axial CT images, and its application to the sagittal plane (an equivalent to Fuchs classification, based on sagittal MRIs) can be seen as interchangeable alternatives. FI of all evaluated muscles progressively increased with age (Fig. 3), but a statistically significant increase between 2 consecutive age groups was observed for all muscles only after age 40 years (Tables II and III). Nevertheless, the rhythm of progression seemed to differ between muscles: for SSp, a median FI value of 2 was found for the >70 group, whereas for ISP and SSc, it was for the 60-70 group, and, for the deltoid, for the 50-60 group (Table II). In addition, half of the patients of the 60-70 group already had a SSp FI score of 2 (Table I).

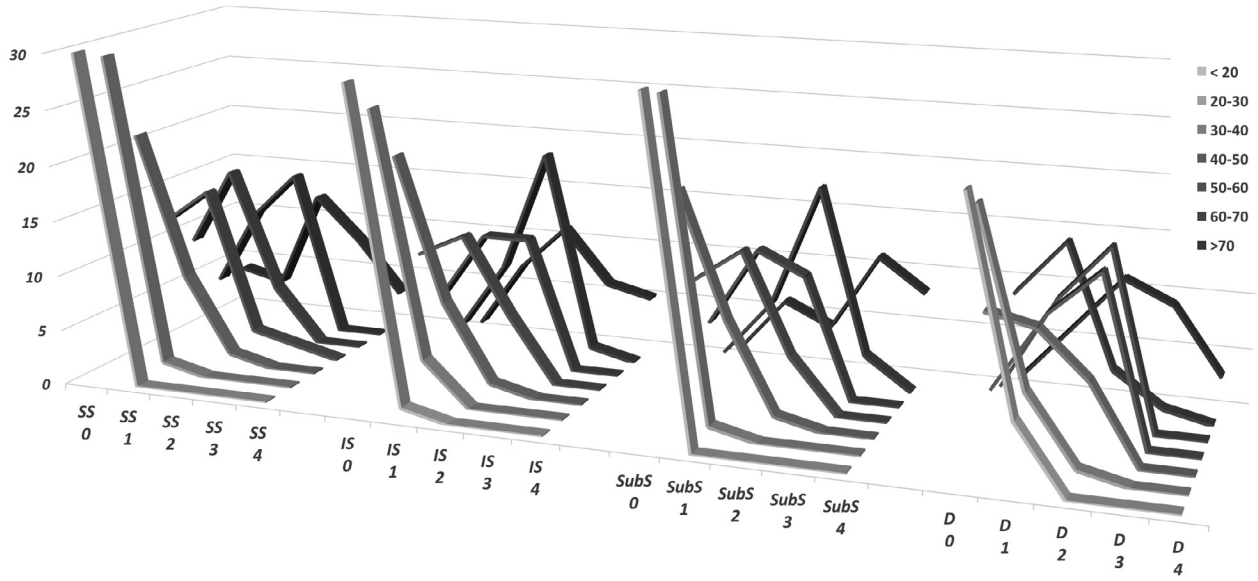

Figure 3 Number of patients presenting with each degree of fatty infiltration of the supraspinatus (*SS*), infraspinatus (*IS*), subscapularis (*SubS*), and deltoid (*D*) muscles for the 7 age groups.

Table II Distribution and median value of fatty infiltration quoted 0 to 4 of the different muscles for the different age groups

Muscle	FI	<20 yrs No. (%)	20-30 yrs No. (%)	30-40 yrs No. (%)	40-50 yrs No. (%)	50-60 yrs No. (%)	60-70 yrs No. (%)	>70 yrs No. (%)
SSp	0	30 (100)	29 (96)	21 (70%)	12 (40%)	9 (30)	4 (12%)	4 (40)
	1	0	1 (3)	8 (27)	15 (50)	16 (53)	11 (37)	3 (9)
	2	0	0	1 (3)	2 (7)	5 (17)	15 (50)	12 (40)
	3	0	0	0	1 (3)	0	0	8 (27)
	4	0	0	0	0	0	0	3 (9)
	Median	0	0	0	1	1	1.5	2
ISp	0	29 (96)	26 (87)	21 (70)	11 (37)	6 (20)	2 (7)	1 (3)
	1	1 (3)	4 (12)	8 (27)	13 (43)	12 (40)	8 (27)	7 (23)
	2	0	0	1 (3)	6 (20)	12 (40)	19 (63)	11 (37)
	3	0	0	0	0	0	1 (3)	6 (20)
	4	0	0	0	0	0	0	5 (17)
	Median	0	0	0	1	1	2	2
SSc	0	30 (100)	29 (96)	20 (60)	11 (37)	6 (20)	2 (6)	1 (3)
	1	0	1 (3)	9 (30)	14 (47)	13 (43)	7 (23)	6 (20)
	2	0	0	1 (3)	5 (17)	11 (37)	18 (60)	4 (12)
	3	0	0	0	0	0	3 (9)	11 (37)
	4	0	0	0	0	0	0	8 (27)
	Median	0	0	0	1	1	2	3
Deltoid	0	24 (80)	22 (73)	12 (40)	4 (12)	3 (9)	10 (33)	1 (3)
	1	6 (20)	7 (23)	11 (37)	11 (37)	11 (37)	15 (50)	6 (20)
	2	0	1 (3)	7 (23)	15 (50)	16 (53)	4 (12)	11 (37)
	3	0	0	0	0	0	1 (3)	9 (27)
	4	0	0	0	0	0	0	3 (9)
	Median	0	0	1	1.5	2	2	2

FI, fatty infiltration; *SSp*, supraspinatus; *ISp*, infraspinatus; *SSc*, subscapularis.

Comparison between groups confirmed that FI tended to be more frequently statistically different as the age interval between compared groups increased (Table III). The age of 70 years seemed to be a particular threshold, because all RC muscles, except the deltoid, had significantly higher FI in the >70 group than in every other age group (Table II). For the deltoid muscle, there was no statistically significant difference between the 60-70 and >70 groups (Table II).

Intermuscle comparison for each group showed that the FI distribution was not significantly different between each

Table III Comparative study of fatty infiltration distribution in the different age groups

Age group	<20 yrs	20-30 yrs	30-40 yrs	40-50 yrs	50-60 yrs	60-70 yrs	>70 yrs
Supraspinatus							
<20 yrs		1	1	.001*	<.0001*	<.0001*	<.0001*
20-30 yrs	1		1	.002*	<.0001*	<.0001*	<.0001*
30-40 yrs	1	1		.48	.053	<.0001*	<.0001*
40-50 yrs	.001*	.002*	.48		1	.008*	<.0001*
50-60 yrs	<.0001*	<.0001*	.053	1		.096	<.0001*
60-70 yrs	<.0001*	<.0001*	<.0001*	.008*	.096		.001*
>70 yrs	<.0001*	<.0001*	<.0001*	<.0001	<.0001*	.001*	
Infraspinatus							
<20 yrs		1	1	<.0001*	<.0001*	<.0001*	<.0001*
20-30 yrs	1		1	.002*	<.0001*	<.0001*	<.0001*
30-40 yrs	1	1		.104	<.0001*	<.0001*	<.0001*
40-50 yrs	<.0001*	.002*	.104		.81	<.0001*	<.0001*
50-60 yrs	<.0001*	<.0001*	<.0001*	.81		.308	<.0001*
60-70 yrs	<.0001*	<.0001*	<.0001*	<.0001*	.308		.017
>70 yrs	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	.017*	
Subscapularis							
<20 yrs		1	.882	<.0001*	<.0001*	<.0001*	<.0001*
20-30 yrs	1		1	.001*	<.0001*	<.0001*	<.0001*
30-40 yrs	.882	1		.346	<.0001*	<.0001*	<.0001*
40-50 yrs	<.0001*	.001*	.346		.882	<.0001*	<.0001*
50-60 yrs	<.0001*	<.0001*	<.0001*	.882		.038*	<.0001*
60-70 yrs	<.0001*	<.0001*	<.0001*	<.0001*	.038*		<.0001*
>70 yrs	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	
Deltoid							
<20 yrs		1	.018*	<.0001*	<.0001*	<.0001*	<.0001*
20-30 yrs	1		.1	<.0001*	<.0001*	<.0001*	<.0001*
30-40 yrs	.018*	.1		.1	.032*	<.0001*	<.0001*
40-50 yrs	<.0001*	<.0001*	.1		1	.17	<.0001*
50-60 yrs	<.0001*	<.0001*	.032*	1		.451	.001*
60-70 yrs	<.0001*	<.0001*	<.0001*	.17	.451		1
>70 yrs	<.0001*	<.0001*	<.0001*	<.0001*	.001*	1	

Results of analysis by analysis of variance with Bonferroni correction.
* Statistically significant ($P < .05$).

RC muscle at any age (Table IV). However, the deltoid presented a different FI pattern than RC muscles for the younger groups, but this difference tended to disappear with advanced age (Table IV). Linear regression confirmed that age was an independent FI determinant for the 4 muscles (Table V). Interestingly, sex and body mass index (BMI) were also determinants for the deltoid, with higher FI in women and in patients with a higher BMI ($P < .0001$; Table V).

Intraobserver and interobserver agreements were considered as nearly perfect: they were 0.91 (95% CI, 0.80-1.00) and 0.88 (95% CI, 0.80-0.97), respectively, for the sagittal plane evaluation and were 0.86 (95% CI, 0.78-0.94) and 0.83 (95% CI, 0.78-0.88), respectively, for the axial plane evaluation.

Discussion

With an aging population that desires to pursue an active lifestyle, indications for RC repair in patients older than 70 kept on increasing.[8] Besides physical evaluation, imaging plays a crucial role in the selection of patients eligible for surgery by describing lesion extent and muscle health. In this purpose, CT and MRI are widely used to evaluate FI in RC, and the replacement of more than half of the muscle with fat is considered to be a relative contraindication for surgical repair.[13]

An accurate assessment of FI is therefore of utmost interest for shoulder surgeons, and the Goutallier classification system remains widely used despite known limitations. In this system, a FI quoted below stage 2 is a requisite to retain a surgical indication.

Even if the exact pathophysiological mechanism of FI in RC tear is not yet totally understood, it is generally considered that a poor muscle quality would reflect a poor tendon quality, prone to retear. As with every muscle group, RC muscles are supposed to involute with aging, with a increased protein degradation inducing a loss of muscle tissue and its replacement by fat.[11]

Table IV Comparative evaluation of fatty infiltration distribution in the different muscles for each age group

Muscle	SSp	ISp	SSc	Deltoid
Age <20				
SSp		.99	.97	.004*
ISp	.99		.99	.027*
SSc	.97	0,99		.004*
Deltoid	.004*	.027*	.004*	
Age 20-30				
SSp		.98	.99	.007*
ISp	.98		.99	.168
SSc	.99	.99		.007*
Deltoid	.007*	.168	.007*	
Age 30-40				
SSp		.98	.96	.014*
ISp	.98		.98	.026*
SSc	.96	.98		.026*
Deltoid	.014*	.026*	.026*	
Age 40-50				
SSp		.99	.99	.006*
ISp	.99		.99	.033*
SSc	.99	.99		.019*
Deltoid	.006*	.033*	.019*	
Age 50-60				
SSp		.449	.65	.017*
ISp	.449		.991	.99
SSc	.65	.991		.918
Deltoid	.017*	.99	.918	
Age 60-70				
SSp		.948	.319	.053
ISp	.948		.978	.981
SSc	.319	.978		.98
Deltoid	.053	.981	.98	
Age >70				
SSp		.99	.4	.98
ISp	.99		.992	.978
SSc	.4	.992		.99
Deltoid	.98	.978	.99	

SSp, supraspinatus; *ISp*, infraspinatus; *SSc*, subscapularis.
Results of analysis of variance with Bonferroni correction.
* Statistically significant ($P < .05$).

Table V Determinants of fatty infiltration of cuff muscles

Variable	SSp	ISp	SSc	Deltoid
Sex	.102	.623	.058	.016*
BMI	.458	.052	.12	<.0001*
Age	<.0001*	<.0001*	<.0001*	<.0001*

SSp, supraspinatus; *ISp*, infraspinatus; *SSc*, subscapularis; *BMI*, body mass index.
* Statistically significant ($P < .05$) by analysis of variance.

Most of studies on RC FI have been done on patients with RC tear, and if FI is recognized to be greater in case of massive tear, multiple muscle tear, and long-standing tear, the respective influence of aging vs. tear/disuse on FI is rarely discussed.

Moreover, results are mostly focused on the SSp muscle, because this muscle seems to present a faster and greater degree of FI in RC tear, and its health appears as the main indicator for repair outcome.[13,15,17,27,29] Interestingly when the influence of age in outcome is evaluated, reported results are discordant, because retear rates and poorer outcomes are correlated with age for some authors but not for others.[3,4,6,20-22] In a study of patients with (n = 109) and without (n = 294) RC tears, Raz et al[29] found an age-related increase of FI for the SSp, ISp, and SSc (FI of the deltoid was not evaluated) but a decrease of cross-sectional area (CSA) only for the SSp and SSc.[29] Moreover, FI seemed to appear earlier in SSp/SSc. The authors concluded that the factors promoting trophicity might differ between ISp/deltoid muscles and SSp/SSc muscles. Our results are in keeping with those of Raz et al,[29] because we found a significant influence of aging in FI of the SSc, SSp, ISp, and deltoid. Even if not completely understood, muscle loss in RC could be seen as an accelerated form of aging.[7] We choose to evaluate FI instead of CSA because Goutallier/Fuchs classifications are more widely used and quicker to realize, and this allowed us to evaluate the deltoid FI. Interestingly, we found that sex and BMI influenced the FI of the deltoid but not the other RC muscles, confirming that if RC muscles and the deltoid interplay to coordinate the shoulder movements, their regulation might differ.

In a series of 50 patients without RC tear evaluated by MRI, Ashry et al[1] reported an age-related increase of FI in both deltoid and RC muscles. They reported a SSp FI within a 0 to 2 range for the 60-61 and 70-71 groups with the mean between 0.2 and 0.5. We found higher degrees of FI in our series, because a median FI of 1 was already seen in patients in their 40s and 1 patient of the 30-40 group presented a FI graded 2. This discrepancy is possibly explained by use of CT instead of MRI. We used the Goutallier classification for CT, which is described as a reliable technique, with reports of high inter-rater agreements, even in its MRI-based variants (Fuchs).[26,32] We found similar level of interobserver agreement in our study ($\kappa = 0.83$-0.91).[31]

To improve reliability in the CT grading, we combined the axial score with a sagittal score, similar as described for MRI by Fuchs.[9] Most of the studies report FI evaluated on MRI, because this is the modality of choice for painful shoulder evaluation, and a higher accuracy of MRI compared with CT has been reported.[28] Nevertheless, our study confirmed that in patients with an intact RC on CTA, FI increases with age and that age is a determinant factor of FI, at the opposite of sex and BMI. In this CT-based study, we found that the cutoff value of 2 retained for surgical indication is frequently observed in patients younger than 70 with an intact cuff. This raises the question whether this cutoff might be too restrictive, and it would be worthy to interpret the RC score compared with the patient's global muscle trophicity. Indeed, motion-limiting progressive muscle loss (also named sarcopenia) occurs in 5% to 13% of people between 60 and 70 years.[25] As previously reported, we found that the deltoid muscle seems

to evolute in a different fashion than the SSp and ISp muscles,[1] being notably influenced by sex and BMI. The deltoid might therefore be a good indicator of general muscle trophicity, apart from shoulder activity-related assessment.

Our study presented several limitations. First, we only retrospectively included patients with the diagnostic of intact cuff on CTA. Thus, patients with bursal-sided or interstitial tear, not detectable on SCTA, might have been included.

Second, we included patients addressed for suspicion of cuff tear, presumably having a painful shoulder that might have limited their activity. Indeed, we did not evaluate asymptomatic patients, and the FI we reported might have been partly secondary to disuse, because we had no information on the level of activity maintained by patients.

Last, we did not sex-match patients in each group because they were randomly selected in each age category.

Conclusions

With the abovementioned limitations, our study confirmed that the FI of RC muscles increases with age and with a significant acceleration after age 40. In those patients with an intact cuff, a median FI value of 2 was found in the >70 group for the SSp, but already in the 60-70 group for ISp and SS, and even in the 50-60 group for the deltoid muscle. Moreover, we found that if an identical trend of FI existed for the different RC muscles, it was different from the deltoid muscle, the FI of the latter also being influenced by sex and BMI, which might more reflect the patient's global muscle status.

Because the outcomes of a surgical management can be in part predicted by RC muscle health, it might be useful to keep in mind that a FI value of 2 on the Goutallier classification, a threshold commonly retained for surgical indication, is frequently observed in patients at approximately 60 years with an intact cuff.

Disclaimer

The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Ashry R, Schweitzer ME, Cunningham P, Cohen J, Babb J, Cantos A. Muscle atrophy as a consequence of rotator cuff tears: should we compare the muscles of the rotator cuff with those of the deltoid? Skeletal Radiol 2007;36:841-5. http://dx.doi.org/10.1007/s00256-007-0307-5
2. Bjorkenheim JM. Structure and function of the rabbit's supraspinatus muscle after resection of its tendon. Acta Orthop Scand 1989;60:461-3.
3. Boileau P, Brassart N, Watkinson DJ, Carles M, Hatzidakis AM, Krishnan SG. Arthroscopic repair of full-thickness tears of the supraspinatus: does the tendon really heal? J Bone Joint Surg Am 2005;87:1229-40. http://dx.doi.org/10.2106/JBJS.D.02035
4. Charousset C, Bellaïche L, Kalra K, Petrover D. Arthroscopic repair of full-thickness rotator cuff tears: is there tendon healing in patients aged 65 years or older? Arthroscopy 2010;26:302-9. http://dx.doi.org/10.1016/j.arthro.2009.08.027
5. Cho NS, Yi JW, Lee BG, Rhee YG. Retear patterns after arthroscopic rotator cuff repair: single-row versus suture bridge technique. Am J Sports Med 2010;38:664-71. http://dx.doi.org/10.1177/0363546509350081
6. Choi S, Kim MK, Kim GM, Roh YH, Hwang IK, Kang H. Factors associated with clinical and structural outcomes after arthroscopic rotator cuff repair with a suture bridge technique in medium, large, and massive tears. J Shoulder Elbow Surg 2014;23:1675-81. http://dx.doi.org/10.1016/j.jse.2014.02.021
7. Chung SW, Yoon JP, Oh KS, Kim HS, Kim YG, Lee HJ, et al. Rotator cuff tear and sarcopenia: are these related? J Shoulder Elbow Surg 2016;25:e249-55. http://dx.doi.org/10.1016/j.jse.2016.02.008
8. Flurin PH, Hardy P, Abadie P, Boileau P, Collin P, Deranlot J, et al. Arthroscopic repair of the rotator cuff: prospective study of tendon healing after 70 years of age in 145 patients. Orthop Traumatol Surg Res 2013;99:S379-84. http://dx.doi.org/10.1016/j.otsr.2013.10.007
9. Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C. Fatty degeneration of the muscles of the rotator cuff: assessment by computed tomography versus magnetic resonance imaging. J Shoulder Elbow Surg 1999;8:599-605.
10. Gerber C, Fuchs B, Hodler J. The results of repair of massive tears of the rotator cuff. J Bone Joint Surg Am 2000;82:505-15.
11. Gerber C, Meyer DC, Frey E, von Rechenberg B, Hoppeler H, Frigg R, et al. Neer Award 2007: reversion of structural muscle changes caused by chronic rotator cuff tears using continuous musculotendinous traction. An experimental study in sheep. J Shoulder Elbow Surg 2009;18:163-71. http://dx.doi.org/10.1016/j.jse.2008.09.003
12. Gladstone JN, Bishop JY, Lo IK, Flatow EL. Fatty infiltration and atrophy of the rotator cuff do not improve after rotator cuff repair and correlate with poor functional outcome. Am J Sports Med 2007;35:719-28. http://dx.doi.org/10.1177/0363546506297539
13. Godèneche A, Elia F, Kempf JF, Nich C, Berhouet J, Saffarini M, et al. Fatty infiltration of stage 1 or higher significantly compromises long-term healing of supraspinatus repairs. J Shoulder Elbow Surg 2017;26:1818-25. http://dx.doi.org/10.1016/j.jse.2017.03.024
14. Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures. Pre- and postoperative evaluation by CT scan. Clin Orthop Relat Res 1994;(304):78-83.
15. Goutallier D, Postel JM, Gleyze P, Leguilloux P, Van Driessche S. Influence of cuff muscle fatty degeneration on anatomic and functional outcomes after simple suture of full-thickness tears. J Shoulder Elbow Surg 2003;12:550-4. http://dx.doi.org/10.1016/S10582746(03)002118
16. Kany J, Flurin PH, Richardi G, Hardy P and French Arthroscopy Society. Rotator cuff tear imaging in patients over 70 years: specific MRI findings? Orthop Traumatol Surg Res 2013;99:S385-90. http://dx.doi.org/10.1016/j.otsr.2013.10.003
17. Kim HM, Dahiya N, Teefey SA, Keener JD, Galatz LM, Yamaguchi K. Relationship of tear size and location to fatty degeneration of the rotator cuff. J Bone Joint Surg Am 2010;92:829-39. http://dx.doi.org/10.2106/JBJS.H.01746
18. Landis JR, Koch GG. An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. Biometrics 1977;33:363-74.
19. Marcus RL, Addison O, Kidde JP, Dibble LE, Lastayo PC. Skeletal muscle fat infiltration: impact of age, inactivity, and exercise. J Nutr Health Aging 2010;14:362-6. https://doi.org/10.1007/s12603-010-0081-2
20. McElvany MD, McGoldrick E, Gee AO, Neradilek MB, Matsen FA 3rd. Rotator cuff repair: published evidence on factors associated with repair integrity and clinical outcome. Am J Sports Med 2015;43:491-500. http://dx.doi.org/10.1177/0363546514529644

21. Melis B, DeFranco MJ, Chuinard C, Walch G. Natural history of fatty infiltration and atrophy of the supraspinatus muscle in rotator cuff tears. Clin Orthop Relat Res 2010;468:1498-505. http://dx.doi.org/10.1007/s11999-009-1207-x
22. Melis B, Nemoz C, Walch G. Muscle fatty infiltration in rotator cuff tears: descriptive analysis of 1688 cases. Orthop Traumatol Surg Res 2009;95:319-24. http://dx.doi.org/10.1016/j.otsr.2009.05.001
23. Melis B, Wall B, Walch G. Natural history of infraspinatus fatty infiltration in rotator cuff tears. J Shoulder Elbow Surg 2010;19:757-63. http://dx.doi.org/10.1016/j.jse.2009.12.002
24. Meyer DC, Rahm S, Farshad M, Lajtai G, Wieser K. Deltoid muscle shape analysis with magnetic resonance imaging in patients with chronic rotator cuff tears. BMC Musculoskelet Disord 2013;14:247. http://dx.doi.org/10.1186/1471-2474-14-247
25. Morley JE. Sarcopenia: diagnosis and treatment. J Nutr Health Aging 2008;12:452-6. https://doi.org/10.1007/BF02982705
26. Müller CT, Buck FM, Mamisch-Saupe N, Gerber C. Good correlation of Goutallier rating of supraspinatus fatty changes on axial and reformatted parasagittal computed tomographic images. J Comput Assist Tomogr 2014;38:340-3. http://dx.doi.org/10.1097/RCT.0000000000000059
27. Nové-Josserand L, Collin P, Godenèche A, Walch G, Meyer N, Kempf JF. Ten-year clinical and anatomic follow-up after repair of anterosuperior rotator cuff tears: influence of the subscapularis. J Shoulder Elbow Surg 2017;36:1826-33. http://dx.doi.org/10.1016/j.jse.2017.03.037
28. Oh JH, Kim SH, Choi JA, Kim Y, Oh CH. Reliability of the grading system for fatty degeneration of rotator cuff muscles. Clin Orthop Relat Res 2010;468:1558-64. http://dx.doi.org/10.1007/s11999-009-0818-6
29. Raz Y, Henseler JF, Kolk A, Riaz M, van der Zwaal P, Nagels J, et al. Patterns of age-associated degeneration differ in shoulder muscles. Front Aging Neurosci 2015;7:236. http://dx.doi.org/10.3389/fnagi.2015.00236
30. Rhee YG, Cho NS, Yoo JH. Clinical outcome and repair integrity after rotator cuff repair in patients older than 70 years versus patients younger than 70 years. Arthroscopy 2014;30:546-54. http://dx.doi.org/10.1016/j.arthro.2014.02.006
31. Schiefer M, Mendonca R, Magnanini MM, Fontenelle C, Pires Carvalho AC, Almeida M, et al. Intraobserver and interobserver agreement of Goutallier classification applied to magnetic resonance images. J Shoulder Elbow Surg 2015;24:1314-21. http://dx.doi.org/10.1016/j.jse.2015.02.011
32. Slabaugh MA, Friel NA, Karas V, Romeo AA, Verma NN, Cole BJ. Interobserver and intraobserver reliability of the Goutallier classification using magnetic resonance imaging: proposal of a simplified classification system to increase reliability. Am J Sports Med 2012;40:1728-34. http://dx.doi.org/10.1177/0363546512452714