Nonoperatively managed small- to medium-sized subscapularis tendon tears: magnetic resonance imaging evaluation with a minimum of 5 years of follow-up

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Background: Isolated or combined subscapularis (SSC) tendon tears are frequently found in patients with shoulder pain. The purpose of this study was to evaluate the structural changes associated with SSC tear in a consecutive series of patients with nonoperatively treated small size to midsize SSC tendon tears using magnetic resonance imaging (MRI).
Methods: In this retrospective case series, all patients with an isolated or combined SSC tendon tear treated nonoperatively between 1999 and 2019 were identified from our MRI and clinical databases. Twenty-one patients with a mean age of 52.6 years (range 26.6-64.8, standard deviation 9.3) with a second MRI scan at a minimum of 5 years of follow-up were enrolled. The mean follow-up was 8.6 years (range 5.6-12.6, standard deviation 1.8). Initial and last follow-up MRI scans were used to determine concomitant cuff lesions, size of the SSC tear, fatty infiltration of the SSC muscle, and biceps pathology.
Results: Five patients had an isolated SSC lesion; 7 patients had a concomitant tear of the supraspinatus, and 9 patients had a supraspinatus and anterior infraspinatus tendon tear. At diagnosis, 14 patients had a type 1 SSC lesion as classified by Lafosse et al, 4 patients had type 2, and 3 patients had type 3 lesions. Nineteen patients (90%) were found to have an SSC tear progression of at least one Lafosse grade ($P < .001$); however, no tear had progressed to an irreparable type lesion (defined as Lafosse type 5). In addition, the size of SSC tendon tears increased significantly from 75 mm^2 to 228 mm^2 ($P < .001$). At the final MRI scan, the grading of fatty infiltration increased by 1 grade in 4 cases and by 2 grades in 4 cases ($P = .042$). At the final follow-up, in eight patients, the condition of the long head of biceps tendon was unchanged from the initial MRI; in nine patients, there was a newly subluxated biceps tendon, and in 6 patients, there was a newly ruptured long head of biceps tendon ($P < .001$).
Conclusion: After a mean of 8.6 years, almost all nonoperatively treated SSC tendon tears had increased in size, but only one-third showed additional progression of muscle fatty degeneration on MRI scan. None of the SSC lesions became irreparable during the observation period.

Patients with a symptomatic subscapularis (SSC) tendon tear are usually considered for operative repair if conservative treatment has failed. Both arthroscopic and open SSC repairs have yielded excellent and durable clinical improvement over the preoperative state after unsuccessful conservative management.[3-9,11,12,14,16,19,20,24-26,31,34,35,37,39] In small- to moderate-sized full-thickness tears of the supraspinatus (SS) and infraspinatus (IS) tendons treated conservatively, tear size, atrophy, and fatty muscle infiltration have been shown to progress so that the tears may become irreparable over time.[23,32,36,43] Analysis of the natural history of SS tendon tears showed a 50% likelihood of tear progression after 4 years.[13,22,28,32,38,42,43] Clearly defined risk factors (ie, pain, initial tear size, and rotator cable disruption) for tear progression have also been identified, both clinically and on imaging studies.[28,41,42,44] Such knowledge of the expected course of tendon tear progression is relevant for consideration of

Table I
Personal data and history.

Case	Sex	Age at first MRI (y)	Side	Etiology	Symptomatic at first MRI	Reason not to operate after first MRI	Treatment after second MRI
1	F	65	R	Degenerative	Yes	Accepts symptoms	Conservative
2	M	64	R	Traumatic	Yes	Relief of symptoms	Conservative
3	M	58	L	Traumatic	Yes	Conservative treatment of the frozen shoulder and subsequent relief of symptoms	Conservative
4	F	62	R	Traumatic	Yes	N/A	Surgery planed, but canceled because of new tumor diagnosis
5	M	27	R	Traumatic	Yes	Relief of symptoms	Conservative
6	M	59	R	Traumatic	Yes	Relief of symptoms	SAS, cuff repair
7	M	60	L	Traumatic	Yes	Relief of symptoms	Conservative
8	M	49	R	Degenerative	Yes	Relief of symptoms	Conservative
9	M	48	R	Degenerative	Yes	Accepts symptoms	Conservative
10	M	45	L	Degenerative	Yes	Relief of symptoms	SAS, cuff repair
11	M	49	R	Traumatic	Yes	Fear of operation	Conservative
12	M	57	R	Traumatic	Yes	Relief of symptoms	Conservative
13	M	39	R	Traumatic	Yes	Relief of symptoms	Conservative
14	M	47	R	Traumatic	Yes	Relief of symptoms	SAS, cuff repair
15	M	47	L	Degenerative	Yes	Accepts symptoms	Conservative
16	M	49	L	Traumatic	Yes	Frozen Shoulder, then accepts symptoms	Conservative
17	M	59	R	Degenerative	Yes	Relief of symptoms	Conservative
18	F	57	L	Degenerative	Yes	Accept symptoms	Conservative
19	M	51	R	Traumatic	Yes	No operation wanted because fear of losing job	SAS with cuff repair and superior capsular reconstruction
20	M	62	L	Degenerative	N/A	N/A	SAS, cuff repair
21	M	50	R	Degenerative	Yes	N/A	Conservative

MRI, magnetic resonance imaging; *N/A*, not available; *SAS*, shoulder arthroscopy.

conservative treatment versus surgical repair. However, as far as we are aware, there is a paucity of published clinical or magnetic resonance imaging (MRI) data on the evolution of nonoperatively treated SSC tendon tears over time. Indeed, an understanding of the natural history is important in identifying the potential risk factors for progression of a SSC tendon tear and can help refine the indications for surgery. Furthermore, an understanding of the rate of tear progression over time is an essential part in patient counseling.

The purpose of the present study was to evaluate the imaging outcome for a consecutive series of patients with symptomatic SSC tendon tears treated nonoperatively, by analyzing the progression of the tear and muscle changes on follow-up MRI with a minimum follow-up of 5 years.

Patients and methods

This case series study was approved by the responsible ethical committee (no. 2018-02285). A database search was conducted to identify all patients presenting to our clinic between 1999 and 2019, who had at least two shoulder MRI scans with a minimum interval of 5 years (n: 3655). Exclusion criteria included any operative treatment (between first and second MRI) of the involved shoulder, type IV or V lesions according to Lafosse, a bony avulsion of the rotator cuff, and aged >65 years, as the benefit of rotator cuff repair in this group of patients remains controversial. All initial scans were reviewed to identify patients with a partial or full-thickness rotator cuff tears treated non-operatively (n: 81). We identified 21 patients with isolated or combined SSC tendon lesions. The study group consisted of 3 women and 18 men with a mean age of 52.6 years (range 26.6-64.9, standard deviation [SD] ± 9.2) at the time of diagnosis. The mean follow-up was 8.6 years (range 5.6-12.6, SD ± 1.8). For all except one patient, the clinical chart review showed rotator cuff tear−related symptoms (pain and functional deficit). Further demographic details and the reasons for conservative treatment are given in Table I.

Imaging assessment

At the time of diagnosis, all twenty-one patients had undergone standardized MR arthrography (n = 15) or native MRI (n = 6) on a 1.0-, 1.5-, or 3-Tesla scanner. The follow-up MRIs were performed with (n = 12) or without (n = 9) arthrography on a 1.5- or 3-Tesla scanner (Siemens, Erlangen, Germany). For the purpose of the study, the images were independently analyzed by a musculo-skeletal radiologist (T.P.) and a fellowship-trained shoulder surgeon (A.K.). The SSC tear was classified according to Lafosse:[24] type I: partial lesion of superior one-third, type II: complete lesion of superior one-third, type III: complete lesion of superior two-thirds, type IV: complete lesion of tendon but head centered and fatty degeneration classified as less than or equal to Goutalier stage III, and type V: complete lesion of tendon but eccentric head with coracoid impingement and fatty degeneration classified as more than or equal to Goutalier stage III. Lafosse type V was considered as irreparable. The size of the SSC tear was measured in mm on a sagittal and axial T2 image. On the sagittal scan, the tear size was measured in a straight line from the tendon edge inferiorly to the inferior border of the rotator interval. On the axial scan, a straight line from tendon edge medially to the lateral footprint was taken. The greatest dimension of the full-thickness tear on both scans was multiplied to calculate the tear area in millimeters squared.

If there was more than an isolated SSC tear, the rotator cuff lesion was classified according to Collin et al as type A-E.[10] The condition of the tendon of the long head of the biceps (LHBT) was assessed for the following: subluxation (yes, no), tendinopathy (yes, no), and complete rupture (yes, no). Intramuscular fatty infiltration (FI) of the SSC was assessed using the computed to-mography criteria of Goutallier et al[17] adapted for MRI by Fuchs et al on T1-weighted parasagittal scans.[15] Type of tear, degree of muscle FI, and biceps pathology were determined in consensus read-out. The length of the SSC tendon, the muscle length, and the location of the musculotendinous unit were evaluated on axial scans (T1) as described by Meyer et al.[30] For these variables, mean values were used for the analysis.

Table II
Parameters at first and second MRI regarding subscapularis and biceps pathology.

| | Subscapularis tear type* | | Subscapularis FI† | | LHBT pathology | | | | | |
| | | | | | Tendinopathy | | Dislocation | | Rupture | |
	1st MRI	2nd MRI	1st MRI	2nd MRI	1st MRI	2nd MRI	1st MRI	2nd MRI	1st MRI	2nd MRI
1	1	2	0	1	Yes	Yes	No	Yes	No	No
2	1	2	0	2	Yes	Yes	No	No	No	No
3	1	2	0	0	No	Yes	No	Yes	No	No
4	1	2	0	N/A	No	Yes	No	Yes	No	No
5	1	1	0	0	No	No	No	No	No	No
6	2	3	0	0	Yes	N/A	No	N/A	No	Yes
7	2	3	0	2	Yes	Yes	No	No	No	No
8	1	3	0	2	No	Yes	No	No	No	No
9	1	2	0	0	Yes	Yes	No	Yes	No	No
10	2	3	1	1	Yes	N/A	Yes	N/A	No	Yes
11	1	3	0	1	Yes	Yes	No	Yes	No	No
12	2	3	0	0	Yes	Yes	No	Yes	No	No
13	1	2	0	0	Yes	Yes	No	No	No	No
14	1	3	0	0	No	Yes	No	No	No	No
15	1	2	0	2	Yes	Yes	No	Yes	No	No
16	3	4	3	3	Yes	N/A	Yes	N/A	No	Yes
17	1	3	0	1	No	Yes	No	No	No	No
18	1	2	0	1	Yes	Yes	No	Yes	No	No
19	3	3	0	0	Yes	N/A	No	N/A	No	Yes
20	1	3	0	0	Yes	Yes	No	No	No	No
21	3	4	1	1	Yes	Yes	No	Yes	No	No

LHBT, tendon of the long head of the biceps; *MRI*, magnetic resonance imaging; *N/A*, not available.
Gray shaded: progression in fatty infiltration or classification level.
  *Lafosse classification.[24]
  †Fatty infiltration as per Fuchs' modification of Goutallier[17] classification.

Statistical analysis

Continuous variables were represented by the mean, standard deviation, and range. Absolute and relative frequencies were used to represent ordinal variables. Progression of pathology was evaluated by paired t-tests and Wilcoxon signed-rank tests for continuous variables (SSC tear area, SSC tendon, and muscle length) and ordinal variables (FI, Lafosse grade SSC lesion, LHBT subluxation/rupture), respectively. The relationship between SSC tear area and tendon length progression was analyzed by Pearson's correlation coefficient. Risk factors for progression (SSC tear area) were tested by a one-way analysis of variance (F-Test). The significance level was chosen at 0.05. Statistical analyses were computed using Stata/IC 15.1 (StataCorp LP, College Station, TX, USA).

Results

Tear distribution

In 5 cases, there was an isolated SSC tear. Seven cases had an associated SS tendon tear, and 9 cases had a SS tear extending into the IS (type A and type C lesions, respectively, as classified by Collin et al[10]).

Findings relating to SSC tendon and LHBT on initial scan

Classifying the SSC lesion according to Lafosse[24] identified 14 type I tears, 4 type II tears, and 3 type III tears. Assessing FI of each SSC muscle showed grade 0 in 17 SSC muscles, grade I in 3 cases, and grade III in one case. The initial mean length of the SSC tendon[30] was 40 mm (range 27-51, SD: ±7), and the mean muscle length was 98 mm (range 77-124, SD: ±13). The mean tear area was 75 mm^2 (range 0-396, SD: ±118 mm^2).

The LHBT was normal in 6 (29%) cases and tendinopathic in 15 (71%) cases. In 2 cases (10%), the LHBT was dislocated; however, there were no cases of completely torn LHBT.

SSC tendon and LHBT on follow-up

On follow-up MRI, we identified 1 type I tear, 8 type II, 10 type III, and 2 type IV tears according to Lafosse.[24] Overall, we found an increase in the SSC tendon tear size in 19 patients (91%) reflected by a higher Lafosse grade. In 5 patients, the SSC tear had increased by 2 grades. In only 2 patients, the grading remained unchanged (P < .001) (Fig. 1). Measuring the tear size in mm (as described previously), we found a significant increase in the tear area from 75 mm^2 (range 0-396, SD: ±118 mm^2) to 228 mm^2 (0-840, SD ± 186) at the last follow-up, which is a mean increase of 152 mm^2 (P < .001). FI of the SSC muscle showed grade 0 in 9 SSC muscles, grade I in 6 cases, grade II in four cases, and grade III in one case. The FI of the SSC muscle progressed in only 8 of the 21 cases (in 4 patients by 1 grade and in 4 patients by 2 grades), but overall, the increase of FI was significant over time (P < .042). The mean length of the SSC tendon increased significantly from 40 mm (range 27-51, SD: ±7) to 47 mm (range 36-63, SD: ±7) (P < .001); the mean muscle length remained almost unchanged from 98 mm (range 77-124, SD: ±13.3) to 97 mm (range 65-132, SD: ±16) (P = .675).

After follow-up, the LHBT showed progressive degeneration: In 5 patients, the LHBT had become tendinopathic, 9 LHBTs showed a new dislocation, and in 4 patients, it was completely torn (P < .001). Only in one case, the tendon was normal at the final follow-up (for more details, see Table II).

Other findings

Over time, there was a progression in the superior-posterior extension of the concomitant rotator cuff lesions, reflected by a change in the Collin classification[10] (type A: 28.6%, type B: 14.3%, and type C: 57.1%). At the latest follow-up, 5 new SS tears (3 partial and 2 transmural) were detected and three SS tears had progressed from partial to transmural lesions. FI of the SS muscle remained stable in 5 cases and increased in 15 cases (by 1 grade in 12 cases and by 2 grades in 3 cases). Four new IS tears were detected, and two

Table III
Parameters at first and second MRI evaluations regarding cuff and humeral head migration.

Case	Supraspinatus (tear*/fatty infiltration†)		Infraspinatus (tear*/fatty infiltration†)		Teres minor (tear*/fatty infiltration†)		ACHD (mm, mean values)	
	First MRI	Second MRI	First MRI	Second MRI	First MRI	Second MRI	First MRI	Second MRI
1	t/0	t/2	n/0	n/1	n/0	n/1	8.5	8
2	t/1	t/3	n/0	n/0	n/0	n/0	8	5.5
3	p/0	p/1	n/0	p/0	n/0	n/0	7.5	7
4	n/0	2/N/A	n/0	n/N/A	n/0	n/N/A	6.5	4
5	p/0	p/0	p/0	p/0	n/0	n/0	8.5	8.5
6	t/0	t/1	p/0	p/1	n/0	n/0	7	6.5
7	t/1	t/2	p/1	t/4	n/0	n/0	6	4
8	n/0	p/0	n/0	p/0	n/0	n/0	5	3
9	p/0	p/0	n/0	n/0	n/0	n/0	6.5	6
10	n/0	t/0	n/0	n/0	n/0	n/0	7	6.5
11	p/0	t/1	n/0	n/1	n/0	n/0	7	6.5
12	t/2	t/3	p/0	p/0	n/0	n/0	4	2
13	n/0	p/1	n/0	n/1	n/0	n/0	7	6
14	t/0	t/1	p/0	p/1	n/0	n/0	7.5	6.5
15	p/1	p/2	n/0	n/2	n/0	n/1	7.5	8.5
16	p/0	p/1	p/0	p/1	n/0	n/0	6.5	7
17	n/0	p/1	n/0	n/1	n/0	n/0	6	5.5
18	p/0	t/1	p/0	p/1	n/0	n/1	7.5	7
19	t/0	t/1	p/0	t/1	n/0	n/0	9.5	4.5
20	p/0	t/0	n/0	p/0	n/0	n/0	6.5	7.5
21	t/0	t/2	p/0	p/1	n/0	n/0	8	8.5

ACHD, acromionhumeral distance; MRI, magnetic resonance imaging; N/A, not available.
Gray shaded: progression in fatty infiltration between the two MRIs.
  *(n: none, p: partial, t: transmural).
  †Fatty infiltration was classified as stage 1 through 4 by Goutallier.[17]

tears showed a progression from partial to a transmural lesion. FI of the IS muscle remained stable in 8 and increased in 12 cases (by 1 grade in 9 cases, by 2 grades in one, and by 3 grades in one) (for more details, see Table III).

Radiographic risk factor analysis for SSC tear size progression

Neither the FI nor the Lafosse classification of the SSC tear could be identified as risk factors for tear size progression (FI: $P = .326$, tear classification: $P = .803$). Furthermore, we could not find a correlation between the progression of SSC tear size area and SSC tendon lengthening (r = 0.17, $P = .476$).

Discussion

This study analyzed the outcome of nonoperatively treated small- to medium-sized SSC tears on MRI, in a population of patients aged less than 65 years, with a mean follow-up period of 8.6 years. We found in over 90% of cases a progression in size of the SSC tear, as per the Lafosse classification. Progression of muscle FI was seen in 38% of cases (8 of 21 cases). However, interestingly, none of these nonoperatively treated SSC tears progressed over a minimum of 5 years to a level of FI or Lafosse grade that we would consider repair to be contraindicated due to high risk of failure.

Understanding the natural history of the nonoperative treatment of tears of the rotator cuff tendons is important in deciding the optimal treatment for each individual patient and is a vital part in counseling a patient when deciding on a treatment strategy. The natural history of nonoperatively treated SSC tendon tears is thus far poorly studied in the literature, and therefore, it is difficult to predict the outcome in conservatively treated patients.

The fact that an increase of SSC tear size was quite consistently associated with development of new or progression of existing, concomitant postero-superior tears merits attention:

Five new SS and 4 new IS tears were observed. Although FI of the SS increased in 15 of 21 tears, it increased in 12 of 21 IS tears and increased in only 8 of 21 SSC tears (ie, half as frequently as in the SS muscle). With the substantial increase in its tendon length, however, the SSC must have failed in continuity without consistently developing substantial FI. Meyer et al[29] have shown that FI secondary to tendon tear is not only associated with musculotendinous retraction but, especially early, also correlated with changes in the pennation angle of the respective muscle. As the pennation angle of the SS is much larger than that of the IS and the SSC is essentially a nonpennate muscle,[40] the discrepancy between increase in tear size and increase of FI between the three muscles seems plausible.

In a previous study, we have found that an increase in tendon length (or elongation of the tendon) on MRI is a feature of partial SSC tears.[30] The present study confirms that an increase of SSC tear size is also associated with further tendon lengthening documented with the significant increase of tendon length over time, although we could not find a correlation between tear size and SSC tendon length in our data.

Concomitant biceps pathologies became very common over time in our cohort, and conservative treatment was associated with a substantial increase of LHBT pathology. All except one patient had a pathological lesion of the LHBT at the latest follow-up. The progression of LHBT disease was directly associated with the enlargement of the SSC tendon tear.

We are aware of several studies analyzing the natural history of superior and postero-superior rotator cuff tears[13,22,28,32,38,42,43] which show a slower and less consistent progression with roughly 50% of tears progressing after a mean of 4 years. Medium-sized (compared with small tears),[43] full-thickness tears (compared with partial tears),[21,43] rotator cable disinsertion,[22] older age (>60 years),[28] smoking,[43] dominant side,[21] and pain[21,27,33,38] have been identified as risk factors for posterosuperior tear progression.
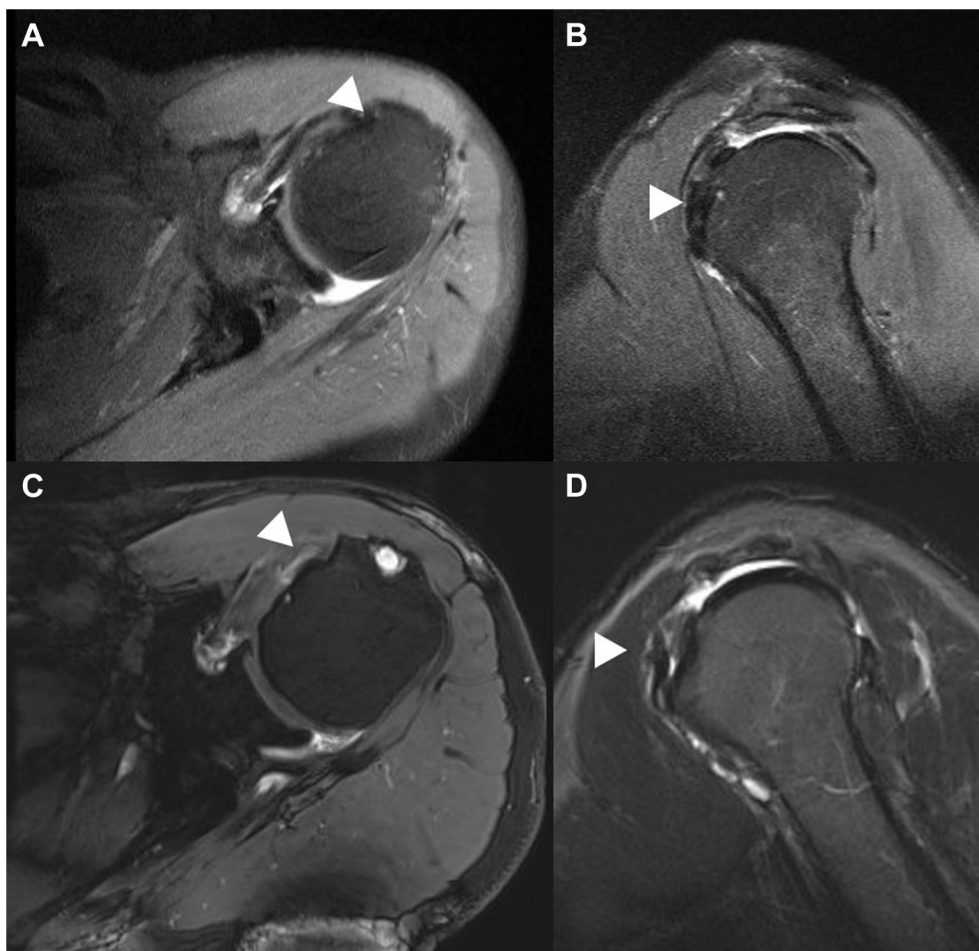
Figure 1 (**A**, **B**) MRI slides of a 60-year-old patient who had a subscapularis tendon tear (*arrowhead*) Lafosse grade II on the initial MRI 2005. (**C**, **D**) After 9 years, a progression of the subscapularis tendon tear (La fosse grade III) and in addition a new dislocation of the LHBT were shown. *LHBT*, tendon of the long head of the biceps; *MRI*, magnetic resonance imaging.

In this series, which focused on SSC tears, we were not able to identify specific tear patterns at risk for SSC tear progression. Because we searched our database for patients with at least two MRI scans within a certain time interval, patients who no longer showed symptoms would be unlikely to return for a second MRI, and therefore, the series may have a negative selection bias. However, the initial 21 ruptures, which were small- to medium-sized SSC lesions, led to only 5 cuff repairs after a second MRI. Further limiting factors of the study were the different rotator cuff tear patterns, as most cases had involvement of the superior/posterior cuff and only few cases showed isolated SSC tears. A further limitation is the different imaging modalities (MR arthrography or native MRI, low- or high-field MRI) because of the retrospective study protocol. Arthro-MRI is the diagnostic tool of choice with a sensitivity of 36%-95% and specificity of 82%-100%,[1,2,18] but the quantification of a SSC tendon tear is more difficult. Finally, we had no clear documentation of the patient's treatment between the two MRI scans; however, we are unaware of any evidence suggesting that different conservative treatment modalities would have influenced the evolution of structural tear progression.

Despite the aforementioned limitations and to the best of our knowledge, this is the first study to document the natural course of SSC tears, documenting tear size progression but an inconsistent development or increase of muscle degeneration in conservatively managed SSC tendon tears. We feel that in the presence of an SSC tear, the patients should be informed of the high likelihood of structural deterioration in such tears and the potentially negative influence of the development or enlargement of tears of the other elements of the rotator cuff. Our current data show that none of the SSC muscles developed imaging criteria of irreparability within the mean follow-up of 8.6 years and support consideration of conservative management in symptomatic SSC tears. Nonetheless, if these data are used to consider conservative management, it should be interpreted in the light of the very good long-term results of isolated SSC tendon repair, which does not seem to be associated with a comparable development or enlargement of lesions of the other cuff elements.[19] We have also re-analyzed original data from our previous study assessing outcomes after arthroscopic SSC tendon repair, to assess whether repair is associated with a high secondary rupture rate of SS and IS tendons.[19] This analysis shows that out of 36 patients, only 2, 7 new, partial IS/SS lesions (=25%), could be observed at the latest follow-up of mean 8.6 years. These results suggest that repair of the SSC might have a protective effect on the other (posterior-superior) muscle tendon units.

These data provide new insight into the course of SSC tendon tear progression over time and may assist in the treatment decision-making process. For us, these data can at least serve to justify electing for systematic conservative management of SSC tears in the elderly and not so active patient population. Randomized, controlled trials comparing conservative with operative treatment of SSC tears may ultimately become necessary to determine optimal treatment of these lesions. A large prospective cohort study of all patients with

SSC tears followed with sequential imaging may ultimately become necessary to provide the true natural history of these tears.

Conclusion

Based on this MRI evaluation, 90% of all nonoperatively treated SSC tendon tears had increased in size after a mean of 8.6 years, and in two-thirds of the cases, posterosuperior tears either developed or increased in size. FI of the SSC muscle remained stable in two-thirds of the study group and did not deteriorate to the point which is highly associated with clinical irreparability.

Disclaimers:

References

1. Adams CR, Brady PC, Koo SS, Narbona P, Arrigoni P, Karnes GJ, et al. A systematic approach for diagnosing subscapularis tendon tears with preoperative magnetic resonance imaging scans. Arthroscopy 2012;28:1592-600. https://doi.org/10.1016/j.arthro.2012.04.142.
2. Adams CR, Schoolfield JD, Burkhart SS. Accuracy of preoperative magnetic resonance imaging in predicting a subscapularis tendon tear based on arthroscopy. Arthroscopy 2010;26:1427-33. https://doi.org/10.1016/j.arthro.2010.02.028.
3. Adams CR, Schoolfield JD, Burkhart SS. The results of arthroscopic subscapularis tendon repairs. Arthroscopy 2008;24:1381-9. https://doi.org/10.1016/j.arthro.2008.08.004.
4. Bartl C, Salzmann GM, Seppel G, Eichhorn S, Holzapfel K, Wortler K, et al. Subscapularis function and structural integrity after arthroscopic repair of isolated subscapularis tears. Am J Sports Med 2011;39:1255-62. https://doi.org/10.1177/0363546510396317.
5. Bartl C, Scheibel M, Magosch P, Lichtenberg S, Habermeyer P. Open repair of isolated traumatic subscapularis tendon tears. Am J Sports Med 2011;39:490-6. https://doi.org/10.1177/0363546510388166.
6. Bennett WF. Arthroscopic repair of anterosuperior (supraspinatus/subscapularis) rotator cuff tears: a prospective cohort with 2-to 4-year follow-up. Classification of biceps subluxation/instability. Arthroscopy 2003;19:21-33. https://doi.org/10.1053/jars.2003.50023.
7. Bennett WF. Arthroscopic repair of isolated subscapularis tears: a prospective cohort with 2-to 4-year follow-up. Arthroscopy 2003;19:131-43. https://doi.org/10.1053/jars.2003.50053.
8. Burkhart SS, Brady PC. Arthroscopic subscapularis repair: surgical tips and pearls A to Z. Arthroscopy 2006;22:1014-27. https://doi.org/10.1016/j.arthro.2006.07.020.
9. Burkhart SS, Tehrany AM. Arthroscopic subscapularis tendon repair: technique and preliminary results. Arthroscopy 2002;18:454-63. https://doi.org/10.1053/jars.2002.30648.
10. Collin P, Matsumura N, Ladermann A, Denard PJ, Walch G. Relationship between massive chronic rotator cuff tear pattern and loss of active shoulder range of motion. J Shoulder Elbow Surg 2014;23:1195-202. https://doi.org/10.1016/j.jse.2013.11.019.
11. Deutsch A, Altchek DW, Veltri DM, Potter HG, Warren RF. Traumatic tears of the subscapularis tendon. Clinical diagnosis, magnetic resonance imaging findings, and operative treatment. Am J Sports Med 1997;25:13-22.
12. Edwards TB, Walch G, Sirveaux F, Mole D, Nove-Josserand L, Boulahia A, et al. Repair of tears of the subscapularis. J Bone Joint Surg Am 2005;87a:725-30. https://doi.org/10.2106/Jbjs.D.02051.
13. Fucentese SF, von Roll AL, Pfirrmann CW, Gerber C, Jost B. Evolution of nonoperatively treated symptomatic isolated full-thickness supraspinatus tears. J Bone Joint Surg Am 2012;94:801-8. https://doi.org/10.2106/JBJS.I.01286.
14. Fuchs B, Gilbart MK, Hodler J, Gerber C. Clinical and structural results of open repair of an isolated one-tendon tear of the rotator cuff. J Bone Joint Surg Am 2006;88:309-16. https://doi.org/10.2106/JBJS.E.00117.
15. 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.
16. Gerber C, Hersche O, Farron A. Isolated rupture of the subscapularis tendon. J Bone Joint Surg Am 1996;78:1015-23.
17. 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 1994:78-83.
18. Gyftopoulos S, J OD, Shah NP, Goss J, Babb J, Recht MP. Correlation of MRI with arthroscopy for the evaluation of the subscapularis tendon: a musculoskeletal division's experience. Skeletal Radiol 2013;42:1269-75. https://doi.org/10.1007/s00256-013-1669-5.
19. Hasler A, Boyce G, Schallberger A, Jost B, Catanzaro S, Gerber C. Arthroscopic repair of isolated subscapularis tears: clinical outcome and structural integrity with a minimum follow-up of 4.6 years. J Shoulder Elbow Surg 2019;28:2171-80. https://doi.org/10.1016/j.jse.2019.03.024.
20. Heikenfeld R, Gigis I, Chytas A, Listringhaus R, Godolias G. Arthroscopic reconstruction of isolated subscapularis tears: clinical results and structural integrity after 24 months. Arthroscopy 2012;28:1805-11. https://doi.org/10.1016/j.arthro.2012.06.011.
21. Keener JD, Galatz LM, Teefey SA, Middleton WD, Steger-May K, Stobbs-Cucchi G, et al. A prospective evaluation of survivorship of asymptomatic degenerative rotator cuff tears. J Bone Joint Surg Am 2015;97:89-98. https://doi.org/10.2106/JBJS.N.00099.
22. Keener JD, Hsu JE, Steger-May K, Teefey SA, Chamberlain AM, Yamaguchi K. Patterns of tear progression for asymptomatic degenerative rotator cuff tears. J Shoulder Elbow Surg 2015;24:1845-51. https://doi.org/10.1016/j.jse.2015.08.038.
23. Kim YS, Kim SE, Bae SH, Lee HJ, Jee WH, Park CK. Tear progression of symptomatic full-thickness and partial-thickness rotator cuff tears as measured by repeated MRI. Knee Surg Sports Traumatol Arthrosc 2017;25:2073-80. https://doi.org/10.1007/s00167-016-4388-3.
24. Lafosse L, Jost B, Reiland Y, Audebert S, Toussaint B, Gobezie R. Structural integrity and clinical outcomes after arthroscopic repair of isolated subscapularis tears. J Bone Joint Surg Am 2007;89:1184-93. https://doi.org/10.2106/JBJS.F.00007.
25. Lanz U, Fullick R, Bongiorno V, Saintmard B, Campens C, Lafosse L. Arthroscopic repair of large subscapularis tendon tears: 2- to 4-year clinical and radiographic outcomes. Arthroscopy 2013;29:1471-8. https://doi.org/10.1016/j.arthro.2013.06.004.
26. Mall NA, Chahal J, Heard WM, Bach BR Jr, Bush-Joseph CA, Romeo AA, et al. Outcomes of arthroscopic and open surgical repair of isolated subscapularis tendon tears. Arthroscopy 2012;28:1306-14. https://doi.org/10.1016/j.arthro.2012.02.018.
27. Mall NA, Kim HM, Keener JD, Steger-May K, Teefey SA, Middleton WD, et al. Symptomatic progression of asymptomatic rotator cuff tears: a prospective study of clinical and sonographic variables. J Bone Joint Surg Am 2010;92:2623-33. https://doi.org/10.2106/JBJS.I.00506.
28. Maman E, Harris C, White L, Tomlinson G, Shashank M, Boynton E. Outcome of nonoperative treatment of symptomatic rotator cuff tears monitored by magnetic resonance imaging. J Bone Joint Surg Am 2009;91:1898-906. https://doi.org/10.2106/JBJS.G.01335.
29. Meyer DC, Hoppeler H, von Rechenberg B, Gerber C. A pathomechanical concept explains muscle loss and fatty muscular changes following surgical tendon release. J Orthop Res 2004;22:1004-7. https://doi.org/10.1016/j.orthres.2004.02.009.
30. Meyer DC, Zimmermann SM, Wieser K, Bensler S, Gerber C, Germann M. Lengthening of the subscapularis tendon as a sign of partial tearing in continuity. J Shoulder Elbow Surg 2016;25:31-7. https://doi.org/10.1016/j.jse.2015.06.014.
31. Monroe EJ, Flores SE, Chambers CC, Zhang AL, Feeley BT, Lansdown DA, et al. Patient-reported outcomes after isolated and combined arthroscopic subscapularis tendon repairs. Arthroscopy 2019;35:1779-84. https://doi.org/10.1016/j.arthro.2019.01.034.
32. Moosmayer S, Gartner AV, Tariq R. The natural course of nonoperatively treated rotator cuff tears: an 8.8-year follow-up of tear anatomy and clinical outcome in 49 patients. J Shoulder Elbow Surg 2017;26:627-34. https://doi.org/10.1016/j.jse.2016.10.002.
33. Moosmayer S, Tariq R, Stiris M, Smith HJ. The natural history of asymptomatic rotator cuff tears: a three-year follow-up of fifty cases. J Bone Joint Surg Am 2013;95:1249-55. https://doi.org/10.2106/JBJS.L.00185.
34. Musil D, Sadovsky P, Stehlik J. Arthroscopic repair of subscapularis tendon tear. Acta Chir Orthop Traumatol Cech 2010;77:228-34 [Czech].
35. Nove-Josserand L, Hardy MB, Leandro Nunes Ogassawara R, Carrillon Y, Godeneche A. Clinical and structural results of arthroscopic repair of isolated subscapularis tear. J Bone Joint Surg Am 2012;94:e125. https://doi.org/10.2106/JBJS.K.00008.
36. Ranebo MC, Hallgren HCB, Norlin R, Adolfsson LE. Clinical and structural outcome 22 years after acromioplasty without tendon repair in patients with subacromial pain and cuff tears. J Shoulder Elbow Surg 2017;26:1262-70. https://doi.org/10.1016/j.jse.2016.11.012.
37. Richards DP, Burkhart SS, Lo IK. Subscapularis tears: arthroscopic repair techniques. Orthop Clin North Am 2003;34:485-98. https://doi.org/10.1016/s0030-5898(03)00096-8.
38. Safran O, Schroeder J, Bloom R, Weil Y, Milgrom C. Natural history of nonoperatively treated symptomatic rotator cuff tears in patients 60 years old or younger. Am J Sports Med 2011;39:710-4. https://doi.org/10.1177/0363546510393944.

39. Toussaint B, Audebert S, Barth J, Charousset C, Godeneche A, Joudet T, et al. Arthroscopic repair of subscapularis tears: preliminary data from a prospective multicentre study. Orthop Traumatol Surg Res 2012;98:S193-200. https://doi.org/10.1016/j.otsr.2012.10.004.

40. Ward SR, Hentzen ER, Smallwood LH, Eastlack RK, Burns KA, Fithian DC, et al. Rotator cuff muscle architecture: implications for glenohumeral stability. Clin Orthop Relat Res 2006;448:157-63. https://doi.org/10.1097/01.blo.0000194680.94882.d3.

41. Yamaguchi K, Ditsios K, Middleton WD, Hildebolt CF, Galatz LM, Teefey SA. The demographic and morphological features of rotator cuff disease. A comparison of asymptomatic and symptomatic shoulders. J Bone Joint Surg Am 2006;88:1699-704. https://doi.org/10.2106/JBJS.E.00835.

42. Yamaguchi K, Tetro AM, Blam O, Evanoff BA, Teefey SA, Middleton WD. Natural history of asymptomatic rotator cuff tears: a longitudinal analysis of asymptomatic tears detected sonographically. J Shoulder Elbow Surg 2001;10:199-203.

43. Yamamoto N, Mineta M, Kawakami J, Sano H, Itoi E. Risk factors for tear progression in symptomatic rotator cuff tears: a prospective study of 174 shoulders. Am J Sports Med 2017;45:2524-31. https://doi.org/10.1177/0363546517709780.

44. Yamanaka K, Matsumoto T. The joint side tear of the rotator cuff. A followup study by arthrography. Clin Orthop Relat Res 1994:68-73.