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ARTHROSCOPY AND SPORTS MEDICINE

All-arthroscopic glenoid reconstruction by iliac crest bone graft transfer does not affect structural integrity and 3-dimensional volume of the subscapularis muscle

Benjamin Bockmann[1] · Arne Johannes Venjakob[2] · Rolf Gebing[3] · Wolfgang Nebelung[2]

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Abstract

Aim The subscapularis muscle is an important active stabilizer of the glenohumeral joint. For this radiological study, we investigated if its radiological integrity is affected after arthroscopic glenoid reconstruction. In the technique used, an autologous iliac crest graft is transported through the rotator interval, and the graft is fixed via an antero-inferior portal with compression screws.

Methods 3 women and 6 men (mean age 31 ± 9 years, min 21, max 46 years) who had a preoperative glenoid deficit of 23% ± 6% (min 13%, max 29%) were included. In a follow-up after an interval of 34 months (min 19, max 50), MRI scans were performed on both shoulders. With ITK-SNAP, a 3D reconstruction software, the volume of the subscapularis muscle in the injured and contralateral shoulder was measured. In addition, signal intensity ratios (PSI) (infraspinatus muscle / cranial subscapularis muscle and infraspinatus muscle / caudal subscapularis muscle) were analyzed and the width of the cranial and caudal portions as well as the length of the subscapularis muscle in the parasagittal plane were determined.

Results The 3D volume showed no difference between operated and healthy shoulders ($p = 0.07$), neither did PSI ratios (infraspinatus muscle / cranial subscapularis muscle: $p = 1.00$, infraspinatus muscle / caudal subscapularis muscle: $p = 1.00$). In the parasagittal plane, length ($p = 0.09$) and cranial width ($p = 0.23$) did not differ. However, the width of the lower muscle was increased in injured shoulders ($p = 0.02$).

Conclusion In this cohort, no relevant volume loss could be found after arthroscopic glenoid reconstruction. However, a greater width of the lower muscle portion could be identified in the parasagittal plane as a possible indication of scarring.

Keywords Arthroscopic glenoid reconstruction · Subscapularis muscle · Fatty infiltration · Shoulder instability · Glenoid deficit · Iliac crest graft

Introduction

The subscapularis muscle (SSC) is an important active stabilizer of the shoulder, and its integrity and function are crucial for centralization of the humeral head [1–4]. As a consequence, arthroscopic procedures that do not interfere with the musculotendinous unit of the SSC have become increasingly relevant when addressing shoulder instability [5, 6], and the positive effect of these techniques on postoperative shoulder function has been previously described [7]. When restoring the antero-inferior support using the Latarjet procedure, loss of internal rotation strength has been shown after open surgery [8]. However, this has not been compared to the arthroscopic Latarjet yet. Since patients with relevant glenoid bone loss often have a history of previous surgeries and a high number of dislocations, protection of the musculotendinous unit seems to be crucial in order to achieve sufficient clinical outcome [9–11].

In this study, we hypothesize that structural and 3-dimensional integrity of the subscapularis muscle is not impaired

✉ Benjamin Bockmann
benjamin_bockmann@hotmail.com

[1] Department of Orthopaedics and Trauma Surgery, St. Josef Hospital, Ruhr University Bochum, Gudrunstraße 56, 44791 Bochum, Germany

[2] Department of Rheumatology and Arthroscopy, Marienkrankenhaus Düsseldorf-Kaiserswerth, An St Swidbert 17, Düsseldorf, Germany

[3] Department of Diagnostic Radiology, St. Vinzenz Hospital, Schloßstraße 85, Düsseldorf, Germany

after all-arthroscopic glenoid reconstruction using iliac crest autografts.

Patients and methods

For our study, we performed standardized MRI scans of both shoulders after arthroscopic glenoid reconstruction using iliac crest bone grafts as previously described [12].

For the reader's convenience, the procedure will now be briefly described:

Surgery is performed in lateral decubitus position. A diagnostic arthroscopy through the standard posterior portal is performed to detect additional pathologies, and the glenoid defect is evaluated through the suprabicipital portal. Once the need for glenoid reconstruction is indicated, a proper bone graft (approximately 2 × 1 × 1 cm) is harvested from the iliac crest. The bone block is punctured with a 1 mm hole and a 2.4 mm K-wire is passed through the glenoid through an antero-inferior working portal. The antero-inferior portal is placed approximately 2–3 cm inferior and 1–2 cm lateral of the tip of the coracoid process. A needle is used to estimate the height of the portal, it should enter the joint at the inferior third or inferior edge of the subscapularis tendon. The portal is then established on skin level without cutting into the SSC. A blunt working cannula is then used to retract soft tissue during surgery. The wire should pentrate the 5 o' clock position and exit into to the infraspinatus fossa. A FiberWire, size 2 (Arthrex, Naples, FL, USA) is then pulled through this tunnel and the bone graft is attached to its anterior ending using a stopper knot. The opposite end of the FiberWire is then dragged in order to pull the graft, passing through the rotator interval and landing at the anterior glenoid. In a next step, two screws (either titanium 3–4-mm screws or bioresorbable 3 × 26 mm Bio-Compression screws, Arthrex) fixate the graft through an antero-inferior portal. Finally, soft tissue repair of the capsule- labrum- complex is performed by suture anchors.

As inclusion criteria, we defined (a) treatment at our unit with the above-mentioned procedure between 2009 and 2015 (b) possibility for informed consent and (c) age > 18. Excluded were all cases that received a different procedure (such as open Latarjet), or received surgical treatment for osseous deficit of the glenoid at a different unit upon presenting to our hospital.

In accordance with these criteria, our patient database was screened and 42 patients were considered eligible. These patients were invited to MRI examinations of both shoulders via mail. To ensure the study's economy, 9 patients were included. We decided to include the first 9 patients who responded to the invitation (Table 1).

3 women and 6 men (average age 31 ± 9 years, range 21–46 years) who showed a glenoid deficit of 23% ± 6%

Table 1 Baseline data and intraoperative findings of patient cohort

Age (years)	Surgeon	Length	Findings	Additional procedure	Nicotine dependence	Painkiller consume	ASA-score	BMI	Gender	Number of previous bankart repairs
21	WN	145	HSL (on-track)		Yes (12/day)	Yes (sporadic use)	1	27	m	1
23	FR	110	LB + HSL (on-track)		Yes (4/day)	No	2	29	m	2
26	FR	110	HSL (on-track)		Yes (15/day)	No	1	19	f	2
29	WN	100			No	No	2	27	m	1
29	WN	70	HSL (on-track)		Yes (15/day)	No	1	25	m	1
30	WN	120	HSL (off-track)	Filling of HSL	No	Yes (due to contralateral shoulder pain)	2	29	f	1
33	FR	93			No	No	1	22	f	0
46	WN	105	SLAP-lesion		No	No	1	25	m	0
46	WN	105	Impingement + SLAP-lesion	Subacromial decompression	No	No	2	28	m	1

HSL Hill–Sachs-Lesion, *LB* loose bodies

(range 13–29%) previous to surgery were included. 4 patients showed a Hill-Sachs lesion during surgery, 1 of which was considered an off-track lesion and consolidated with bone material from the iliac crest.

All patients gave written informed consent prior to inclusion in the study. The ethics committee of the Medical Association of North Rhine approved the study protocol (file number 2,016,324).

Follow- up

In a follow up eximation taking place after a mean interval of 34 months (19 to 50) after the procedure, we performed MRI scans of both the injured and the healthy shoulder. Before surgery, bone loss had been quantified in CT scans [13]. During the follow- up, all patients completed a questionnaire evaluating re-dislocations of the injured shoulder.

For the MRI examination, we used a 1.5 Tesla MRI scanner (Vantage Titan, Toshiba Medical Systems GmbH, Neuss, Germany). A shoulder array coil was used to position the respective shoulder in the scanner in neutral rotation. For the injured side, fat saturated T2 sequences similar to previously described protocols were facilitated (image size 210 × 300 mm, slice thickness 0.5 mm, repetition time (TR) 2016.0 ms; echo time (TE) 30.0 ms) and coronal, axial and parasagittal reformats were built. For the healthy side, a standard T2 protocol was used (image size 190 × 190 mm, slice thickness 3 mm, repetition time (TR) 2016.0 ms; echo time (TE) 30.0 ms). Again, coronal, axial and parasagittal reformats were built.

Data acqusition

The first author of this work evaluated all scans (BB), and two experienced surgeons on the fellowship level performed a re-evaluation (AJV and WN). The injured shoulder pre- and post-surgery as well as the uninjured shoulder post-surgery were available, leading to a total of 27 scans. We measured the following parameters as described before:

Comparison of the injured and contralateral shoulder:

1. *Volume of the SSC musculotendinous unit* The volume of the musculotendinous unit was measured as described by Chung et al. [14], using ITK-SNAP, a semiautomatic segmentation software (s. Fig. 1). By doing this, we followed the recent conclusions of Vidt et al. [15], who were able to show that volume is a better indicator for SSC degeneration than 2-dimensional evaluations. For the segmentation, parasagittal scans were used in DICOM-format, and the subscapularis tissue was marked on each scan from the lateral tip of the tendon till the spina scapulae reached the scapular body ('Y-shaped position'). Since the injured side was reconstructed with thinner slices (0.5 vs 3 mm), every 6th picture was used on the injured side, leading to the same amount of slices being used for both shoulders. In a last step, the volume of the musculotendinous unit was

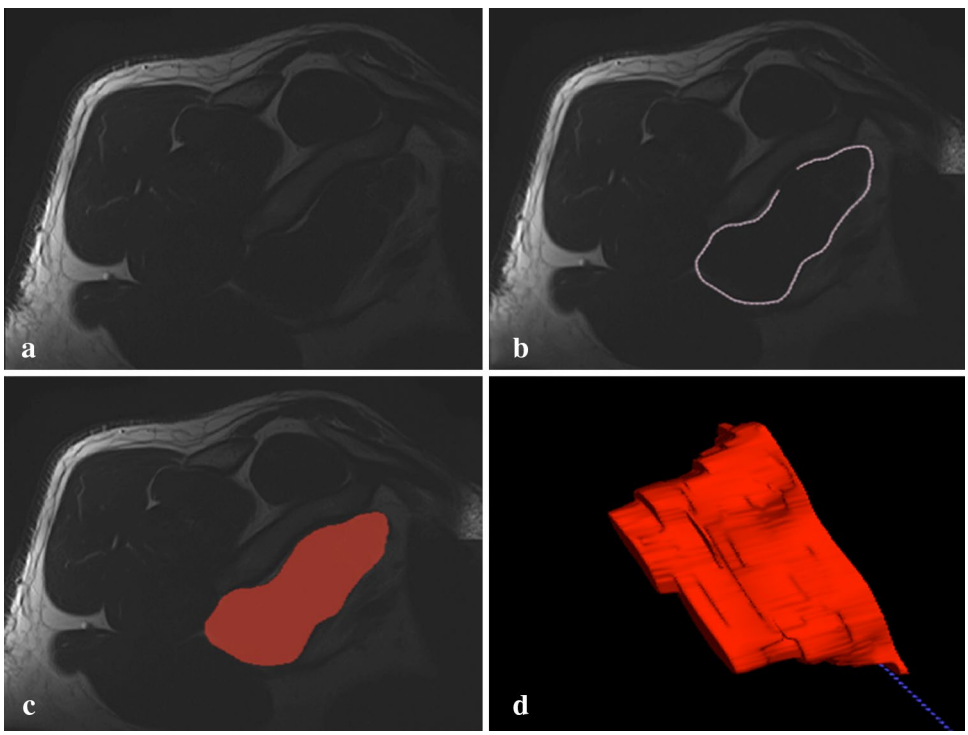

Fig. 1 Creation of a SSC 3D-model: The volume of the muscle (**a**–**c**) is marked on every slice until a 3-dimensional model is created (**d**)

evaluated using the 'Volumes and Statistics' function of ITK-SNAP (s. Fig. 2).

2. *Pixel signal intensity of the infraspinatus muscle (ISP), upper (crSSC) and lower (caSSC) subscapularis muscle* We measured signal intensities of different parts of the SSC and the infraspinatus muscle using parasagittal images as described by Scheibel et al. [16] (s. Fig. 3a). In the 'Y-shaped position', 5 elliptic regions of interest (ROI) of the same size (50 mm^2) were drawn in a standardized fashion, and signal intensity within these regions was measured and recorded. The software automatically calculated the respective minimal signal intensity, maximal signal intensity, average signal intensity, and standard deviation of the signal intensity. The ROIs were positioned in the background noise just above skin level, upper part of SSC muscle, lower part of the SSC muscle and center of ISP muscle. Afterwards, the signal-to-noise-ratio was calculated as described by Hendrick et al. [17]. In order to compare signal intensities on each slice, the ratio between ISP and crSSC on the one hand and ISP and caSSC on the other hand were evaluated. For this parameter, scans from the contralateral and injured shoulder post-surgery were examined.
3. *Width of the upper and lower SSC, length of the complete muscle* The width and length of the SSC were detected as described before [16] (s. Fig. 3b). In the 'Y-shaped position', the width of the upper and lower SSC as well as the total length of the muscle body was evaluated. As with PSI values (s. above), the status of the healthy shoulder and the injured shoulder at final follow-up were used.

Comparison of the injured shoulder pre- and post-operatively:

1. *Fatty infiltration of theSSC* In order to examine the fatty infiltration of the musculotendinous unit, we used the Goutallier classification as proposed by Fuchs et al. [18]. Two standardized measurement settings were used as described: The first one was performed at coracoid level, the second one at the inferior glenoid rim. The degen-

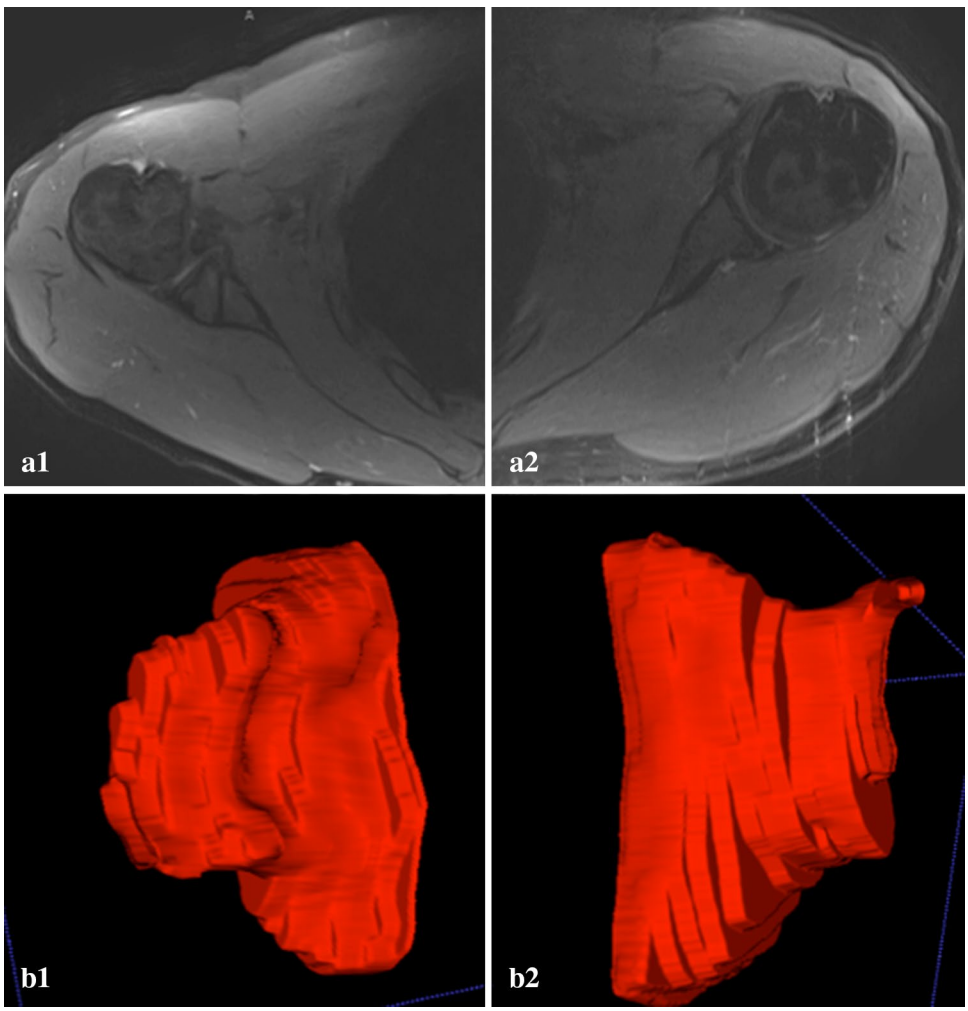

Fig. 2 Exemplary case of a young, male patient. No difference in 3-dimensional volume could be detected between the injured (**a1** + b**1**) and the healthy shoulder (**a2** + **b2**) (both models were created based on 3 mm slices for better visualization)

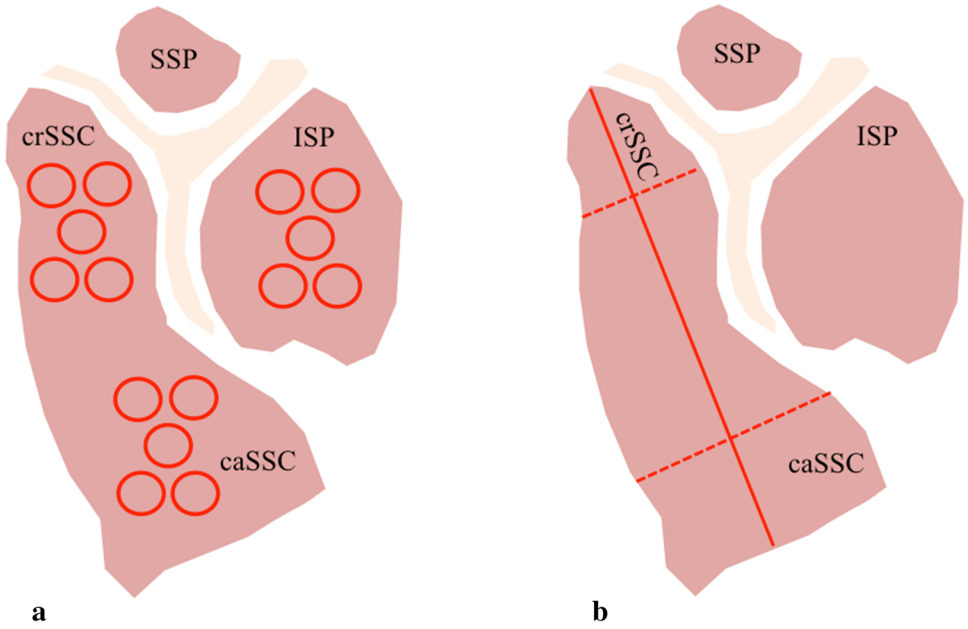

Fig. 3 **a** To measure Pixel Signal Intensity (PSI), 5 elliptic regions of interest (ROI) of the same size (50 mm^2) were drawn in a standardized fashion, and PSI within these regions was measured and recorded. **b** Additionally, we measured the width of the upper and lower SSC as well as the total length of the muscle body (*SSp* musculus supraspinatus, *ISp* musculus infraspinatus, *crSSC* cranial portion of the musculus subscapularis, *caSSC* caudal portion of the musculus subscapularis)

eration was graded from 0 to 4 in the pre-operative and post-operative scans of the injured shoulder.

Statistical evaluation The respective results were collected in an Excel database (Microsoft Excel 2012 for Mac, Microsoft, Redmont, USA). Data analysis was performed using IBM SPSS statistics 22 (Statistical Package for the Social Science, IBM Cooperation, Armonk, N.Y., USA). An audit of the normal distribution was assessed by the Kolmogorov–Smirnov test. Normally distributed quantitative variables were compared using the *t*- test for dependent samples, and the sign test was used for non-normally distributed data. To compare single patients to the rest of the cohort, Mann–Whitney-*U* tests and analysis of variances (ANOVA) were used. A p value < 0.05 was considered statistically significant. A 2-sided post-hoc analysis was performed as described by Rosner [19].

Results

A questionnaire that was handed to all patients prior to performing the MRI scans showed no re-dislocation between surgery and follow-up.

Concerning the radiologic analysis, 3-dimensional volume measurements did not show any difference between both shoulders ($p = 0.07$), and neither did the ISP/crSSC ratio ($p = 1.00$) and ISP/caSSC ratio ($p = 1.00$). The width of the upper SSC ($p = 0.23$) and length of the muscle ($p = 0.09$) did not show any differences, either. The width of the lower SSC, however, was larger in injured shoulders ($p = 0.02$). Of note, the median results for these parameters did not differ (Table 2).

The average of the Goutallier Score for fatty infiltration revealed a moderate increase for both the cranial (before surgery: 0.11, 0 to 1; after surgery: 0.33, 0 to 1) and the caudal measurements (before surgery: 0.22, 0 to 1; after surgery: 0.44, 0 to 2). However, this increase was not significant ($p = 0.50$ for both parameters). Of note, the patient with the most severe fatty infiltration also showed similar degeneration in the healthy shoulder and had had arthroscopic screw removal on the injured side upon participating in the study. Also, there was no difference compared to the rest of the cohort in terms of upper SSC width ($p = 0.651$) or lower SSC width ($p = 0.516$) of the injured shoulder. In addition, there was no significant difference with regards to the Goutallier score for the cranial ($p = 0.444$) and caudal ($p = 0.222$) measurements when compared to the rest of the cohort. Of note, the usage of metal screws, as performed in one other patient, did not affect the results for upper SSC width ($p = 0.764$) or lower SSC width ($p = 0.749$) of the injured shoulder. Moreover, there was no significant difference with regards to the Goutallier score for the cranial ($p = 0.444$) and caudal ($p = 0.444$) measurements.

The power analysis revealed mediocre statistical power for the parameters tested (SSC volume: $1 - \beta = 0.147$, ISP/crSSC ratio: $1 - \beta = 0.292$, ISP/caSSC ratio: $1 - \beta = 0.181$, width of the upper SSC: $1 - \beta = 0.100$, width of the lower SSC: $1 - \beta = 0.050$, length of SSC: $1 - \beta = 0.170$).

Table 2 Results for radiographic parameters

	N	Minimum	Maximum	Median	95% CI
SSC Volume injured (cm^3)	9	22.6	263.6	75.4	51.8–175.1
SSC Volume contralateral (cm^3)	9	24.1	88.5	59.1	42.7–71.6
ISP/crSSC ratio injured	9	0.81	3.26	1.28	1.00–2.12
ISP/crSSC ratio contralateral	9	0.19	2.03	1.63	0.92–1.87
ISP/caSSC ratio injured	9	1.07	2.02	1.86	1.43–1.94
ISP/caSSC ratio contralateral	9	0.67	2.25	1.70	1.21–2.06
SSC cranial width injured (mm)	9	22	39	26	23–33
SSC cranial width contralateral (mm)	9	17	36	25	22–30
SSC caudal width injured (mm)	9	23	45	32	28–40
SSC caudal width contralateral (mm)	9	11	41	32	23–36
SSC length injured (mm)	9	77	107	92	85–99
SSC length contralateral (mm)	9	53	99	88	73–95

Discussion

In this study, we hypothesized that the structural and 3-dimensional integrity of the subscapularis muscle is not impaired after all-arthroscopic glenoid reconstruction using iliac crest autografts. Our results confirm this hypothesis. Despite small differences in inferior SSC width, no volumetric or structural differences between the injured and the healthy shoulder could be found. However, mild degeneration was seen in some of our patients.

In our unit, glenoid reconstruction is performed arthroscopically using iliac crest grafts [12]. So far, good functional results have been reported after this procedure [13, 20]. However, the structural status of the SSC after this technique has not been examined yet. Severe fatty infiltration of this muscle after surgery can lead to mediocre results [7], so the muscle's integrity is a crucial concern for shoulder surgeons.

Previous works have dealt with the SSC integrity after open and arthroscopic surgery before. Scheibel et al. [7] were able to show that open shoulder stabilization via subscapularis tenotomy can lead to fatty degeneration of the muscle, which resulted in postoperative dysfunction. However, the overall clinical outcome in comparison to arthroscopic stabilization did not show differences of statistical significance. The radiologic findings are supported by our results, although we did not compare our patients clinically to those after open procedures. Another study by the same author [16] correlated open primary and revision stabilization. In this work, revision of a previously operated shoulder via the L-shaped tenotomy approach lead to further increase of fatty infiltration. Although more patients showed signs of SSC insufficiency after revision surgery, no significant difference could be shown for clinical score outcomes.

Another important aspect after glenoid reconstruction is degeneration after open procedures. In these cases, one could expect higher local soft tissue damage. Steffen and Hertel [21] followed a cohort of patients after open bone block transfer with a mean follow-up of 9.2 years. In this cohort, just like in ours, mild degeneration in terms of fatty streaks was found in some of the patients. On the other hand, SSC atrophy of 7.4% was observed, which was not found in our cohort. However, it should be kept in mind that a higher number of dislocations and a longer follow-up interval might explain this difference.

Maynou et al. [22] performed a post-operative CT analysis of patients who had undergone open Latarjet procedures. Splitting of the SSC in direction of the fibers was compared to an L- shaped incision, and patients who had received the latter showed a higher incidence of fatty infiltration. This finding implies that the distinct technique and not the general principal of open SSC surgery plays an important role in muscle preservation. Caubère et al. [8] supported these findings. In their work, the group examined the external and internal rotation strength after open Latarjet using the SSC splitting approach. Their results showed no muscle atrophy and minimal or no fatty infiltration in any of the patients; however, at 1-year follow-up, the operated shoulders showed a significant loss of rotational power.

Summing up, further research is needed to elucidate the degree to which clinical function of the SSC can be preserved during and after surgery. Open procedures do not necessarily lead to fatty infiltration [8], if the anatomy of the SSC is respected, and fatty infiltration is not always associated with unsatisfying score results [7]. One way of evaluating the risk of postoperative dysfunction might be to consider the overall situation of the patient, including BMI, smoking, physical activity and the number of preoperative dislocations. In our study, the width difference of the SSC was localized in the lower SSC, as described in the methods and in Fig. 3. The reason for this cannot be fully explained by our data. Since the bone block is carved to fit into the deficient glenoid as good as possible and the labrum is attached to it, overlapping bone seems implausible as a

reason. Hence, the manipulation of the SSC during surgery and the dislocations themselves seem the best explanation.

The authors are aware of this study's limitations. First of all, the cohort presented is small, which led to mediocre results in the power analysis. Second, different MRI protocols were used. Although the same number of slices was used for both shoulders, this might lead to imprecise measurement results. Third, the measurements were performed free-handedly, which might have impaired their accuracy. Fourth, the clinical integrity of the muscle cannot be validated by the data presented. Fifth, it should be mentioned that despite of the good radiological results of this procedure, high priority should be given to the protection of the axillary nerve, which can be at risk when using an anteroinferior portal [6, 23].

On the other hand, this is the first study to evaluate the 2- and 3-dimensional integrity of the subscapularis muscle after all-arthroscopic glenoid reconstruction.

Conclusion

In this cohort, no relevant volume loss could be found after arthroscopic glenoid reconstruction. However, a greater width of the lower muscle portion could be identified in the parasagittal plane as a possible indication of scarring.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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