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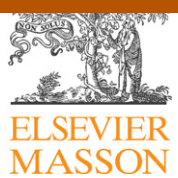

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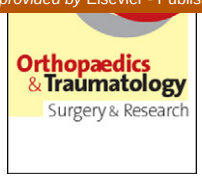

ORIGINAL ARTICLE

Muscle fatty infiltration in rotator cuff tears: Descriptive analysis of 1688 cases

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KEYWORDS
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Muscle;
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Summary
Introduction: Fatty infiltration (FI) is an important prognosis factor in the anatomical and functional outcomes of rotator cuff repairs. The objective of this study was to analyze the natural history of muscle FI and better evaluate its onset and aggravation time frame.
Material and methods: A total of 1688 medical charts of patients operated on for rotator cuff tear and whit a preoperative CT arthrogram (82%) or an MRI (18%) were reviewed. Surgery was performed between 1988 and 2005. The FI of each muscle was assessed as minimal (in Goutallier's stages 0 and 1), intermediate (in stage 2), and severe (in stages 3 and 4). Regarding supraspinatus, we retained the mean FI observed in the sagittal, coronal, and axial planes; for the infraspinatus and the subscapularis, we retained the observed mean on two views at the upper and lower levels of the glenoid in the axial plane.
Results: We found a statistically significant correlation ($p < 0.0005$) between FI, the type of tendon lesion, and patient age for the supraspinatus, the infraspinatus, and the subscapularis. Statistically, the FI significantly increased ($p < 0.0005$) with time elapsed for the supraspinatus and the infraspinatus but not significantly for the subscapularis. The mean time to tendon rupture observed for intermediate FI was three years for the supraspinatus and 2.5 years for the infraspinatus and the subscapularis when their tendons ruptured. The mean time observed to severe FI was five, four, and three years for the supraspinatus, the infraspinatus, and the subscapularis, respectively.
Discussion and conclusion: The more extensive the lesion, the longer the time following rupture, and the older the patient is, the more severe the FI is. The objective of surgery is to intervene before intermediate FI sets in, which means irreversible functional loss.
Level of evidence: Level IV. Diagnostic Retrospective Study.

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Introduction

Rotator cuff pathology is not only a tendon pathology, but also a muscle pathology. Tendon tear can lead to the onset of progressive and irreversible fatty infiltration (FI) of the muscle belly as well as the belly of the adjacent muscles. This infiltration was described for the first time in 1989 by Goutallier et al. [1] and classified into five stages depending on the fat/muscle ratio on axial views. This classification, initially described on CT for the infraspinatus and the subscapularis muscles, was later extended to the supraspinatus [2] then on MRI T1-weighted sequences in the sagittal plane [3]. The Goutallier classification dates from 20 years ago and FI has become the most important prognostic factor for anatomical and functional results of rotator cuff repairs. All the research that has tested this classification has confirmed what Goutallier [4] had already written in 1994: ''after rotator cuff repair, even with satisfactory results, the muscle condition does not improve. Stage 2 or higher FI is responsible for permanent muscle function loss and increases the rate of secondary tear.'' Surgical repair should therefore ideally be performed before the onset of stage 2 infiltration. Nevertheless, all rotator cuff tears do not warrant surgical treatment and most of them, notably those occurring after 55 years of age, should first be treated medically (rest, adaptation of daily and occupational movements, rehabilitation, NSAIDs, antalgics, physical therapy, infiltrations, etc.). It is most often after medical treatment fails that surgery or arthroscopic surgery is discussed. The natural history of FI is poorly known and the time necessary for medical treatment can make the difference between a reparable and an irreparable rotator cuff status because FI can progress beyond stage 2.

The objective of this study was to define the natural history of FI, the time to onset of the different stages in relation to the type of tear, patient age, and time.

Material and methods

We reviewed the medical files of 2500 rotator cuff tears treated surgically by the senior author between 1988 and 2005 for tendon repair, arthroscopic debridement, or a reversed shoulder prosthesis. A CT arthrogram or a preoperative MRI were present and could be analyzed in 1822 cases.

We removed the cases that had already been operated and isolated cases of FI of the infraspinatus muscle with no full-thickness tendon rupture; only MRIs including T1-weighted axial, sagittal, and coronal sequences on which FI could be analyzed were retained. We studied 1688 files for which we correlated FI of each rotator cuff muscle with the type of tendon lesion identified on the images and confirmed on the surgical report, sex, the side involved, traumatic or progressive injury, the time between the beginning of symptoms and the imaging studies, and patient age when the images were taken. Table 1 shows the distribution of the lesions discovered on imaging and their epidemiology. The supraspinatus tendon presented a partial or full-thickness rupture in 93.2% of the cases, the subscapularis in 37.5% of the cases, and the infraspinatus in 24.4% of the cases. The mean age at imaging was 57.2 years and men accounted for 59.5% of the cases. The initial injury was traumatic in 39.6% of the cases. FI was assessed using Goutallier's classification on the CT and using the same classification adapted by Fuchs et al. [3] on MRI. Supraspinatus FI was evaluated on coronal, sagittal, and axial images (Fig. 1) and the mean of the three values was retained. For the infraspinatus and subscapularis muscles, we retained the mean of the two measurements taken on the axial views at the superior and inferior parts of the glenoid, as recommended by Goutallier et al. [4] (Figs. 2 and 3).

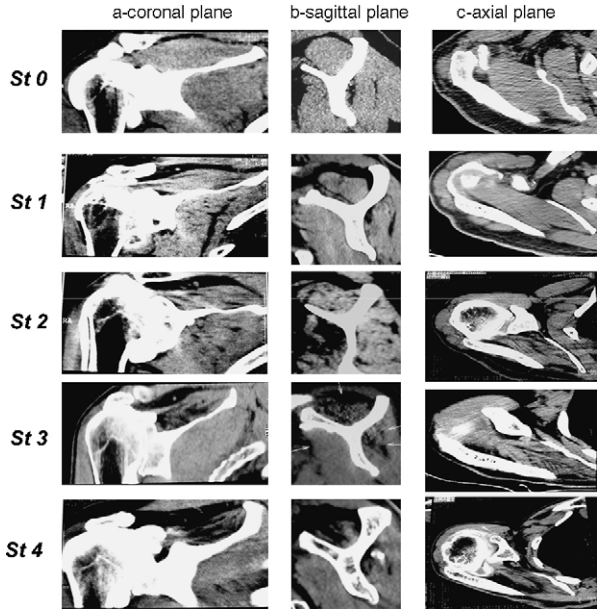

Figure 1 Supraspinatus FI assessment on the three planes: coronal (a), sagittal (b), and axial (c). The mean of three values was retained.

Table 1 Frequency of tendon tears and epidemiology.

	SS $n = 577$	Partial SS $n = 232$	Isolated SScap $n = 115$	SS + SScap $n = 353$	SS + IS ± TM $n = 246$	SS + IS + SScap $n = 165$
Distribution (% of cases)	34.2	13.7	6.8	20.9	14.6	9.8
Mean age	56.8	51.7	52.0	58.5	59.9	63.0
Traumatic onset (% by type of lesions)	35.8	33.5	46.0	45.1	43.6	39.0

SS: full-thickness rupture of supraspinatus tendon; partial SS: partial rupture (deep or superficial or intratendinous) of the supraspinatus tendon; SScap: subscapularis tendon rupture; IS: infraspinatus tendon rupture; TM: teres minor tendon rupture.

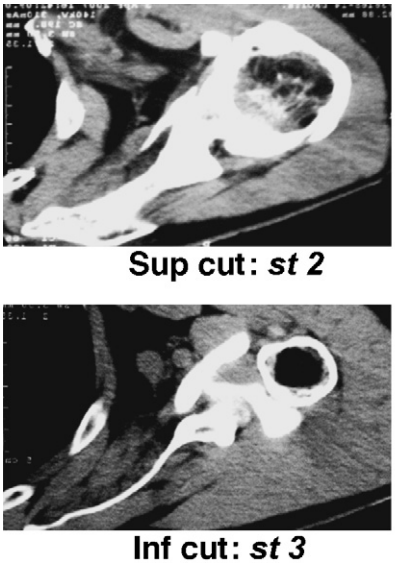

Figure 2 Subscapularis FI assessment. We retained the mean of the two values assessed at the high and low parts of the glenoid on the axial plane.

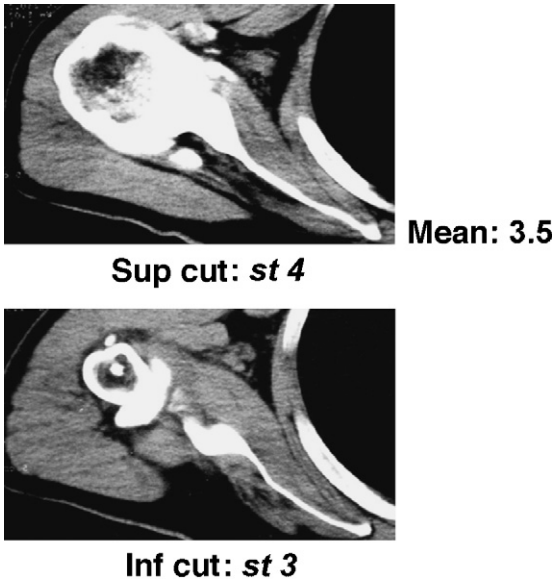

Figure 3 Infraspinatus FI assessment. We retained the mean of two values assessed at the high and low parts of the glenoid on the axial plane.

Statistical analysis

To simplify and reinforce the statistical analysis, Goutallier stages 0 and 1 were grouped into ''minimal FI,'' stage 2 into ''intermediate FI'', and stages 3 and 4 into ''severe FI.''

We used the Fisher exact test (dichotomous variable) or the chi-square test likelihood ratio (categorical variables) to test the qualitative variables. For the quantitative variables, we performed a one-way analysis of variance (ANOVA) followed by a Bonferroni test of multiple comparisons (factor with more than two modalities). Since the values were sometimes quite widely scattered (mean different from the median — nonhomogenous variances), we used the Kruskal-Wallis nonparametric test, and then we performed the Wilcoxon test on paired samples to demonstrate any differences.

To refine the analysis of the respective influence of the FI factors, we performed binary logistical regression using the paired responses of the dependent variable.

Results

The supraspinatus muscle was found to be the most frequently involved in our study (Table 2). The subscapularis muscle whose tendon was partially or totally torn in 37.5% of the cases was less often infiltrated with fat than the infraspinatus whose tendon was found to be ruptured in 24.4% of the cases.

Influence of tendon lesions on FI

FI of the supraspinatus increased with the size of the rupture and the number of tendons ruptured ($p < 0.0005$). Table 3 shows that FI was greater in partial lesions of the supraspinatus and greater in massive lesions involving the three tendons (supraspinatus, infraspinatus, and subscapularis). It could be present with a supraspinatus tendon intact as well as in isolated subscapularis lesions.

Table 4 shows that for the infraspinatus, the FI increased with the size of the tear ($p < 0.0005$). It could be present with a nonruptured tendon as well as in partial and isolated supraspinatus lesions, isolated subscapularis lesions, and supraspinatus + subscapularis lesions. It was statistically greater when the infraspinatus tendon was torn.

Table 5 shows that FI of the subscapularis muscle was possible even when its tendon was intact, but it was statistically more frequent and more severe when the tendon was ruptured ($p < 0.0005$). FI was greater in isolated ruptures of the subscapularis tendon than in more extensive ruptures involving the supraspinatus + infraspinatus ± teres

Table 2 Frequency of fatty infiltration.

FI	Supraspinatus muscle $n = 1677$ (%)	Infraspinatus muscle $n = 1619$ (%)	Subscapularis muscle $n = 1606$ (%)
Minimal (stages 0 and 1)	66	73	84
Intermediate (stage 2)	28	18	12
Severe (stages 3 and 4)	6	9	4

Table 3 Relationship between supraspinatus muscle fatty infiltration and cuff tear size.

	Partial SS $n = 231$ (%)	Isolated SScap $n = 114$ (%)	SS $n = 571$ (%)	SS + SScap $n = 352$ (%)	SS + IS ± TM $n = 244$ (%)	SS + IS + SScap $n = 165$ (%)
Minimal	93	95	73	63	41	28
Intermediate	7	4	25	34	41	52
Severe	0	1	2	3	18	20

SS: full-thickness rupture of supraspinatus tendon; partial SS: partial rupture (deep or superficial or intratendinous) of the supraspinatus tendon; SScap: subscapularis tendon rupture; IS: infraspinatus tendon rupture; TM: teres minor tendon rupture.

Table 4 Relationship between infraspinatus muscle fatty infiltration and cuff tear size.

	Partial SS $n = 218$ (%)	Isolated SScap $n = 112$ (%)	SS $n = 547$ (%)	SS + SScap $n = 341$ (%)	SS + IS ± TM $n = 241$ (%)	SS + IS + SScap $n = 160$ (%)
Minimal	94	93	84	83	36	22
Intermediate	5	7	13	15	34	45
Severe	1	0	3	2	30	33

SS: full-thickness rupture of supraspinatus tendon; partial SS: partial rupture (deep or superficial or intratendinous) of the supraspinatus tendon; SScap: subscapularis tendon rupture; IS: infraspinatus tendon rupture; TM: teres minor tendon rupture.

Table 5 Relationship between subscapularis muscle fatty infiltration and cuff tears size.

	SS $n = 547$ (%)	SS + IS ± TM $n = 235$ (%)	Isolated SScap $n = 112$ (%)	SS + SScap $n = 339$ (%)	SS + IS + SScap $n = 158$ (%)
Minimal	97	92	67	70	55
Intermediate	3	8	28	21	31
Severe	0	0	5	9	14

SS: full-thickness rupture of supraspinatus tendon; partial SS: partial rupture (deep or superficial or intratendinous) of the supraspinatus tendon; SScap: subscapularis tendon rupture; IS: infraspinatus tendon rupture; TM: teres minor tendon rupture.

minor tendons without involving the subscapularis tendon. Subscapularis + supraspinatus tears had a lower FI rate than isolated subscapularis ruptures: this surprising observation can be explained by the diversity of the subscapularis lesions observed in association with supraspinatus ruptures; when the long portion of the biceps was dislocated on the imaging studies or at surgery, by definition we accepted that the rupture involved the subscapularis even if, often, only certain very superior fibers were disinserted. Similarly, we observed all degrees of involvement of the tuberosity insertion of the subscapularis and no satisfactory classification could account for all of this diversity.

Influence of the time to symptom onset and the imaging studies

The time between the beginning of symptoms and the imaging studies increased regularly in a statistically significant manner between the different stages of FI for the supraspinatus ($p < 0.0005$) and the infraspinatus ($p < 0.0005$) but not for the subscapularis.

For the supraspinatus and the infraspinatus, an intermediate FI appeared a mean four years after the onset of symptoms and the severe FI appeared six years after. The date of the beginning of problems was often imprecise in the progressive injuries, whereas it was easier to determine in the traumatic injuries. In traumatic onset, severe FI took a mean five years to arise for the supraspinatus, four years for the infraspinatus, and three years for the subscapularis (Table 6).

Influence of patient age

Patient age always increased significantly ($p < 0.0005$) following the different stages of FI for the three main muscles. Interestingly, age at the different stages was approximately the same for the different muscles (Table 7).

This age factor was also found when the overall series was broken down into three groups according to age (Table 8): less than 50 years, 50—60 years, and more than 60 years. The frequency and the severity of the FI of the three muscles increased statistically in a linear fashion between these three age groups.

Statistical regression

The size of the tendon lesion, the time delay since symptom onset, and patient age were all three highly significant

Table 6 Average time to onset of different fatty infiltration stages assessed in overall series and traumatic vs progressive onset.

Time to onset (months)	Supraspinatus FI			Infraspinatus FI			Subscapularis FI		
	Minimal	Intermediate	Severe	Minimal	Intermediate	Severe	Minimal	Intermediate	Severe
Overall series	24	46	70	26	44	67	24	34	46
Traumatic onset	19	35	58	19	31	46	17	31	39
Progressive onset	29	54	84	33	56	84	33	36	55

Table 7 Average age at different FI stages.

	Supraspinatus FI			Infraspinatus FI			Subscapularis FI		
	Minimal	Intermediate	Severe	Minimal	Intermediate	Severe	Minimal	Intermediate	Severe
Mean age	54	62	67	55	62	65	56	62	63

Table 8 Frequency of FI stages in different age groups.

	Supraspinatus FI			Infraspinatus FI			Subscapularis FI		
	Minimal (%)	Intermediate	Severe (%)	Minimal (%)	Intermediate	Severe (%)	Minimal (%)	Intermediate	Severe (%)
$\leq$ 50 years	90	9%	1	91	6%	3	92	5%	3
50 < > 60 years	73	24%	3	80	15%	5	87	10%	3
$\geq$ 60 years	47	41%	12	56	28%	16	77	17%	6
		$p < 0.0005$			$p < 0.0005$			$p < 0.0005$	

Supraspinatus FI: $\leq$ 50 years, $n = 393$; 50 < > 60 years, $n = 602$; $\geq$ 60 years, $n = 696$.
Infraspinatus FI: $\leq$ 50 years, $n = 385$; 50 < > 60 years, $n = 580$; $\geq$ 60 years, $n = 669$.
Subscapularis FI: $\leq$ 50 years, $n = 385$; 50 < > 60 years, $n = 576$; $\geq$ 60 years, $n = 660$.

factors for the appearance and aggravation of FI. An overall multiple regression was performed to attempt to separate out the most important factor or factors. We considered muscular FI a dependent variable and age, time to onset, and the tendon lesions co-variables. The three co-variables were highly significant ($p < 0.0005$), but we could not detect one co-variable that was more important for the supraspinatus and infraspinatus muscles. On the other hand, for the subscapularis, the time to onset did not have a significant influence on FI development.

We then performed binary logistic regressions by pairing the FI values in each group of tendon lesions: age appeared to be preponderant over duration for both the supra- and infraspinatus muscles.

Discussion

FI of the rotator cuff muscles was described in 1989 by Goutallier et al. [1]. Since then, this notion has not ceased to gain importance in the degenerative and traumatic pathology of the shoulder. Goutallier et al. first showed that it was irreversible and then demonstrated its influence on the result of rotator cuff tendon repairs [4—9]; these authors proved that FI was correlated with the extent of the tendon tear and suspected a relation between the time between the rupture and the imaging studies, but could not prove it.

In 1993, Bernageau et al. estimated that FI was independent of patient age [5] but dependent on the time between the onset of symptoms and the imaging studies: this correlation was difficult to prove for the supraspinatus muscle, contrary to the infraspinatus, which could develop a grade 2 or higher infiltration within six months.

This study confirmed Goutallier's results in a statistically significant manner and the influence of lesion extent in FI: the larger the tear, the faster and more severe the FI was. Rupture of the infraspinatus tendon is not indispensable for a FI of the muscle to appear, but when the infraspinatus tendon is torn, this FI is much more rapid and severe. The time between the rupture and the imaging studies, as suspected by Goutallier et al., is statistically correlated with FI for the supra- and infraspinatus but not for the subscapularis. The great diversity in what is considered a rupture of the subscapularis may explain this absence of statistical correlation.

The influence of age is a new factor that had not been reported and that we found to be highly significant. With the large number of cases analyzed, we were able to demonstrate a very strong relationship between patient age for the three major muscles: the older the subject is, the more severe the FI is, although we were not able to prove that the speed of appearance or aggravation was greater in older subjects.

We attempted to precisely describe the delay of FI onset in relation to the different age groups and the lesions, but

the scattered values and the high standard deviations did not provide statistically significant results. The widely scattered time delays observed and the high standard deviations were indisputably the weak point and the limitation of our study. In the infraspinatus muscle, Gerber et al. [10] recently demonstrated that tendon disruption modified the muscle's pennation angle and that fat could also infiltrate between the muscle fibers. Tendon and muscle disruption could be the fourth fundamental factor in the appearance and rapid progression of FI. We were not able to take this into account in our study because it is difficult to evaluate on MRI, CT arthrogram, or during surgery, particularly in infraspinatus and subscapularis muscles. It is theoretically easier to assess for the supraspinatus muscle, but the variety of rupture types and extents make its quantification somewhat random: certain full-thickness tears have no disruption because a few fibers remain attached to the tubercle or the adjacent muscles. In other ruptures (traumatic), muscle disruption seemed clear and easily detected on the imaging studies as well as during surgery, but these cases were too rare to allow this criterion to be statistically analyzed within the entire series. When imaging will have become sufficiently reliable to measure the muscles' pennation angle, we may well be able to foresee the installation and development of muscular FI more precisely in rotator cuff tears.

The influence of FI on rotator cuff repairs has been analyzed a number of times: Fuchs et al. [11], Jost et al. [12], Liem et al. [13], and Goutallier et al. [4] have shown that after repair, FI increases significantly compared to the preoperative stage.

Gladstone et al. [14] showed that muscular FI was the most important prognostic factor for the result of arthroscopic repairs of rotator cuff tendons. They confirm that, to avoid compromising the repair results, one must intervene before the development of irreversible muscle changes, i.e., before stage 2 FI. All rotator cuff ruptures do not require surgery and it is important to be able to approach the natural history of FI as closely as possible so as to assist in the therapeutic indications and separate the cases in which rapid repair is desirable from those in which conservative medical treatment can be given without risking rapid progression toward FI.

Our results found a strong, statistically significant relation between FI, the size of the tendon lesion, patient age, and time to onset. We individualized the traumatic injuries more precisely, the extent of the different tendon lesions, and patient age into different groups so as to provide more precise information on the time to onset of stage 2 intermediate and stages 3 and 4 severe FI. The time to onset of intermediate FI of the supraspinatus can be evaluated at four years in the tears including a full-thickness tear of the tendon. For the infraspinatus muscle, when it was ruptured, the time to onset of severe FI was from three to six years depending on patient age.

Conclusion

FI of the rotator cuff muscles is closely related to patient age, the extent of the tendon rupture, and the time to onset. The more extensive the tear and the older the patient, the more rapidly one should make a decision for surgical repair. Other factors such as the extent of tendon and muscle retraction seem to play an important role but could not be evaluated in this study.

Conflict of interest

None.

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