


RESEARCH ARTICLE

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Atrophy patterns in isolated subscapularis lesions



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Abstract

Background: While supraspinatus atrophy can be described according to the system of Zanetti or Thomazeau there is still a lack of characterization of isolated subscapularis muscle atrophy. The aim of this study was to describe patterns of muscle atrophy following repair of isolated subscapularis (SSC) tendon.

Methods: Forty-nine control shoulder MRI scans, without rotator cuff pathology, atrophy or fatty infiltration, were prospectively evaluated and subscapularis diameters as well as cross sectional areas (complete and upper half) were assessed in a standardized oblique sagittal plane. Calculation of the ratio between the upper half of the cross sectional area (CSA) and the total CSA was performed. Eleven MRI scans of patients with subscapularis atrophy following isolated subscapularis tendon tears were analysed and cross sectional area ratio (upper half /total) determined. To guarantee reliable measurement of the CSA and its ratio, bony landmarks were also defined. All parameters were statistically compared for inter-rater reliability, reproducibility and capacity to quantify subscapularis atrophy.

Results: The mean age in the control group was 49.7 years (± 15.0). The mean cross sectional area (CSA) was 2367.0 mm² (± 741.4) for the complete subscapularis muscle and 1048.2 mm² (± 313.3) for the upper half, giving a mean ratio of 0.446 (± 0.046). In the subscapularis repair group the mean age was 56.7 years (± 9.3). With a mean cross sectional area of 1554.7 mm² (± 419.9) for the complete and of 422.9 mm² (± 173.6) for the upper half of the subscapularis muscle, giving a mean CSA ratio of 0.269 (± 0.065) which was seen to be significantly lower than that of the control group ($p < 0.05$).

Conclusion: Analysis of typical atrophy patterns of the subscapularis muscle demonstrates that the CSA ratio represents a reliable and reproducible assessment tool in quantifying subscapularis atrophy. We propose the classification of subscapularis atrophy as Stage I (mild atrophy) in case of reduction of the cross sectional area ratio < 0.4 , Stage II (moderate atrophy) in case of < 0.35 and Stage III (severe atrophy) if < 0.3 .

Keywords: Isolated subscapularis atrophy, Subscapularis repair, Rotator cuff, Rotator cuff atrophy, Subscapularis atrophy

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Background

Prognostic factors in the outcomes of rotator cuff repair have been extensively described and discussed in the literature. Beyond clinical factors such as age, surgeon experience and concomitant diseases, structural factors including tears size and muscle quality seem to have the greatest influence on postoperative outcome [4, 5, 19, 21, 26, 32, 34].

Higher grades of preoperative muscular atrophy and fatty infiltration, specifically, have been demonstrated to result in poorer function and increased re-tear rates post-operatively, and have been shown individually to be independent predictors of outcome [10, 11, 19, 24, 34]. Although muscular atrophy and fatty infiltration may be independent predictors, these properties are clearly linked. Atrophy, describing a decrease in muscle mass, is known to be influenced by fatty infiltration, representing involution of fat between muscle fibers [24].

Although rotator cuff repair is generally recommended to reduce pain and improve shoulder function, proper pre-operative evaluation of fatty infiltration as reported by Goutallier et al. [12] and muscular atrophy on cross sectional imaging is crucial in determining the feasibility of rotator cuff repair during preoperative planning. In addition to muscular retraction as described by Patte et al. [27], muscular atrophy represents an important factor in assessing the feasibility of reconstruction.

In 1996, Thomazeau et al. [35] introduced an MRI classification to quantify supraspinatus atrophy, by calculating the occupation ratio of the muscle within the supraspinatus fossa. Similarly, Zanetti et al. [38] described atrophy of the supraspinatus muscle belly by relation to a tangential line connecting the superior aspect of the coracoid and the scapular spine.

Combined anterosuperior rotator cuff atrophy was characterized by Warner et al. [37], but while Schröder et al. [31] and Scheibel et al. [30] described atrophy of the subscapularis by measuring the vertical, the cranial-transverse and the caudal-transverse diameters as well as the signal to noise ratio of the SSC and the ISP muscle, none of these authors proposed a system of classification.

Isolated subscapularis tendon tears are a rare entity with a prevalence of only 4% among all rotator cuff lesions [7]. Most of the tears appear due to traumatic events like external rotation of the abducted arm in younger patients or hyperextension [8], while non-traumatic lesions are described as a consequence of subcoracoid impingement [23, 29] or sub-/luxation of the long head of the biceps tendon [36].

The purpose of this study was to further describe atrophy patterns of the subscapularis muscle and to propose a reliable method for quantifying and classifying subscapularis atrophy.

Methods

In this retrospective case-controlled study, 49 patients who underwent MRI imaging of the shoulder between

2007 and 2014 in this institution without rotator cuff pathology, were selected at random as a control group. Exclusion criteria were glenohumeral disorders (labral/SLAP lesions or instability etc.), osteoarthritis, full or partial thickness rotator cuff tear, atrophy or fatty infiltration of any rotator cuff muscle, humeral head migration, neurologic disorders involving the shoulder girdle or any previous shoulder surgery, as well as prolonged duration of pain or immobilization. This study was approved by the institutional ethics committee and informed consent was obtained from all patients.

The study group comprised 11 patients presenting with isolated SSC pathology and muscular atrophy, between December 2002 and November 2007. Standardized MRI examinations were performed with the arm in neutral position on a 3.0-Tesla system (Verio; Siemens Medical Solutions) with use of a dedicated phased-array shoulder coil. T1 and T2-weighted sequences in axial, coronal and oblique-sagittal planes were recorded. Subscapularis atrophy was assessed in the oblique sagittal plane [2, 16, 25, 33, 35, 37].

SSC muscle atrophy was analyzed by two blinded examiners, one radiologist specializing in musculoskeletal imaging and one experienced orthopedic shoulder specialist. All values were calculated independently and the mean value taken for definite analysis. In addition, inter-observer reliability was assessed.

Subscapularis diameters and ratio (cranial-transverse/caudal-transverse)

Maximum vertical and transverse (cranial-transverse and caudal-transverse) diameters were calculated in millimeters in the same plane, as described by Scheibel et al. [30]. Measurements are performed on parasagittal images, using the most lateral image on which the spine of the scapula is in contact with the coracoid process (Y-shaped position). The vertical diameter is defined as the distance between the highest and the lowest point of the subscapularis muscle. The measuring line of the cranial-transverse diameter is placed perpendicular to the vertical diameter, ending at the top of the concavity of the subscapularis groove. The maximal caudal-transverse diameter was also measured perpendicular to the vertical diameter and ends at the most inferior point of the scapula.

Cross sectional area (CSA) and its ratio (upper half/total muscle)

The cross-sectional area of the SSC was measured in the "Y-position" (using the most lateral image where the scapular spine is in contact with the body of the scapula) of the MRI sagittal oblique plane. By this means, a standardized view can be guaranteed for reproducible calculation. The CSA was measured using manual tracing of

the SSC muscle outline on the PACS workstation and specified in square millimeters (mm^2) based on the technique of Juul- Kristensen et al. [17] and modified by Bartl et al. [3] (Fig. 1).

To determine the upper 50% of the subscapularis area in the same plane, the center of the vertical diameter was calculated (Fig. 2a and b).

At this point a conditional line was created perpendicular to the vertical diameter to define the upper half of the subscapularis cross sectional area at the midpoint of the vertical diameter (Fig. 3a and b). Using these data, the ratio of the CSA of the upper half relative to the total CSA of the SSC was calculated.

Cross sectional area (CSA) with defined bony vertical landmark and its ratio (upper half/total muscle)

In all 49 patients of the reference group, the subscapularis muscle, determined at the “Y-shaped position”, was cranially bounded at its upper margin by the bony ventral tip of the scapular “Y” and never extended directly to the coracoid (Fig. 2).

Given this observation, the ventral tip of the scapular “Y” represents a bony margin of the subscapularis muscle and may be used as osseous landmark of the vertical diameter to evaluate the cranial extent of the SSC, particularly in patients with marked atrophy. In patients with physiological subscapularis muscle bulk, without atrophic changes, the cranial extent of the SSC seems to be equivalent to the measuring method described by Scheibel et al. [30] assessing the vertical, the cranial-transverse and the caudal-transverse diameters of the SSC.

In contrast, particularly in patients with marked cranial SSC atrophy, this difference (real cranial vertical diameter tip vs. defined bony landmark – (Fig. 4 and)) may represent a significant bias in measuring CSA ratio and therefore in evaluating SSC atrophy given that the ratio of the upper half of the SSC in relation to the total muscle alters dependent on the vertical diameter measured.

The CSA (with and without defined bony cranial landmark) and its ratios as well as the muscle diameters of the 49 control scans, as well as the 11 patients with subscapularis atrophy, were compared for statistical difference.

Statistics

With a sample size of 11 patients with atrophy and 49 controls, the study was adequately powered (> 80%) to detect an effect size (Cohen’s d = mean difference between groups / standard deviation within groups) of one. Power calculation was performed with nQuery Advisor 7.0.

Statistical analysis was performed using SPSS software version 24.0 (IBM corp, Armonk, New York, USA) and R version 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria). Correlations of assessments by the raters were calculated using the Pearson correlation coefficient. Correlation coefficients were compared using Dunn and Clark’s test provided in the R package *cocor* [6]. To evaluate differences between the control and the atrophy group diameters, cross sectional areas and the CSA ratio of the subscapularis muscle, the ROC curve was determined. Measurement of the CSA ratio bony referenced vs. not bony referenced was compared by the Bland-Altman procedure. All statistical tests were performed two-tailed and the level of significance was set at $p < 0.05$.

Results

The control group comprised 33 male and 16 female participants ($n = 49$) with a mean age of 49.7 (range, 33,6 – 69,2).

SSC diameters were $9.3 \text{ cm} \pm 1.5$ (vertical), $2.7 \text{ cm} \pm 0.6$ (cranial-transverse) and $3.1 \text{ cm} \pm 0.8$ (caudal-transverse), respectively. The diameter ratio (cranial-transverse (caudal-transverse)) was 0.886 ± 0.159 .

The mean cross-sectional area of the SSC calculated conventionally was $2318.0 \text{ mm}^2 (\pm 743.0)$ for the complete subscapularis muscle and $1021.3 \text{ mm}^2 (\pm 292.7)$ for the upper half. The subsequent mean CSA ratio was $0.448 (\pm 0.052)$.

Inter-rater reliability demonstrated a correlation of 0.985.

By calculating the cross sectional area (CSA) defined by cranial bony landmarks, the mean total area and area of the upper half of the SSC was $2367.0 \text{ mm}^2 (\pm 741.4)$ and $1048.2 \text{ mm}^2 (\pm 313.3)$, respectively. The resulting mean ratio (upper half/total muscle) was $0.446 (\pm 0.046)$. Inter-rater reliability demonstrated a correlation of 0.999. The mean vertical diameter was $9.0 \text{ cm} (\pm 1.5)$.

Comparing these two methods of calculating CSA ratio, it was seen that a significantly more accurate and representative measurement may be achieved by use of the bony-referenced method ($p = 0.001$).

The atrophy group consisted of eight male (72.7%) and three female (27.2%) patients ($n = 11$) with a mean age of 56.7 (range, 44,0 - 71,7).

Calculated conventionally, diameters were $7.6 \text{ cm} \pm 0.8$ (vertical), $1.0 \text{ cm} \pm 0.7$ (cranial-transverse) and $2.8 \text{ cm} \pm 0.6$ (caudal-transverse), respectively. The diameter ratio (cranial-transverse/caudal-transverse) was 0.355 ± 0.282 .

The mean cross sectional area was $1572.4 \text{ mm}^2 (\pm 411.8)$ for the complete and $510.0 \text{ mm}^2 (\pm 173.1)$ for the upper half of the subscapularis muscle. The mean CSA ratio of $0.322 (\pm 0.056)$ was significantly reduced as

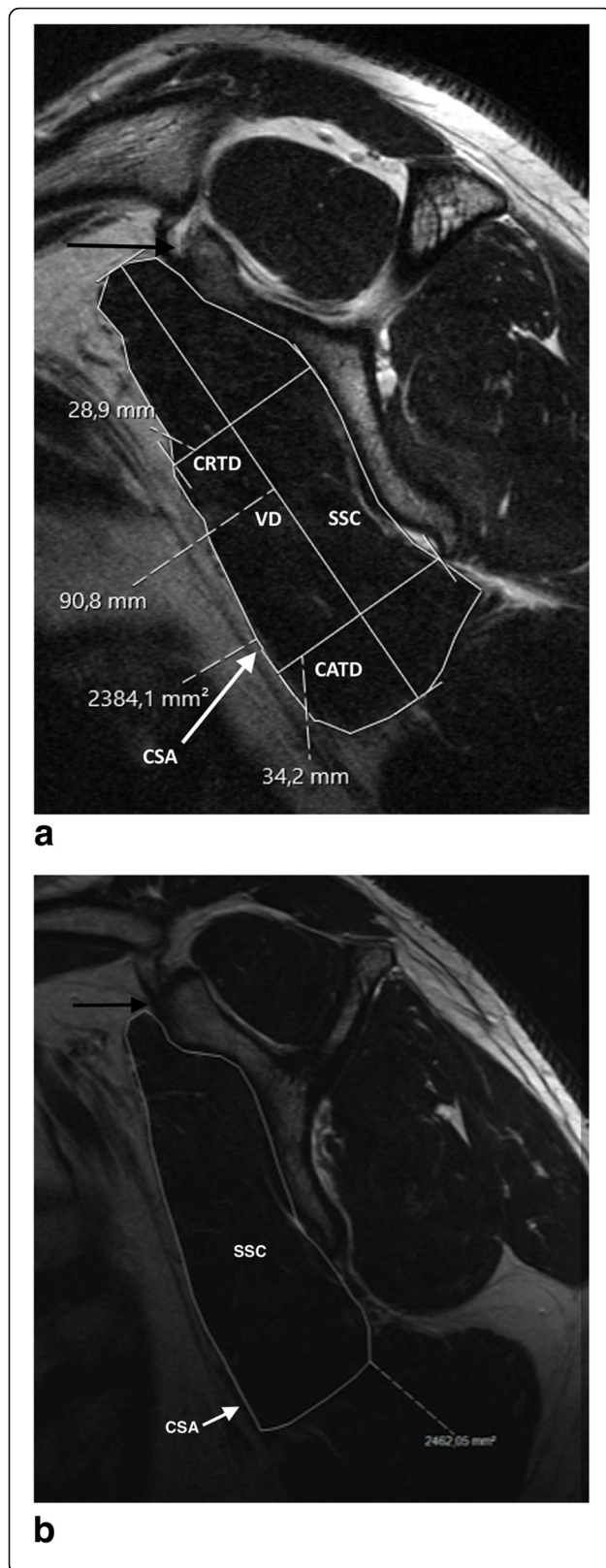


Fig. 1 a Healthy subscapularis muscle - measuring of the vertical diameter (VD), cranial transverse diameter (CRTD), caudal transverse diameter (CATD) and cross sectional area (CSA); SSC: subscapularis muscle; black arrow: ventral tip of the scapular "Y". **b** "Y-position" of the MRI sagittal oblique plane: Healthy subscapularis muscle - measuring of the cross sectional area (CSA); SSC: subscapularis muscle; arrow/CSA: cross sectional area; black arrow: ventral tip of the scapular "Y"

compared to the control group (0.448 ± 0.052 , $p = 0.001$). The area under the ROC curve (AUC) was 0.99.

Inter-rater reliability showed a correlation coefficient of 0.98.

Using the bony-referenced method, the osseous-bounded vertical diameter was $8.4 \text{ cm} \pm 0.8$. The CSA of the 11 patients with atrophy showed mean values of $1554.7 \text{ mm}^2 (\pm 419.9)$ for the total muscle and $422.9 \text{ mm}^2 (\pm 173.6)$ for the upper half, both significantly reduced as compared to the control group (total CSA $2367.0 \text{ mm}^2 (\pm 741.4)$, upper half CSA $1048.2 \text{ mm}^2 (\pm 313.3)$, $p = 0.001$).

This also resulted in a significant reduced mean CSA ratio (0.269 ± 0.065) in the atrophy group as compared to the control group ($p = 0.001$) and perfect discrimination was shown in the ROC curve with an AUC value of 1. Inter-rater reliability showed a correlation of 0.99.

When comparing CSA ratio values for the conventional versus the bony referenced method in both groups, significantly more accurate and reflective measurements may be achieved by use of the bony referenced method ($p = 0.001$) (Fig. 5a and b).

Assessing all measured and calculated parameters (CSA ratio, CSA of the upper half and the total muscle as well as the three diameters) for capacity to quantify subscapularis atrophy, the CSA ratio represents the most reliable tool with an area under the curve (AUC) of 1.00 when using the bony-referenced method, and 0.984 using the conventional method ($p < 0.001$).

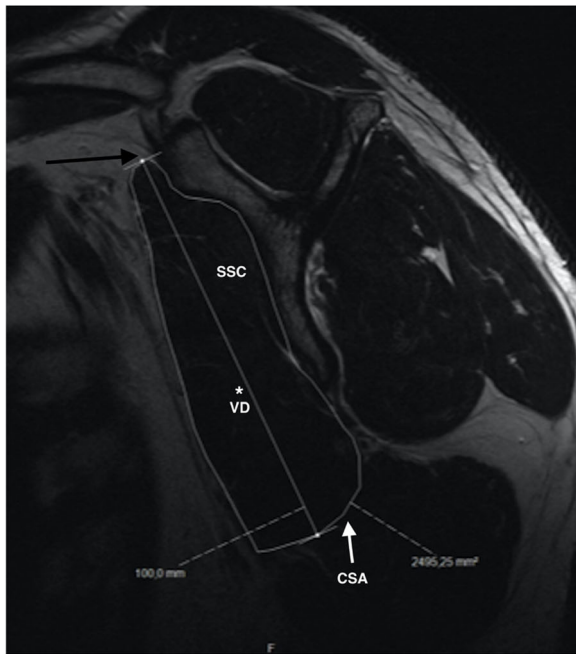
Based on these data, we propose that subscapularis atrophy be graded into a four-stage classification:

- Stage 0: no atrophy; CSA ratio > 0.4
- Stage I: mild atrophy; CSA ratio $< 0.4-0.35$
- Stage II: moderate atrophy; CSA ratio $< 0.35-0.3$
- Stage III: severe atrophy; CSA ratio < 0.3

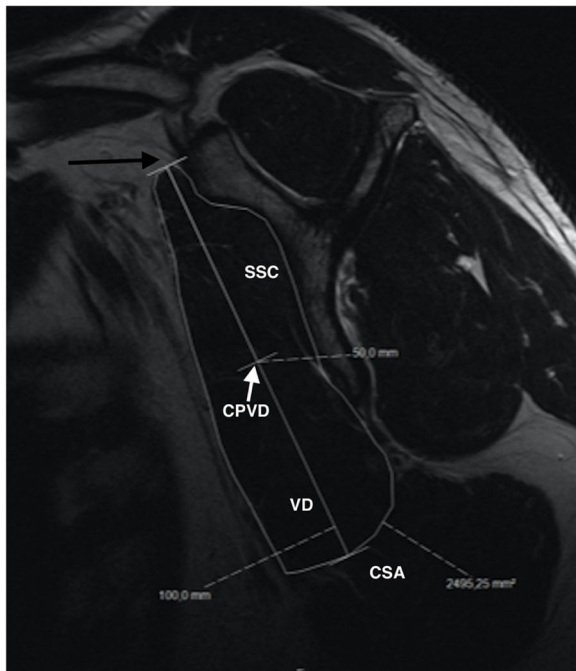
According to this classification, subscapularis atrophy with bony landmark could be graduated as mild (Stage I) in 1 out of 11 (9.1%) patients. Four (36.4%) patients had moderate atrophy (Stage II) whereas severe atrophy (Stage III) could be detected in six (54.5%) patients (see Table 1).

Discussion

The present study demonstrates that subscapularis atrophy may be quantified by measurement of the CSA ratio

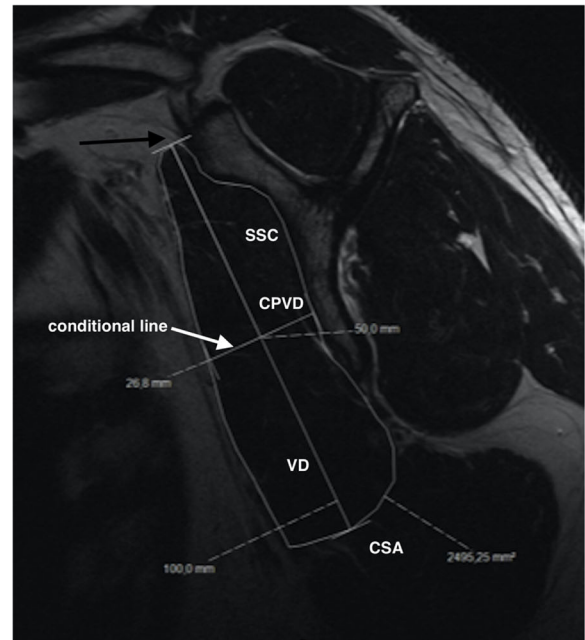


a

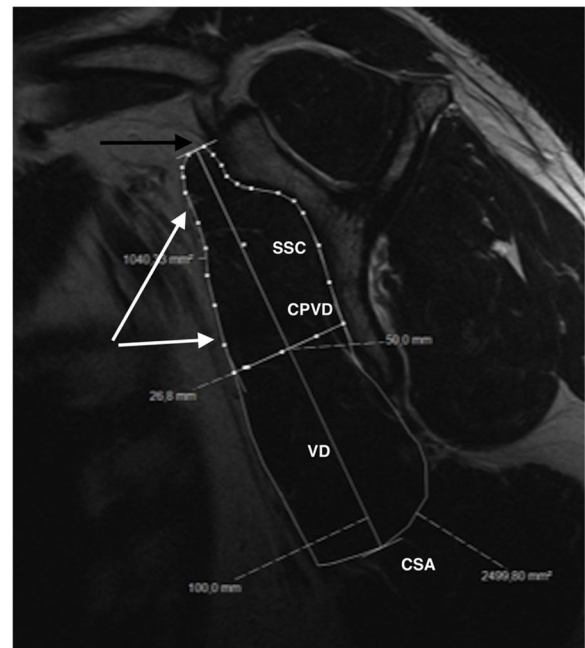


b

Fig. 2 **a** Healthy subscapularis muscle - measuring of the vertical diameter (VD); SSC: subscapularis muscle; asterisk/VD: vertical diameter; arrow/CSA: cross sectional area; black arrow: ventral tip of the scapular "Y". **b** Healthy subscapularis muscle - determining the center of the vertical diameter; SSC: subscapularis muscle; VD: vertical diameter; arrow/CPVD: center point of the vertical diameter; CSA: cross sectional area; black arrow: ventral tip of the scapular "Y"



a



b

Fig. 3 **a** Healthy subscapularis muscle - conditional line at the center point of the vertical diameter; SSC: subscapularis muscle; VD: vertical diameter; CPVD: center point of the vertical diameter; CSA: cross sectional area; white arrow: conditional line perpendicular to the vertical diameter to define the upper half of the subscapularis cross sectional area at the midpoint of the vertical diameter; black arrow: ventral tip of the scapular "Y". **b** Healthy subscapularis muscle - defining the upper half of the subscapularis CSA; SSC: subscapularis muscle; VD: vertical diameter; CPVD: center point of the vertical diameter; CSA: cross sectional area; white arrows: definition of the upper half of the subscapularis cross sectional area at the center point of the vertical diameter

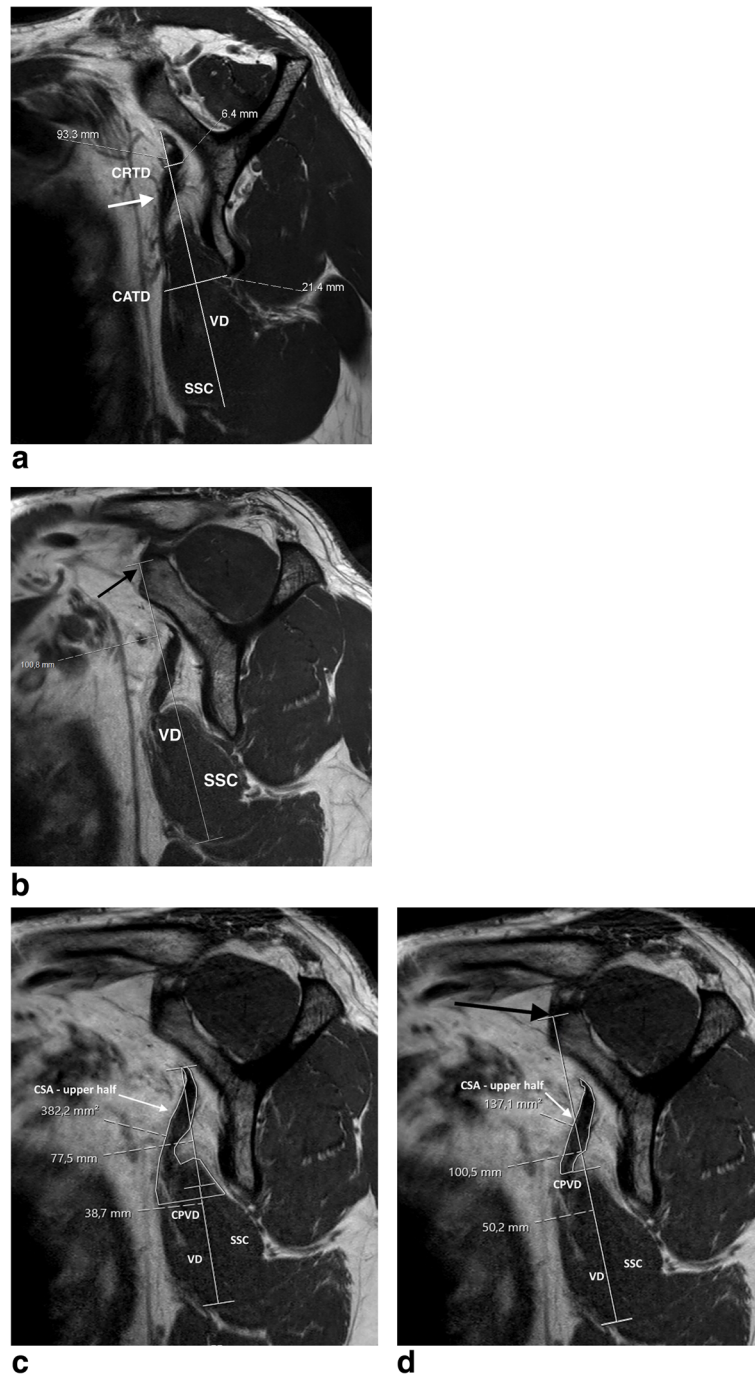


Fig. 4 **a** and **b** Atrophic subscapularis muscle - measuring of the vertical diameter without **(a)** and with **(b)** bony landmark; SSC: subscapularis muscle; white arrow: cranial atrophy of the SSC; VD: vertical diameter; CRTD: cranial transverse diameter; CATD: caudal transverse diameter; black arrow: ventral tip of the scapular “Y” as bony landmark to define the bony referenced VD. **c** and **d**: Atrophic subscapularis muscle - measuring of the cross sectional area of the upper half of the SSC muscle without **(c)** and with **(d)** bony landmark; SSC: subscapularis muscle with cranial atrophy; VD: vertical diameter; black arrow: ventral tip of the scapular “Y” as bony landmark to define the bony referenced VD; white arrow: CSA (cross sectional area) of the upper half of the muscle; CPVD: center point of the vertical diameter

using a “Y”-view MRI slice, and classified into a four-stage grading system proposed here.

Analyzing atrophy patterns of the subscapularis muscle after reconstruction of isolated subscapularis

tendon tears, it has been shown that SSC atrophy always occurs from the top down [15, 28]. The cranial aspect of the SSC seems to be affected the most whereas isolated atrophy within the caudal area of the SSC was not seen

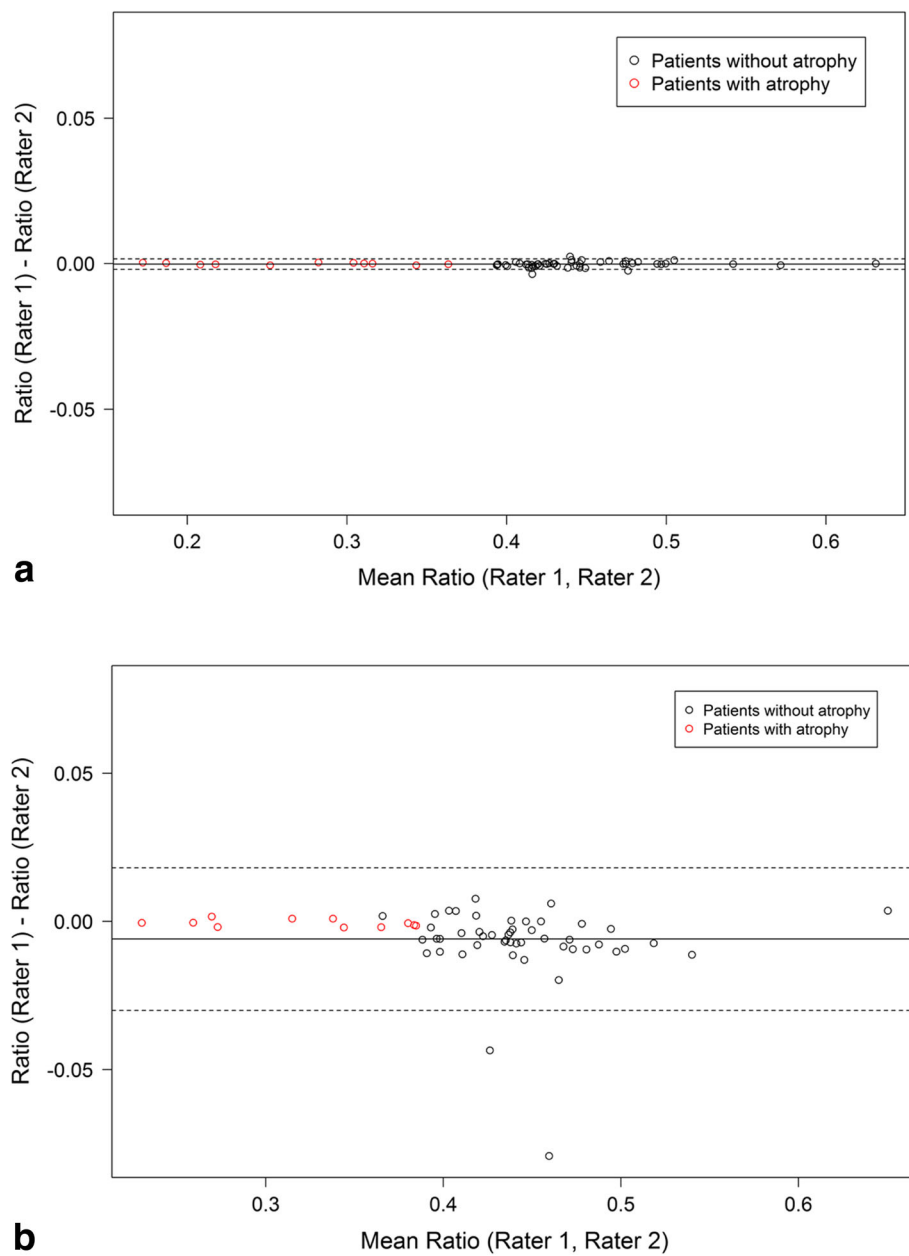


Fig. 5 a Inter-rater reproducibility regarding the CSA ratio of the atrophy and the control group – with bony landmark. **b** Inter-rater reproducibility regarding the CSA ratio of the atrophy and the control group – without bony landmark

in the present cohort nor has been described in the literature previously.

Evaluating the normal MRI images of the 49 control patients, it was seen that the SSC never extends beyond the coracoid process in the oblique sagittal plane. This ventral tip of the scapular “Y” may therefore be considered a bony landmark of the maximal cranial extension of the subscapularis muscle.

While classifications of muscular fatty infiltration are well described by Goutallier et al. [12] by means of computerised tomography (CT) and by Fuchs et al. [9] using

MRI, grading systems of muscular atrophy remain rare. Thomazeau et al. [35] and Zanetti et al. [38] published classification systems for supraspinatus atrophy and Warner et al. [37] described a method of classifying combined antero-superior rotator cuff atrophy. In their study Warner et al. [37] introduced a measurement of muscle atrophy based on oblique sagittal plane image medial to coracoid process. The stage is specified by the amount of muscle above or below a line drawn from the edge of the coracoid to the inferior tip of the scapular spine. In addition, the Zanetti tangent line connects the

Table 1 Patients Demographics – Atrophy group

Patient No	Vertical diameter bony landmark (mm)	CSA upper half bony landmark (mm ²)	CSA total muscle bony landmark (mm ²)	CSA-Ratio upper half/total bony landmark	Vertical Diameter (mm)	CSA upper half (mm ²)	CSA total muscle (mm ²)	CSA-Ratio upper half/total
1	68	348.2	1014.0	0.34	64	357.0	1038.0	0.34
2	89	276.8	1098.9	0.25	79	328.8	1205.0	0.27
3	92	297.1	1427.2	0.21	72	391.0	1242.0	0.31
4	87	213.5	1240.9	0.17	77	292.1	1269.4	0.23
5	85	708.2	1948.4	0.36	84	753.0	1957.9	0.38
6	89	603.6	1985.1	0.30	82	744.0	1940.0	0.38
7	95	438.1	2012.6	0.22	89	557.0	2150.0	0.26
8	77	278.2	1490.4	0.19	67	405.0	1502.3	0.27
9	80	362.1	1283.5	0.28	73	469.0	1234.0	0.38
10	84	698.3	2247.7	0.31	83	727.0	2152.0	0.34
11	74	427.6	1353.4	0.32	71	586.1	1606.0	0.36

Orange: Patients with severe atrophy (bony referenced CSA ratio < 0.30): n = 6; Orange with diagonal line: moderate atrophy (bony CSA ratio < 0.35–0.30): n = 4
 Blue: Patients with severe atrophy (conventional CSA ratio < 0.30): n = 4; Blue with diagonal line: moderate atrophy (conventional CSA ratio < 0.35–0.30): n = 3

superior aspect of the coracoid and the scapular spine. A convex overhang of the muscle above the line indicates no atrophy and a decrease of the muscle area towards the line or a concavity below the line represents mild, moderate or severe atrophy, respectively. No quantification of atrophy was presented.

Thomazeau et al. [35] used the supraspinatus fossa as osseous landmark to define SSP atrophy. Contrary to the SSP there is no three-side bony limitation of the SSC to guarantee three-side reproducible measurements. Defining osseous landmarks in calculating subscapularis atrophy is challenging and may explain the previous absence of a standardized SSC atrophy grading system.

Schröder et al. [31] and Scheibel et al. [30] semi-quantitatively evaluated atrophy of the subscapularis by measuring the vertical, the cranial-transverse and the caudal-transverse diameters. In addition, the signal to noise ratio of the SSC and the ISP were examined, although without proposing any grading of muscular atrophy. In patients with massive atrophy, usually appearing in the upper part of the muscle, this method may become insufficiently accurate as the cranial-transverse diameter is often difficult to determine due to loss of volume. This potential issue is corroborated by the observations of the present study. Therefore, a reliable

determination of atrophy exclusively based on the above mentioned three diameters (vertical, cranial-transverse and caudal-transverse) may be inadequate. Likewise, assessing subscapularis atrophy by comparing the signal to noise ratio of the subscapularis and the infraspinatus muscle may be skewed by the requirement for a non-atrophic infraspinatus muscle.

Atrophy of the subscapularis muscle is commonly seen in the upper part, theorised to be a result of the tendency of the subscapularis tendon to ruptures from the top down, as the inferior part of its humeral insertion is of muscular origin and not tendinous. For this reason, it is useful to evaluate the upper part as compared to the total muscle.

Although isolated caudal lesions of the subscapularis tendon [1, 14, 18] have been, rarely, described in literature, there are no reports of isolated atrophy of the lower part of the SSC. In the present study, caudal atrophy of the SSC was not seen in any of the 11 patients with subscapularis atrophy. It may therefore be assumed that the distal border of the SSC, even in case of higher grades of atrophy, is unlikely to change position significantly.

Given these findings, determining the cross-sectional area seems to be a more reliable method to assess

subscapularis atrophy, particularly when using a defined plane in the oblique sagittal “Y-View” (using the most lateral image where the scapular spine is in contact with the body of the scapula). As each patient has a unique subscapularis cross sectional area (atrophic or not), calculating the CSA ratio of the upper part in relation to the total muscle seems to represent a reliable and reproducible tool to assess SSC atrophy.

Using conventional methods, defining the maximal vertical spread from the base to the preserved top of the subscapularis, biased CSA ratios (upper half of the SSC in relation to the total muscle) may result in mild atrophic muscles as compared to severely atrophic cases (see Table 1).

Analyzing the data and MRI images of the control group it was seen that healthy, non-atrophic SSC muscles never extend the coracoid process. Thus, it is proposed to use the ventral tip of the scapular “Y” as a defined osseous landmark for the upper margin of the subscapularis muscle in calculation of the CSA ratio to ensure easily reproducible measurements. This was supported by the good correlation (correlation coefficient: 0.99 - bony referenced) between the two independent examiners determining the CSA ratio in this study.

The major difference between the CSA ratio and the CSA ratio with bony landmark is that the area of the upper half in relation to the total muscle decreases by taking the original vertical diameter for reference (see Fig. 4c and d). Thus, the centerline between the upper and the total muscle is translated cranially and the area of the upper muscle part decreases. In case of (severe) muscle retraction subscapularis measurement with bony landmark may also constitute a more accurate way of evaluation – provided that measurement is performed at a defined sagittal oblique plane of the MRI (“Y-position”). A severe retracted tendon is supposed to lead to a decrease of the CSA ratio, too.

This observation was confirmed by analysis of the measurements of the atrophy group (see Table 1). Compared to the conventional, non-bony-referenced measurement, (mean value 510.0 ± 173.1) the area of the upper part of the SSC was significantly decreased ($p < 0.001$) in all patients by using the osseous landmark measurement technique (mean value 422.9 ± 173.6). Patients of the atrophy group also had a significantly ($p < 0.001$) reduced bony landmark CSA ratio with mean values of 0.269 ± 0.065 as compared to the conventionally measured CSA ratio with mean values of $0.322 \pm .056$. However, it has to be stated that both groups are of limited size. Due to the reason that isolated subscapularis tendon tears only represent a very small part of all rotator cuff tears there is still a lack of studies presenting data regarding isolated subscapularis tears in larger numbers of patients [3, 13, 20, 22] – especially regarding subscapularis atrophy.

Comparing all parameters (three diameters, CSA and CSA ratio) regarding capacity to quantify subscapularis atrophy, the bony referenced CSA ratio represents the most reliable tool with an area under the curve (AUC) of 1.00 ($p = .0001$).

Based on the bony referenced CSA ratio, a quantitative classification of subscapularis atrophy is proposed as follows:

Stage 0 with a ratio of > 0.4 represents no atrophy and is also seen in healthy patients. Mild atrophy with a CSA ratio < 0.4 – 0.35 is classified as Stage 1. Stage 2 indicates moderate atrophy with ratio values < 0.35 – 0.3 . Values < 0.3 represent severe atrophy of the subscapularis.

A reliable and reproducible pre-operative analysis of isolated subscapularis atrophy in cases of SSC rupture may assist decision-making and inform choice of treatment and feasibility of subscapularis repair. Postoperatively, it may be used to monitor healing and evaluate clinical outcome.

To confirm this, further prospective combined clinical-radiological studies will be necessary to validate whether quantitative pre-operative assessment of subscapularis atrophy is a useful prognostic indicator of post-operative outcome.

Limitations

There are some limitations to the present study which must be considered. Firstly, the number of patients within the control group, acting as anatomical “normal” examples, and within the atrophy group is limited.

Secondly, the differences in the mean age between the study and the control group may act as a bias. Additionally, functional parameters such as clinical tests, strength, subjective satisfaction or pain evaluation are missing in the atrophy group to draw further clinically related conclusion, although the 11 patients in this cohort nonetheless acted well to illustrate the significant differences in the CSA ratio as compared to the control group. Prospective clinical studies with larger numbers of patients and separate cohorts, including clinical parameters and equal gender distribution, are needed to confirm our findings. In addition, the atrophy group consists of patients with isolated subscapularis atrophy. It would be interesting to see if there are any changes on muscular atrophy over the course of time.

Furthermore intra-rater reliability is missing.

For this reason a more comprehensive study including clinical parameters is being undertaken to provide clinical correlation and to allow recommendations to be made regarding treatment options, on the basis of pre-operative MRI evaluation of subscapularis atrophy.

Conclusion

Analyzing atrophy patterns in cases of isolated subscapularis tears it was demonstrated that the bony referenced cross sectional area ratio (area of the upper half in

proportion to the total muscle) may represent a reliable and reproducible method of quantifying and subsequently classifying isolated subscapularis atrophy, although data regarding subscapularis atrophy are limited as isolated subscapularis tears represent a very rare entity.

Abbreviations

CATD: Caudal transverse diameter; CPVD: Center point of the vertical diameter; CRTD: Cranial transverse diameter; CSA: Cross sectional area; SSC: Subscapularis muscle; VD: Vertical diameter

Acknowledgments

This study was conducted at the Department of Orthopedic Sports Medicine and the Department of Radiology, Klinikum rechts der Isar, Technical University of Munich, Munich, Germany.

Authors' contributions

GS: Study design, data analysis & interpretation, abstract, introduction, material & methods, results, and discussion. AV: Data acquisition/analysis, and measurements. DH: Data analysis, statistical analysis, results, and discussion. SW: Radiological data collection, data analysis, and measurements. BH: Statistical analysis and study design. PF: Concept/realization data acquisition, and results. SR: Study design, data acquisition, and methods. BMH: Data interpretation, figures and critical review. JEP: Study design, data analysis & interpretation and critical review. AI: Study conception and critical review. All authors agreed to be accountable for all aspects of the work and approved the final manuscript to be published.

Funding

No source of outside financial funding was used for this study. This work was supported by the German Research Foundation (DFG) and the Technical University of Munich (TUM) in the framework of the Open Access Publishing Program. Open Access funding enabled and organized by Projekt DEAL.

Availability of data and materials

All relevant data supporting the conclusions are included within the article and tables.

The raw data are part of a greater institutional investigation project. The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee of the Technical University Munich, Munich, Germany (Vote-Nr: 308/14).

Consent for publication

Not applicable.

Competing interests

AB Imhoff is consultant for Arthrex Inc. The other authors declare, that they have no competing interests.

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Received: 25 August 2019 Accepted: 9 April 2021

Published online: 22 April 2021

References

- Achtmich A, Braun S, Imhoff AB, Martetschlagner F. Isolated lesions of the lower subscapularis tendon: diagnosis and management. *Knee Surg Sports Traumatol Arthrosc.* 2017;25(7):2182–8.
- 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(11):1592–600. <https://doi.org/10.1016/j.arthro.2012.04.142>.
- Bartl C, Salzmann GM, Seppel G, Eichhorn S, Holzappel K, Wortler K, et al. Subscapularis function and structural integrity after arthroscopic repair of isolated subscapularis tears. *Am J Sports Med.* 2011;39(6):1255–62. <https://doi.org/10.1177/0363546510396317>.
- Cole BJ, Mccarty LP 3rd, Kang RW, Alford W, Lewis PB, Hayden JK. Arthroscopic rotator cuff repair: prospective functional outcome and repair integrity at minimum 2-year follow-up. *J Shoulder Elbow Surg.* 2007;16:579–85.
- Defranco MJ, Bershadsky B, Ciccone J, Yum JK, Iannotti JP. Functional outcome of arthroscopic rotator cuff repairs: a correlation of anatomic and clinical results. *J Shoulder Elbow Surg.* 2007;16:759–65.
- Diedenhofen B, Musch J. cocor: a comprehensive solution for the statistical comparison of correlations. *PLoS One.* 2015;10:e0121945.
- Edwards TB, Walch G, Nove-Josserand L, Boulahia A, Neyton L, O'connor DP, et al. Arthroscopic debridement in the treatment of patients with isolated tears of the subscapularis. *Arthroscopy.* 2006;22(9):941–6. <https://doi.org/10.1016/j.arthro.2006.05.009>.
- Flury MP, John M, Goldhahn J, Schwyzer HK, Simmen BR. Rupture of the subscapularis tendon (isolated or in combination with supraspinatus tear): when is a repair indicated? *J Shoulder Elb Surg.* 2006;15(6):659–64. <https://doi.org/10.1016/j.jse.2005.07.013>.
- 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.
- Gerber C, Schneeberger AG, Hoppeler H, Meyer DC. Correlation of atrophy and fatty infiltration on strength and integrity of rotator cuff repairs: a study in thirteen patients. *J Shoulder Elbow Surg.* 2007;16:691–6.
- Gladstone JN, Bishop JY, Lo IK, Flatow EL. Fatty infiltration and atrophy of the rotator cuff do not improve after rotator cuff repair and correlate with poor functional outcome. *Am J Sports Med.* 2007;35(5):719–28. <https://doi.org/10.1177/0363546506297539>.
- 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.
- Grueninger P, Nikolic N, Schneider J, Lattmann T, Platz A, Chmiel C, et al. Arthroscopic repair of traumatic isolated subscapularis tendon lesions (Lafosse type III or IV): a prospective magnetic resonance imaging-controlled case series with 1 year of follow-up. *Arthroscopy.* 2014;30(6):665–72. <https://doi.org/10.1016/j.arthro.2014.02.030>.
- Hartzler RU, Burkhart SS. Medial biceps sling takedown may be necessary to expose an occult subscapularis tendon tear. *Arthrosc Tech.* 2014;3(6):e719–22. <https://doi.org/10.1016/j.eats.2014.09.005>.
- Hinton MA, Parker AW, Drez D Jr, Altcheck D. An anatomic study of the subscapularis tendon and myotendinous junction. *J Shoulder Elbow Surg.* 1994;3:224–9.
- Jain NB, Collins J, Newman JS, Katz JN, Losina E, Higgins LD. Reliability of magnetic resonance imaging assessment of rotator cuff: the ROW study. *PM R.* 2015;7:245–254 e243 quiz 254.
- Juul-Kristensen B, Bojsen-Moller F, Finsen L, Eriksson J, Johansson G, Stahberg F, et al. Muscle sizes and moment arms of rotator cuff muscles determined by magnetic resonance imaging. *Cells Tissues Organs.* 2000;167(2-3):214–22. <https://doi.org/10.1159/000016784>.
- Koo SS, Burkhart SS. Subscapularis tendon tears: identifying mid to distal footprint disruptions. *Arthroscopy.* 2010;26(8):1130–4. <https://doi.org/10.1016/j.arthro.2010.06.017>.
- Kuzel BR, Grindel S, Papandrea R, Ziegler D. Fatty infiltration and rotator cuff atrophy. *J Am Acad Orthop Surg.* 2013;21(10):613–23. <https://doi.org/10.5435/JAAOS-21-10-613>.

20. 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(6):1184–93. <https://doi.org/10.2106/00004623-200706000-00005>.
21. Liem D, Lichtenberg S, Magosch P, Habermeyer P. Magnetic resonance imaging of arthroscopic supraspinatus tendon repair. *J Bone Joint Surg Am.* 2007;89(8):1770–6. <https://doi.org/10.2106/00004623-200708000-00015>.
22. Liu Y, Lafosse L, Opsomer G, Villain B, Kempf JF, Collin P. Ten-year clinical and magnetic resonance imaging evaluation after repair of isolated subscapularis tears. *JSES Int.* 2020;4(4):913–8. <https://doi.org/10.1016/j.jseint.2020.04.026>.
23. Lo IK, Burkhart SS. The etiology and assessment of subscapularis tendon tears: a case for subcoracoid impingement, the roller-wringer effect, and TUFF lesions of the subscapularis. *Arthroscopy.* 2003;19(10):1142–50. <https://doi.org/10.1016/j.arthro.2003.10.024>.
24. Melis B, Defranco MJ, Chuinard C, Walch G. Natural history of fatty infiltration and atrophy of the supraspinatus muscle in rotator cuff tears. *Clin Orthop Relat Res.* 2010;468(6):1498–505. <https://doi.org/10.1007/s11999-009-1207-x>.
25. Oh JH, Kim SH, Choi JA, Kim Y, Oh CH. Reliability of the grading system for fatty degeneration of rotator cuff muscles. *Clin Orthop Relat Res.* 2010; 468(6):1558–64. <https://doi.org/10.1007/s11999-009-0818-6>.
26. Oh JH, Kim SH, Ji HM, Jo KH, Bin SW, Gong HS. Prognostic factors affecting anatomic outcome of rotator cuff repair and correlation with functional outcome. *Arthroscopy.* 2009;25(1):30–9. <https://doi.org/10.1016/j.arthro.2008.08.010>.
27. Patte D. Classification of rotator cuff lesions. *Clin Orthop Relat Res.* 1990;254: 81–6.
28. Pfirrmann CW, Zanetti M, Weishaupt D, Gerber C, Hodler J. Subscapularis tendon tears: detection and grading at MR arthrography. *Radiology.* 1999; 213(3):709–14. <https://doi.org/10.1148/radiology.213.3.r99dc03709>.
29. Richards DP, Burkhart SS, Campbell SE. Relation between narrowed coracohumeral distance and subscapularis tears. *Arthroscopy.* 2005;21(10): 1223–8. <https://doi.org/10.1016/j.arthro.2005.06.015>.
30. Scheibel M, Tsynman A, Magosch P, Schroeder RJ, Habermeyer P. Postoperative subscapularis muscle insufficiency after primary and revision open shoulder stabilization. *Am J Sports Med.* 2006;34(10):1586–93. <https://doi.org/10.1177/0363546506288852>.
31. Schroeder RJ, Scheibel M, Tsynman A, Magosch P, Habermeyer P. Magnetic resonance analysis of the subscapularis muscle after open anterior shoulder stabilization. *Rofo.* 2006;178(7):706–12. <https://doi.org/10.1055/s-2006-926684>.
32. Sherman SL, Lyman S, Koulouvaris P, Willis A, Marx RG. Risk factors for readmission and revision surgery following rotator cuff repair. *Clin Orthop Relat Res.* 2008;466(3):608–13. <https://doi.org/10.1007/s11999-008-0116-8>.
33. Slabaugh MA, Friel NA, Karas V, Romeo AA, Verma NN, Cole BJ. Interobserver and intraobserver reliability of the Goutallier classification using magnetic resonance imaging: proposal of a simplified classification system to increase reliability. *Am J Sports Med.* 2012;40(8):1728–34. <https://doi.org/10.1177/0363546512452714>.
34. Thomazeau H, Boukobza E, Morcet N, Chaperon J, Langlais F. Prediction of rotator cuff repair results by magnetic resonance imaging. *Clin Orthop Relat Res.* 1997;344:275–83.
35. Thomazeau H, Rolland Y, Lucas C, Duval JM, Langlais F. Atrophy of the supraspinatus belly. Assessment by MRI in 55 patients with rotator cuff pathology. *Acta Orthop Scand.* 1996;67(3):264–8. <https://doi.org/10.3109/17453679608994685>.
36. Walch G, Nove-Josserand L, Boileau P, Levigne C. Subluxations and dislocations of the tendon of the long head of the biceps. *J Shoulder Elb Surg.* 1998;7(2):100–8. [https://doi.org/10.1016/S1058-2746\(98\)90218-X](https://doi.org/10.1016/S1058-2746(98)90218-X).
37. Warner JJ, Higgins L, Parsons IMT, Dowdy P. Diagnosis and treatment of anterosuperior rotator cuff tears. *J Shoulder Elbow Surg.* 2001;10:37–46.
38. Zanetti M, Gerber C, Hodler J. Quantitative assessment of the muscles of the rotator cuff with magnetic resonance imaging. *Investig Radiol.* 1998;33(3): 163–70. <https://doi.org/10.1097/00004424-199803000-00006>.

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