

Fatty Degeneration of Subscapularis Muscle after Total Shoulder Arthroplasty: A CT-scan Analysis from SFI study Group

Hugo Barret¹ (*), Arnaud Godeneche², Thierry Joudet³, Christophe Charousset⁴, Stephane Audebert⁵, Yves Lefebvre⁶, Johannes Barth⁷, Jerome Garret⁸, David Gallinet⁹, Jacques Guery¹⁰, SFI¹¹, Nicolas Bonneville¹

(*) corresponding author: hugobarret89@gmail.com

1. Hôpital Pierre Paul Riquet - CHU de Toulouse - Place Baylac, 31059, Toulouse Cedex 09, France

2. Centre Orthopédique Santy, Ramsay Santé, Hôpital Privé Jean Mermoz, Lyon, France

3. Clinique du Libournais, Libourne, France

4. Institut Ostéo Artculaire Paris Courcelles, Paris, France

5. Department of Orthopaedic Surgery, Clinique du Cambresis, Cambrai, France

6. Institut de l'épaule de Strasbourg (Strasbourg Shoulder Institute), Strasbourg, France

7. Clinique des Cèdres, Echirolles, France

8. Clinique du Parc, Groupe ELSAN, Lyon, France

9. Centre épaule main Besançon, 16, rue Madeleine-Brière, 25000 Besançon, France

10. Polyclinique du Val de Loire, Nevers, France

11. Shoulder Friends Institute, 60 Rue de Courcelles, 75008 Paris, France



Background: Postoperative dysfunction of subscapularis muscle is a well-known cause of failure following anatomic total shoulder arthroplasty surgery (aTSA).

Purpose: To evaluate postoperative fatty degeneration of subscapularis muscle following anatomic shoulder replacement.

Methods: In a prospective multicenter study, we included patients who underwent aTSA, with preoperative subscapularis fatty degeneration grade 0 (Goutallier classification system) and with CT-scan performed at 12 months postoperative. The fatty degeneration and trophicity of the subscapularis muscle were analysed by two senior surgeons. The subscapularis was divided into an upper and lower part on a sagittal view.

Results: From an indexed database comprising 120 patients, 100 patients (104 CT scans) were included. Subscapularis tenotomy (n = 77) or peel-off technic (n = 27) was performed. Tendon repair was performed either by trans osseous fixation with looped sutures (n = 89) or with anchors alone (n = 15). After a mean follow-up of 16 ± 4 months, fatty degeneration of the subscapularis muscle increased in all patients. In the upper part of the subscapularis, the mean Goutallier stage was 2 ± 0.3. In the lower part of the subscapularis, the mean Goutallier stage was 1.2 ± 0.3 (p = 0.01). The trans osseous reinsertion technique provided better protection of the subscapularis than anchors in the upper and lower parts of the subscapularis (1.8 ± 0.7 vs 2.67 ± 1, p = 0.04; and 1 ± 0.8 vs 1.8 ± 1.1, p = 0.01, respectively). Inter- and intra-rater reliability was satisfactory for the assessment of fatty degeneration, while inter- and intra-rater reliability was moderate for trophicity.

Conclusion: In short-term follow-up after aTSA without preoperative subscapularis muscle injury, fatty infiltration is greater in the upper subscapularis than in the lower subscapularis, regardless of the surgical technique used. Transosseous reinsertion of the subscapularis tendon appears to cause less damage to the subscapularis muscle in anatomic shoulder arthroplasty. A longer clinical and radiological follow-up is necessary to find the best management of the subscapularis in aTSA.

What this study adds: a precise assessment of the subscapularis in anatomical prostheses with a division between the upper and lower subscapularis.

Potential impacts on research, practice, or policy: use of transosseous reinsertion of the subscapularis rather than anchors; medium- and long-term follow-up of patients and the subscapularis with precise imaging examinations

Study Design: Case series

Level of evidence: Level IV

Keywords: osteoarthritis; anatomic total shoulder arthroplasty, CT scan; fatty degeneration; subscapularis; stemless.

<https://doi.org/10.70885/hmsj.2025.08.001>

A correction has been applied to this article on 15.01.2026: <https://doi.org/10.70885/hmsj.2026.01.003>

Introduction

Total shoulder arthroplasty (TSA) is an increasingly common procedure, with incidence growing of two-fold between 2012 and 2017 in the USA, especially with stemless implant [1]. In patients under 55 years old, the cumulative percent revision rate at 5 years was reported of 12% for stemmed aTSA and 7% for stemless aTSA [2]. In addition to glenoid loosening, which is the main cause of failed aTSA, aTSA instability due to subscapularis failure is a common cause requiring revision followed by loosening [3]. Postoperative subscapularis insufficiency is a risk factor for poor clinical outcomes in terms of both internal rotation deficiency and prosthetic instability [4]. Failure of the subscapularis can lead to subluxation or even anterior humeral dislocation.

Subscapularis management during the surgical procedure of an aTSA remains challenging from the approach to the repair. Biomechanical studies reported advantages in sparing of the subscapularis or osteotomy of the lesser tuberosity (LTO) over tenotomy or peel [4]. However, clinical outcomes did not prove any differences at short term regarding strength and functional scores [5]. No statistically differences were also observed regarding fatty degeneration between LTO and peel [6]. Surprisingly, LTO does not protect against fatty degeneration and Gerber et al. reported progression of fatty degeneration in 45% of cases, despite consolidation of the lesser tuberosity [7].

The subscapularis muscle can be divided into 2 parts, upper and lower, by analogy with the posterior cuff [8]. Muscular activity of the inferior subscapularis appears to be greater than the upper, particularly in anterior elevation and abduction [9]. In active internal rotation, the upper part of the subscapularis is the most active based on electromyography, while the lower part is more stabilizing during external rotation [10]. As previously seen, failure of the subscapularis and its fatty infiltration can lead to loss of range of motion, decreased shoulder function and prosthetic instability. To our knowledge, no study compared postoperative fatty degeneration of the upper and lower subscapularis muscle.

Therefore, the aim of this study was to evaluate subscapularis muscle evolution on CT-scan following aTSA. Our hypothesis was that fatty degeneration increased differently between upper and lower part of the muscle, whatever the management performed.

Methods

This study was approved by our Ethics Committee (RnIPH 2022-32).

Study Design

Between January 2019 and December 2021, we performed a prospective multicentre study (10 centres, 10 surgeons) in which we included patients (1) who underwent anatomic aTSA (ISA Stemless®, Isa Onlay®, MOVE-UP, Alixan France), for (2) primary glenohumeral osteoarthritis, (3) with preoperative grade 0 of subscapularis muscle fatty degeneration (Goutallier classification) and (4) reviewed with CT-scan performed between 12 to 24 months postoperatively. (5) A minimum clinical follow-up required was 2 years. We excluded patients with a history of surgery on the shoulder involved.

Surgical Technique

With the patient in the beach chair position, under general anaesthesia and inter-scalene block, a delto-pectoral approach was performed. Tenotomy (n=77) or peel (n=27) of the subscapularis tendon was carried out according to each surgeon's preference in order to expose and dislocate the humeral head. Release of the subscapularis was then performed. After removing osteophytes, the head was removed with a cut at the level of anatomical neck. The humerus was prepared to accept a stemless implant (n=68) or short stem (n=36) depending on bone quality (if the stemless fixation is poor, a short stem should be used) (ISA Stemless®, Isa Onlay®, MOVE-UP). Then, the glenoid step started by improving exposure with a circumferential capsulotomy, before sizing the glenoid. A press-fit hybrid implant was inserted, after reaming and peg preparation with a pin guide. The humeral anchor or short stem was then impacted, and a trial of head was positioned. The glenohumeral joint was reduced, the stability tested and the final humeral head component was implanted. The subscapularis tendon was then repaired according surgeon preference [15]. The transosseous technique using four suture loops with a secure knot was performed with holes drilled prior to implanting the stem directly with the needle and electric scalpel in n = 89 patients. Fixation of the subscapularis using four double-row anchors was performed in n = 15 patients. The subscapularis was fixed in neutral rotation.

All patients were immobilized in a sling for 4 weeks and had the same rehabilitation protocol regardless of the tension or repair of the subscapularis. They were allowed to remove the brace to perform a self-education program with pendulum exercises (5 times a day, 5 minutes for each session), starting the day after surgery. Conventional physiotherapy were started after 4 weeks, and external rotation protected during 6 weeks, based on intraoperative evaluation of tensile forces required to fix the subscapularis tendon.

Clinical evaluation

Preoperatively, patient characteristics were gathered from medical records. Postoperatively, patients were evaluated clinically prospectively in each centre at 1.5, 3, 6, 12 and 24 months using a standardized method with pain scale, Constant score [11], SSV score [12] and American Shoulder and Elbow Surgeons (ASES) score. Subscapularis insufficiency was analysed using the mobility category of the Constant score. Complications, reoperations and revision surgeries were collected.

Radiological evaluation

CT scan evaluation was performed in 2D with Horos software (v3.3.6) by two shoulder-trained surgeons (JT, HB) with determination of inter- and intrarater reliability. Intrarater reliability was measured at one-week time intervals (Figure 1). The two surgeons evaluated all patients using individual measurements, which were then averaged. The CT scan acquisition protocol was standardised for all the patients with 1 mm thick slices

greater than 200 in axial section and then in sagittal section to analyse the subscapularis muscle, trophicity and fatty infiltration.

Postoperatively, a CT-scan was performed between 12 and 24 months. First, we used the axial view and Friedman's line. Then we used the sagittal view, taking the first section with the Y of the scapula. The first analysis focused on the fatty degeneration of the subscapularis muscle on the sagittal Y-view [13]. The analysis separated the half superior and half inferior part according to Collin et al [8]. (Figure 2) Fatty degeneration was analysed according to Goutallier classification system.

Hypertrophy of the subscapularis muscle was assessed by analogy with that of the teres minor muscle [29]: the subscapularis muscle is considered hypertrophic if its thickness exceeds the anteroposterior width of the glenoid. The subscapularis muscle was divided into two parts and the trophicity of the minor/inferior subscapularis muscle was assessed after surgery [8]. To divide the upper and lower parts of the subscapularis muscle, a line perpendicular to the body of the scapula and following the lower edge of the spine of the scapula was drawn [8] (Figure 2 and 3).

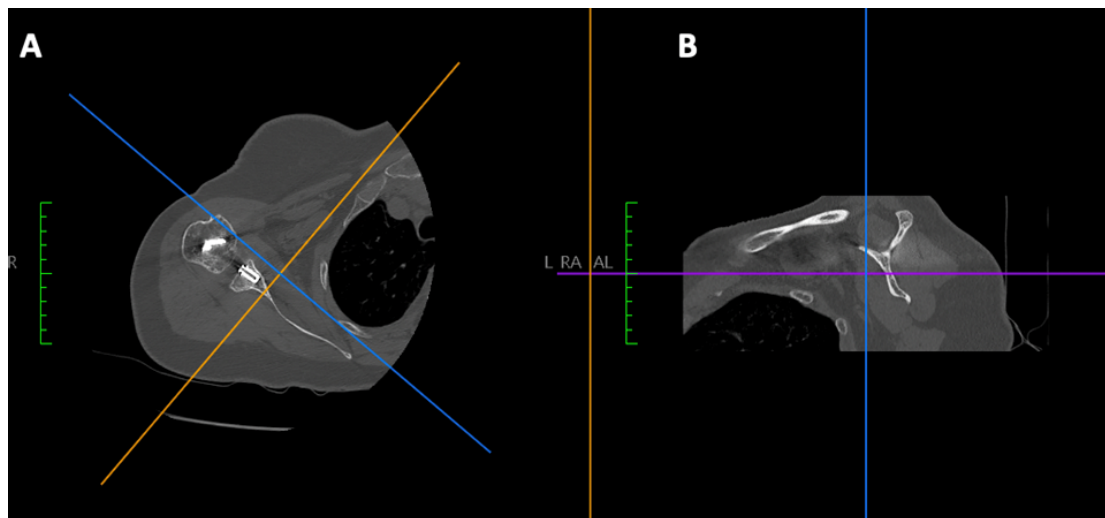


Figure 1. Preparing CT scan for subscapular analysis on the Y-section Use of the CT's axial section (A). The plane passing through the main axis of the scapula provides a satisfactory Y-section (B). In Figure A, the blue line represents Friedman's line, which is shifted along the subscapularis; the orange line is its perpendicular line. In Figure B, the blue line is the same as in Figure A, while the purple line is its perpendicular line.

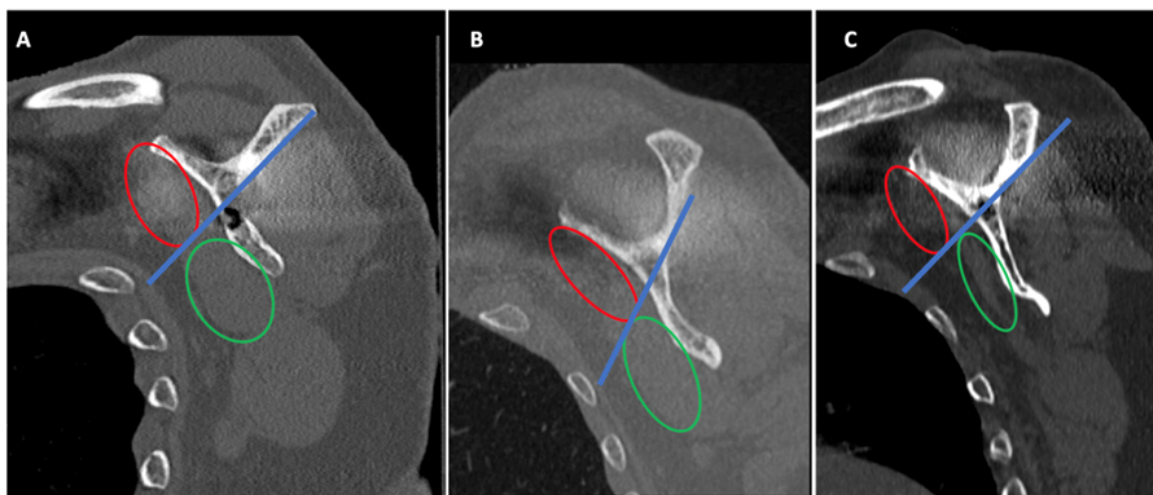


Figure 2. Assessment of upper and lower half subscapularis muscle (A) fatty degeneration Goutallier grade 1 in the upper part (red circle) and grade 0 in the lower part (green circle); (B) grade 3 fatty infiltration in the upper part of the subscapularis (red circle) and stage 1 in the lower part (green circle); (C) stage 4 fatty infiltration in the upper part (red circle) and stage 3 in the lower part (green circle) of the subscapularis muscle (red circle). The blue line is the line that separates the upper and lower parts of the subscapularis. It follows the lower edge of the spine and is perpendicular to the body of the scapula.

Statistical analysis

The Shapiro-Wilk test was used to analyse the data distribution. A paired *t*-test was used to compare normally distributed data, and the Mann-Whitney U test to compare non-normally distributed data. A Chi-square test was used to compare categorical data. If any cell had three numbers or fewer, we used the Fisher exact test. The significance level was set at a *p* value of less than 0.05. We performed statistical analyses using XLSTAT software (Addinsoft). The Cohen *k* was calculated to assess the measurement reproducibility (inter-rater and intra-rater reliability). A *k* coefficient of 0 indicated no agreement; 0.01-0.20, none to slight agreement; 0.21-0.40, fair agreement; 0.41-0.60, moderate agreement; 0.61-0.80, substantial agreement; and 0.81-1.00, almost perfect agreement. Multivariate regression analysis analysed the correlation between clinical scores and subscapular infiltration.

Results

Clinical results

From an index database of 120 patients, 104 CT scans were analysed in 100 patients at 16+/-4 months post-operative follow-up. The 16 shoulders that were excluded did not complete the CT scan during the inclusion period. The mean age of patients was 69+/-11 years, with 59 women and 41 men, all of whom had primary osteoarthritis of the shoulder. The mean VAS for pain was 0.8 (SD 0.5), the mean Constant-Murley score was 78 (SD 8), the mean SSV was 78 (SD 15), and the mean ASES score was 79 (SD 11). No correlation was found between the Constant score, ASES score, SSV score and subscapularis fatty infiltration.

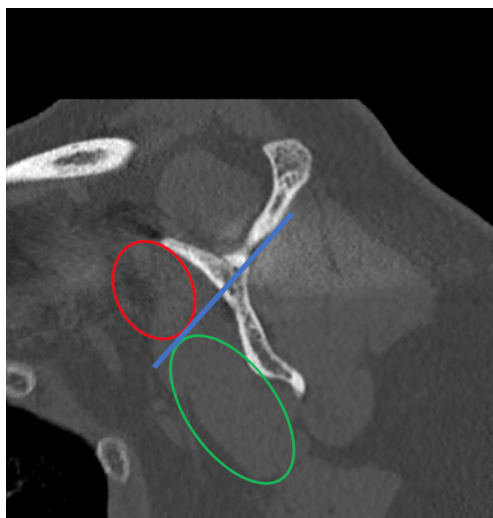


Figure 3. Hypertrophy of lower subscapularis muscle (green circle) Hypertrophy of the subscapularis muscle was assessed by analogy with that of the teres minor muscle; the subscapularis muscle is considered hypertrophied if its thickness exceeds the anteroposterior width of the glenoid cavity²⁹. We then represented it on a sagittal section to highlight this hypertrophy.

Table 1: Tenotomy versus Peel Off

	SSc Tenotomy N = 77	Peel off N = 27	P value
Upper half fatty infiltration of SSc	2.06 (± 0.8)	2.0 (± 0.8)	0.839
Lower half fatty infiltration of SSc	1.18 (± 0.9)	0.78 (± 0.6)	0.062
SSc Hypertrophic			0.886
Yes	25 (32%)	7 (26%)	
No	52 (68%)	20 (74%)	
Upper half fatty infiltration of SSc			0.311
1	13 (16.9%)	6 (22.2%)	
2	43 (55.8%)	12 (44.5%)	
3	16 (20.8%)	9 (33.3%)	
4	5 (6.5%)	0	
Lower half fatty infiltration of SSc			0.706
0	41 (53.2%)	17 (63%)	
1	25 (32.5%)	7 (25.9%)	
2	4 (5.2%)	2 (7.4%)	
3	7 (9.1%)	1 (3.7%)	

SSc = Subscapularis

Table 2: Transosseous repair vs tendon-tendon repair

	Transosseous repair N = 89	Tendon-tendon repair + anchors N = 15	P value
Mean Upper SSc fatty infiltration	1.4 (± 0.7)	2.2(± 1)	0.04*
Lower SSc Hypertrophic			0.33
Yes	29 (33%)	3 (20%)	
No	60 (67%)	12 (80%)	
Upper SSc infiltration			0.03*
0	36 (41%)	2 (13.0%)	
1	33 (37%)	4 (27.0%)	
2	10 (11%)	4(27%)	
3	8 (9%)	4 (27%)	
4	2 (2%)	1 (6.0%)	

SSc = Subscapularis; * statistically significant result

Radiological results

Fatty degeneration of the subscapularis was at stage 1 in 18% of cases (19/104) for the upper part and in 56% of cases for the lower part of the subscapularis. In the upper part, mean fatty degeneration was stage 2.0 ± 0.3 and stage 1.2 ± 0.3 in the lower part. The lower part of the subscapularis muscle was hypertrophic in one third of the patients.

No difference was found between tenotomy and peel off technique on postoperative fatty degeneration. Transosseous repair seems to alter the subscapularis muscle less in both the upper and lower parts (upper subscapularis 1.8 ± 0.7 vs. 2.67 ± 1 , $p=0.04$; lower part 1 ± 0.8 vs. 1.8 ± 1.1 , $p=0.01$) than tendon repair with anchors (**Table 1 and 2**).

Intra and inter observer outcomes

Inter and intra-rater reliability is satisfactory (kappa between 0.767 and 0.895) for upper and lower part of the subscapularis. Inter and intra-rater reliability is moderate for "subscapularis hypertrophy" evaluation (k between 0.587 and 0.626).

Revision and complications

At a mean follow-up of 2 years, two patients underwent revision surgery: one for infection and one for symptomatic loosening. No revisions were performed for instability and/or subscapularis insufficiency.

Discussion

Reinsertion of the subscapularis is a fundamental element in anatomic total shoulder arthroplasty surgery (aTSA). The consequences of poor subscapular evolution on clinical outcome and aTSA survival can be dramatic, leading to instability, loss of strength, pain and loosening in the medium term of follow-up [4,14]. Regardless of the reinsertion technique used, this series showed a progression of fatty infiltration of the subscapularis muscle to a stage 2 on average of the upper part. In the short term follow-up, no revision or re-operation was necessary in this series following the evolution of the subscapularis. With non-matched groups, the technique that seemed to damage the subscapularis the least was transosseous reinsertion with loop compared with anchors (upper subscapularis 1.8 ± 0.7 vs. 2.67 ± 1 , $p=0.04$; lower part 1 ± 0.8 vs. 1.8 ± 1.1 , $p=0.01$) analysed using the characteristics present in this study.

The evolution of the subscapularis during an anterior approach is a very important notion that has been studied for over a decade by surgeons [15]. Functional results of anatomic total shoulder arthroplasties were correlated with subscapularis tendon healing and muscular evolution [16]. Whatever the technique used to manage the subscapularis tendon, the repaired subscapularis tendon had less resistance than the native subscapularis tendon [17]. Techniques sparing the tendinous portion of subscapularis existed and have been described with better bio-mechanical characteristics [18,19]. Radiographic analysis of subscapularis sparing techniques seemed to show uncertain positioning of the humeral component and unresected osteophytes [20]. Techniques most used to approach the glenohumeral joint are tenotomy, peel and lesser tuberosity osteotomy (LTO). Gerber et al. were one of the first teams to investigate the evolution of the subscapularis muscle after LTO in anatomical TSA, with 45% of patients showing worsening infiltration despite 100% osteotomy healing [7]. Gerber et al did not find a cause for this fatty infiltration [7]. Our series shows an increase in fatty infiltration of the upper subscapularis, regardless of the preparation or repair technique used. The lower part of the subscapularis did not appear to have fatty infiltration in more than 85% of patients. No LTO was performed in our series. De Wilde's series of C type LTO showed the absence of short-term fatty evolution in over 94% of patients by sparing the anterior axillary vessels with careful dissection and capsulotomy, as well as an osteotomy perpendicular to the lesser tuberosity [21]. The authors of this series explained that particular attention was paid to non-dissection of the subscapularis, with an osteotomy perpendicular to the fibers of the subscapularis and not parallel as described by Gerber [21].

Fatty infiltration of the subscapularis is essential to analyse in terms of functional results after aTSA and follow-up. There is a paucity of literature on the analysis of modifications to the subscapularis muscle and fatty infiltration after aTSAs. A new classification has been published for MRIs that allows the upper and lower parts of the subscapularis to be analysed separately with independent evolution [30]. Fatty infiltration appears to follow the characteristic evolution of subscapularis lesions. Indeed, Yoon et al. described fatty infiltration that begins in the upper part and subsequently spreads to the lower part [30]. We did not use this classification because CT scans were used in this series. This choice may be a limitation, as it appears that fatty infiltration is better visualised on MRI than on CT scans [30].

Subscapularis hypertrophy was present in one third of patients in this series, with no correlation with fatty infiltration of the subscapularis muscle. By analogy, hypertrophy of the Teres Minor can be seen in lesions of the posterior rotator cuff and/or subscapularis [29]. In this series of aTSAs, there were no lesions of the posterior rotator cuff, so hypertrophy of the subscapularis muscle was therefore not due to an adaptation strategy for the posterior rotator cuff deficiency.

LTO presents complications that are probably underestimated, with revision surgeries often difficult and uncertain results following failed LTO [22]. LTO presents a longer surgical time with technical difficulties that are greater compared to tenotomy or peel [23]. This is why we did not choose this technique to manage the subscapularis in this series with a majority of stemless prostheses. As in our series, Lapner found no difference in internal rotation strength and functional scores [24], with strength still lower than in a healthy ipsilateral shoulder control [25]. Once again, no series in the literature has separated the upper and lower subscapularis in the analysis of fatty degeneration [9]. No difference in the evolution of the upper and lower subscapularis was found between peel and tenotomy in this series. On the other hand, this series shows that transosseous reinsertion appears to reduce the risk of fatty degeneration compared with anchor and suture tendon reinsertion.

If we look specifically at stemless anatomical prostheses, which account for the majority of aTSA in this series, particular attention should be paid to the tenotomy group. Indeed, Werner et al have shown in their biomechanical study of stemless anatomical prostheses that if the tenotomy is performed 1 cm from the lesser tuberosity, a third of patients will have no tendon left to achieve a correct tendon-tendon suture [26]. This anatomical and biomechanical point may explain the failure of tendon-tendon reinsertion, and hence the rapid evolution of subscapular fatty infiltration. The addition of anchors seems to be an indispensable element in tendon-tendon suturing, adding strength to the fixation [26]. Even though, our series showed a better subscapularis

muscle with transosseous reinsertion. From a biomechanical point of view, transosseous reinsertion with a mini plate and double anchor row in Werner's series showed no difference in strength, but the muscular evolution was not analyzed [27]. For stemless anatomic prostheses, no difference in functional scores was found depending on subscapular management: tenotomy, peel or LTO [28].

This study has several limitations: the groups was unbalanced in favor of the tenotomy and transosseous reinsertion group. The humeral implants were from the same laboratory, but with and without stems of the humerus. On the other hand, this was a prospective series, with more than 100 cases. Each CT scan was interpreted twice by 2 senior orthopaedic surgeons specializing in shoulder surgery with good reliability concerning fatty infiltration of the subscapularis. No interpretation of the healing of the subscapularis could be carried out with the CT scan, nor could a comparison be performed between the volume of the subscapularis pre- and postoperatively. Indeed, preoperative fatty infiltration of the subscapularis was included in the database by each of the 10 surgeons in the series. All patients included in this series had a preoperative Goutallier score of 0 for the subscapularis. Preoperative CT scans were not available for analysis by the software. Finally, there was no correlation between subscapularis muscle fatty degeneration and clinical and functional scores, which may be explained by short-term follow-up, a small number of patients in some groups and a center effect.

Conclusion

In short-term follow-up after aTSA without preoperative subscapularis muscle injury, fatty infiltration is greater in the upper subscapularis than in the lower subscapularis, regardless of the surgical technique used. Transosseous reinsertion of the subscapularis tendon appears to cause less damage to the subscapularis muscle in anatomic shoulder arthroplasty. A longer clinical and radiological follow-up is necessary to find the best management of the subscapularis in aTSA.

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Source of funding

None

Conflict of Interest

Hugo Barret: none. Arnaud Godeneche, Thierry Joudet, Christophe Charousset, Stephane Audebert, Yves Lefebvre, Johannes Barth, Jerome Garret, David Gallinet, Jacques Guery, SFI, Nicolas Bonnevalle are designers of the Move Up prosthesis with royalties.

Authors' contribution

HB: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Resources, Software, Supervision, Validation, Visualization, Writing - Original Draft, Writing - Review & Editing

AG, TJ, CC, SA, YL, JB, JG, DG, : Data Curation, , Investigation, Methodology, Project Administration, Resources, Validation, Visualization , Writing - Review & Editing

SFI: Investigation, Methodology, Project Administration,

NB: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Project Administration, Resources, Software, Supervision, Validation, Visualization, Writing - Original Draft, Writing - Review & Editing

Acknowledgments

Joanne Archambault (PhD) provided editorial support; her fees were paid by Move Up.

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