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ORIGINAL PAPER

Rotator cuff tear characteristics: how comparable are the pre-operative MRI findings with intra-operative measurements following debridement during arthroscopic repair?

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Abstract

Purpose Magnetic resonance (MRI) is a valuable imaging method which can detect pre-operative rotator cuff tear characteristics accurately. However, tendon degeneration almost always necessitates a certain amount of debridement during arthroscopic repair, which alters tear size and shape. The aim of this study is to question the accuracy of the pre-operative tear size and classification in MRI and its relation to the tear size and type of the debrided tendon during arthroscopic repair.

Methods A retrospective survey was performed to identify shoulders that underwent arthroscopic rotator cuff repair. Rotator cuff tears with an adequate history, a standard pre-operative MRI, and available surgical video records with appropriate measurements were included. Traumatic tears, calcifying tendonitis, isolated subscapularis tears, and revisions were excluded. In total, 60 shoulders' (30 males, 27 females; age 55.2 [35–73]) preoperative MRIs and intra-operative measurements were analyzed by orthopaedic surgeons and radiologists. Tear width and type were recorded. Interdisciplinary and intradisciplinary consistency of measurements and classifications were analyzed. Tear width measured on pre-operative MRI and after debridement were compared.

Results Average measured tear width was 9 ± 5.3 mm on MRI. Surgeons (9.98 ± 4.6 mm) measured tears significantly wider than radiologists (7.71 ± 6.6 mm). Radiologists (ICC, 0.930; CI, 0.883–0.959) showed superior consistency on MRI than surgeons (CI, 0.502; CI, 0.105–0.726). Average tear width measured after debridement (29.3 ± 9.6 mm) was significantly higher than tear width measured on pre-operative MRI ($p < 0.0001$). None of the researchers assessing tear type on pre-operative MRI showed agreement with surgeons assessing intra-operative data.

Conclusions There were significant differences between the pre-operative tear characteristics on MRI and the debrided tendon characteristics during surgery, which were extensive enough to classify the tear in a different category.

The study was performed in Koc University, School of Medicine

Level 2 Diagnostic Study

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Keywords Rotator cuff · Shoulder arthroscopy · Rotator cuff tear · Tendon debridement · Magnetic resonance imaging · Tear measurement

Introduction

Magnetic resonance imaging (MRI) plays an important role in the evaluation of rotator cuff pathology and its prognosis. MRI is not only beneficial for characterizing the tear size and pattern, but also for detecting the prognostic structural changes such as fatty degeneration and muscle atrophy. These benefits together with the increasing accessibility of a high-quality MRI render this diagnostic tool essential in pre-operative planning [1–4].

Defining the rotator tear size and type is the critical initial step in surgical planning. Information that the MRI provides regarding the biceps tendon pathology, rotator cuff tear size, and type is often used to determine the surgical method (single row, double row, side-to-side, diamond back, layered repair, and other complex repairs) [5]. Tear characteristics are directly related to prognosis. It is easier to repair a small crescent-type tear and achieve a good outcome with a simple technique. However, retracted, U-shaped wide tears are considered to have a bad prognosis and require advanced surgical methods for successful healing [1, 6, 7]. Furthermore, MRI is also valuable to identify patients with irreparable tears and proceed with salvage techniques [8, 9]. Hence, size and type of the tear are foundations for most of the classifications [10, 11].

Many studies compared the MRI with arthroscopic measurements and concluded that it was a reliable tool [12]. Although MRI accurately defines the shape of the tear, morphology of the tear is almost always altered during surgery. Debridement of the lateral edge of the cuff is usually a routine part of the intervention and is considered beneficial for the healing process [13]. Naturally, after debridement, cuff tear enlarges, which can be extensive enough to alter the pre-operative tear type. The change in tear size and type and its relation with the pre-operative information that the MRI provides have not been studied previously.

We hypothesized that the tear size and tear type that MRI provides pre-operatively were not consistent with the tear characteristics of the debrided tendon during arthroscopic repair. Our aim was to clarify the changes in tear characteristics, which played a fundamental role in all rotator cuff tear classifications. For this purpose, we have retrospectively compared patients' pre-operative MRI measurements with our intra-operative findings.

Patients and methods

Following the institutional review board approval, a retrospective survey of 290 consecutive rotator cuff (RC) repair surgeries at a single centre in a five year period was performed. To standardize the surgical technique, only senior surgeon's patient data was used. A detailed analysis of patients with cuff tear symptoms for more than three months, who had MRIs that were obtained in the same centre and who had intra-operative real-time video records with appropriate measurements, was performed. Open repairs, partial thickness RC tears, shoulders with acute traumatic RC tears, cases with accompanying calcifying tendonitis, and isolated subscapularis tears were excluded (Table 1). After analysis, 60 shoulders of 57 patients (30 males, 27 females) with an average age of 55.2 years (35–73 years old) were enrolled to the study. Six researchers, who were blind to each other's assessments and patients' clinical information, were distributed into three groups: (1) two orthopaedic surgeons assessing measurements in video records, (2) two orthopaedic surgeons measuring MRIs, and (3) two radiologists measuring MRIs.

MRI assessment

MRI images were obtained in a standard fashion with a 3T system (Skyra; Siemens Medical Solutions, Erlangen, Germany) and a dedicated shoulder array coil. Patients underwent imaging with their arm in a neutral position. T1-weighted spin-echo images (TR/TE 420/11) were obtained in the sagittal oblique plane (parallel to the glenohumeral joint). Fat-saturated, PD-T2-weighted images (TR/TE 2300–2800/45–46) were obtained in the sagittal plane, coronal oblique plane (perpendicular to the glenohumeral joint), and axial plane. The parameters for all sequences were as follows: section thickness was 3 mm, with an intersection gap of 0.4 mm; matrix size was 384 × 288; and field of view ranged from 14 to 18 cm.

The MRI images were reviewed retrospectively on a picture archiving and communication system workstation (Centricity; GE Healthcare, Milwaukee, WI, USA) by two radiologists (with 10 and 11 years of musculoskeletal radiology experience) and two orthopaedic surgeons (with 7 and 8 years of arthroscopy experience), independently. The readers were blind to the results of the arthroscopic and any other clinical, pathological, or radiological findings of the patients. In each patient, tear width was measured in sagittal planes of the PD-T2-weighted images (MR/tw) and classified according to the tear shape using Davidson and Burkhart's method [14]. Tear types were classified as crescent (type 1), longitudinal (L or U) (type 2), massive contracted (type 3), and cuff tear arthropathy (type 4). Matched coronal plane slices were used to verify that the tear width measurement

Table 1 Inclusion and exclusion criteria of the study

Inclusion criteria	Exclusion criteria
• Adequate documentation of the surgery and tear size	• Lack of tear size measurements in patient reports
• Adequate video records of the surgery	• Lack of reliable measurements in video records
• Available preoperative MRI obtained within 3 months before surgery	• Partial thickness RC tears
Obtained from the same device in the institution	• RC surgery performed for
• Arthroscopic supraspinatus and/or infraspinatus repair	Calcifying tendinitis
• Degenerative tears without any traumatic tear history	Acute traumatic tears
	Subscapularis tears
	• Cuff tear arthropathy (grade 4 in Davidson and Burkhart's method [9])

was on the tendon footprint. Complete detachment of the tendon from the footprint was the prerequisite for being considered as a complete tear and included for measurement. If the tendon has any continuity on consecutive slices without a gap, it was considered as an attached tendon segment, even the MRI signal was more hyperintense compared to the healthy tendon segment (Fig. 1).

Intra-operative assessment

Digital real-time video recordings of the performed arthroscopies were reviewed by two orthopaedic surgeons independently (7 and 12 years of shoulder arthroscopy experience). The same camera, documentation system, and display were used during the surgeries (Karl Storz, Tuttlingen, Germany). Surgery and measurements were performed on beach chair position without traction. The readers were blind to the MRI and any other clinical and pathologic findings of patients. Following the debridement of the tendon, a probe with laser marks (10-mm first marking with 5-mm increments) was routinely used for measuring the anteroposterior width of the tear, either from posterior or anterior portal (Arthrex, Naples, FL, USA) (Fig. 2). Tear width measurements were recorded from the most anterior attachment to the most posterior corner, as a straight line passing from the footprint. In cases with rotator interval release or massive tears with rotator interval detachment, bicipital sulcus was used as the most anterior point. This straight line also represented the sagittal plane which was used for pre-operative measurement on the MRI. The data were used as the actual tear width of the repaired tendon (VR/w: video record width). This width will also be defined as "debrided tendon width" in the following sections.

Intra-operative debridement and measurements were performed by the senior surgeon. The amount of debridement had been decided intra-operatively, taking the tendon quality and fibril arrangement into account. Although subjective in nature, to standardize the process, a non-aggressive shaver was used in all circumstances and tear margins were removed until the healthy fibril arrangement was visualized (Fig. 3). This was the standard approach in all of our surgery for more than a decade and was not related directly to the study method.

Before initiation of the study, agreement on measurement methods was reached by all researchers on a test patient, who was not included in the study. As the methods used were previously published and not developed for this study, a pilot study for reliability and validity was not performed. In the first part of the study, interobserver agreement for the MRI measurements of orthopaedic surgeons and radiologists and video record measurements of orthopaedic surgeons were analyzed. Subsequently, agreement for the MRI measurements of radiologists and orthopaedic surgeons was compared. Finally,

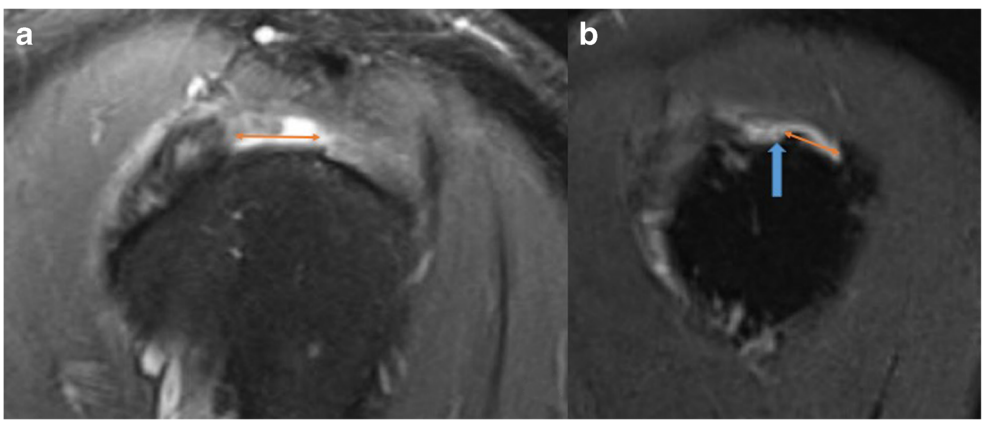

Fig. 1 Tear width measurement in two different patients. To be considered as a complete tear, tendon has to be detached from the footprint completely (**a**). If the tendon has any amount of continuity on all consecutive slices without a gap, it was considered as an attached tendon segment, even the MRI signal is hyperintense compared to the healthy tendon segment (**b**) (blue arrow, attached tendon; orange arrow segment, tear)

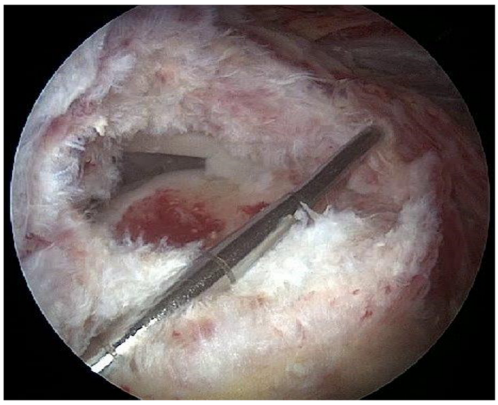

Fig. 2 Measurement of the tear width (VR/tw) during arthroscopy. A straight probe with laser markings (5-mm increments) was used

comparison of MRI data and debrided tendon characteristics, which was the main objective of the study, was performed.

Statistical analyses

Statistical analyses were performed using IBM SPSS Statistics, Version 23.0 (IBM Corp, Armonk, NY). The Shapiro-Wilk test was used to assess normality of the data. In addition to descriptive statistical methods (average and standard deviation), intraclass correlation coefficient (for the determination of the consistency of quantitative data like tear width), the Wilcoxon Signed Rank test (for the comparison of the same measurements in different groups), and chi-square (for the comparison of categorical variables like tear type) were used. The results were evaluated according to a $p < 0.05$ significance level and 95% confidence interval.

Results

Average duration of the symptoms was 11.2 months (4–18). Both shoulders were affected in three patients. Acromions were classified as Bigliani type 1 in 17, type 2 in 25, and type 3 in 18 patients [15]. Rotator cuff repair was successfully completed in all patients. Acromioplasty was performed in 46 patients. Fourteen patients also underwent arthroscopic distal clavicle resection. In 18 patients, biceps tenodesis or tenotomy was made. Transosseous equivalent arthroscopic knotless double-row suture bridge technique was the repair technique of choice in all patients.

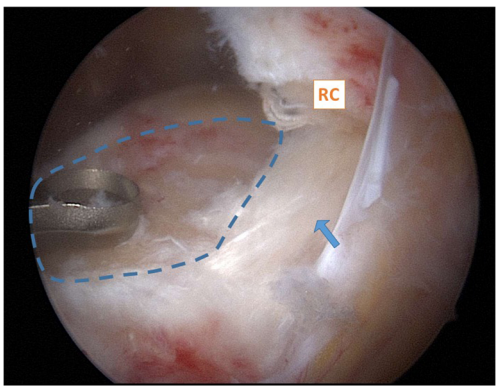

Fig. 3 Preparation of rotator cuff and footprint. Debridement of the degenerated tendon and visualization of the healthy fibril orientation are vital for a successful healing (dotted, footprint; arrow, debrided tendon; RC, rotator cuff)

Tear width measurements

Tear widths on MRI and video records, agreement in each group (intraclass correlation, ICC), and 95% confidence intervals (CI) are summarized in Table 2. The pre-operative tear width measured by the surgeons (average 9.98 ± 4.6 mm) was significantly larger than the pre-operative tear width measured by the radiologists (7.71 ± 6.6 mm) ($p < 0.0001$). The pre-operative average tear width (MR/tw) was 9 ± 5.3 mm for all researchers. Average tear width measured after debridement during the arthroscopy (29.3 ± 9.6 mm) was significantly larger than tear width measured on pre-operative MRI ($p < 0.0001$).

Tear classifications

There was no agreement on the tear classification among orthopaedic surgeons in video assessment ($_K = 0.118$, $p = 0.180$) and MRI assessment ($_K = 0.013$, $p = 0.284$). Radiologists showed high agreement on tear type ($_K = 0.769$, $p < 0.0001$). None of the researchers assessing tear type on pre-operative MRI showed agreement with surgeons assessing intra-operative data ($p > 0.1$ for all pairs).

Discussion

In this retrospective analysis, we have evaluated the accuracy of pre-operative measurements performed by orthopaedic surgeons and radiologists, and their consistency with intra-operative findings following rotator cuff debridement. The main purpose was to quantify the difference between the tear type and the tear width sizes measured in the pre-operative MRI and during arthroscopy after tendon debridement. We have observed that the average tear width after debridement was 29.34 ± 9.6 mm, whereas it was measured as low as 9 ± 5.3 mm in pre-operative MRI. Furthermore, we did not observe a consistency among researchers for the tear classifications based on MRI and intra-operative findings. These results supported our hypothesis that the tendon debridement can be extensive enough to alter not only the extent of the tear but also the type attributed.

MRI is considered a reliable diagnostic tool in detecting and quantifying rotator cuff tears [12, 16, 17]. Consistency

Table 2 Average tear width measurements of the researchers and interobserver agreement in each group. MRI measurements of surgeons showed the lowest agreement, where radiologists had the highest agreement (ICC, intraclass correlation coefficient; CI, 95% confidence interval)

	Measured data (mm)	First researcher	Second researcher	ICC	CI	*p*
Between surgeons (video)	VR/w	26.9 ± 9.7	29.9 ± 9.8	0.746	0.583–0.851	.000
Between surgeons (MRI)	MR/tw	8.23 ± 5.2	11.71 ± 5	0.502	0.105–0.726	.000
Between radiologists (MRI)	MR/tw	7.92 ± 7.1	7.47 ± 6.5	0.930	0.883–0.959	.000
Between surgeons and radiologists (MRI)	MR/tw	9.98 ± 4.6	7.71 ± 6.6	0.651	0.411–0.795	.000

of the MRI findings had been tested previously against both ultrasonographic and arthroscopic findings. Teefey et al. published a level I diagnostic study in 2004, one of the most cited papers in this topic, comparing the ultrasound and MRI with the arthroscopic findings [12]. They concluded that the MRI successfully predicted the retraction and width of the tear with an accuracy of 63% and 80%, respectively. However, they tested the accuracy of MRI against the tear size before tendon debridement. Dwyer et al. also addressed the strength of pre-operative MRI on predicting the reparability of the tear. Similar to several studies, they also did not consider the effect of debridement [18]. Bryant et al. draw attention to the difference in size by concluding that the ultrasound and MRI underestimated the tear size by 33% and 30%, respectively [17]. Although the authors did not take debridement into account, this study was the first to mention the mismatch.

As a standard approach for more than a decade, our decision on the extend of debridement had been based on the tendon quality observed during surgery. Fibril arrangement of the tendon-bone attachment is monitored macroscopically, as a non-aggressive shaver removes tear margin. Adequate tendon debridement and footprint preparation to increase the vascularity of this area have been shown to facilitate the healing process and have become crucial parts of the rotator cuff repair surgery [19, 20]. Degeneration predominantly effects the most lateral edge of the tendon, which is responsible for the healing, and alters biochemical environment with structural changes. This is another reason why debridement plays an important role in treatment [21]. Occasionally, tendon mobilization requires some advanced techniques, such as detaching anterior portion of supraspinatus from rotator interval or lateral detachment of infraspinatus from footprint when there is delamination. These also have a role on tear enlargement before repair. Currently, there are no published methods available to standardize the tendon debridement extent with objective criteria and studies on this topic inevitably have a subjective aspect. To limit the disparities that the preferences of various surgeons' for debridement would have caused, we have included patients of a single surgeon who was specialized on shoulder arthroscopy and surgery performed in a single institution. Furthermore, traumatic injuries which would require less debridement or rotator cuff injuries with accompanying conditions such as calcifying tendinitis were excluded. Rotator cuff tears which were enrolled in this study consisted of atraumatic degenerative tears without cuff tear arthropathy. In addition to patient selection, utilization of the same MRI device, same arthroscopy and recording equipment, and same reading terminal were other efforts for standardization.

Reliability of MRI in interpretation of rotator cuff tendon problems has been studied by many researchers since its widespread use in daily practice. In a recent study, Jain et al. reported a kappa value of 0.20 with 53% agreement in reported transverse tear size among a trained physiatrist, an orthopaedic surgeon, and a musculoskeletal radiologist [22]. In our study, we have observed that radiologists (ICC, 0.930; 95% CI, 0.883–0.959) showed higher agreement on MRI data when compared with surgeons (ICC, 0.502; 95% CI, 0.105–0.726). This finding was no surprising, considering that the standardization in reporting was a routine part of a radiologist's training. On the other hand, surgeons measured tear width significantly larger when compared to radiologists, which could be related to the expected tear enlargement during arthroscopy and the surgeon's tendency to ignore the non-viable tendon (hyperintense part) edge. Clarifying the reasons behind this difference was beyond this studies scope; however, significant difference pointed the diversity in interpretation. This study was not designed to question the reliability of a diagnostic tool or the classification system and our results should not be used against MRI or the preferred tear classification.

In our study, we have evaluated the tear size mismatch caused by debridement and concluded that the tendon repair was performed for tears more than three times wider than expected tear size measured on pre-operative MRI. This is the first study that directly questions the difference between the measured tear width on preoperative MRI and the tear width after debridement during arthroscopic repair. Although

this difference was not quantified before, practically debridement is often performed, and tear enlargement is an expected part of the surgery.

Another purpose of this study was to question if the performed debridement would change the pre-operatively attributed tear type. We have observed that none of the surgeons assessing intra-operative findings showed consistency with other researchers assessing MRI. It was not possible to clarify the reason of this inconsistency with the current methods of the study: either the type became worse (increase) due to debridement or the researchers' decisions were just inconsistent. We have also observed that surgeons did not show agreement on tear shape during surgery. Classification method used in this study relies on measurements and tear shapes. Lack of intra-operative consistency suggested that classification method should be limited to pre-operative MRI evaluation, instead of using as an intra-operative tool.

Rotator cuff footprint is not a straight line but an area, and tendon attachment is curved (Figs. 2 and 3). However, our intra-operative tool was a straight device (probe). MRI always provides straight planes (slices) and all measurements were performed as straight lines. Therefore, for an accurate comparison, a straight measurement passing from the footprint was necessary. Curved intra-operative measurements would not be comparable to MRI measurements.

Lack of measurement on the amount of tendon retraction can be considered as a limitation for our intra-operative data collection. Although it was possible to obtain the extent of retraction from pre-operative MRI, we would not be able to compare it with any intra-operative finding. Therefore, amount of retraction on coronal plane was not included in our study. Another limitation was the subjective nature of debridement decision. As it was discussed before, there are no methods to quantify the amount of necessary debridement currently. We believe that a single surgeon—single institution with adequate standardization of patients and meticulous data acquisition—minimized possible misleading effects on the results.

Conclusion

The main purpose of this study was to draw attention to the tear size enlargement and changes in the tear type that debridement creates. As our results indicate, there was a significant difference between the tear size measured on MRI and the actual rotator cuff tear after debridement. Tear types assessments among surgeons and radiologist were not consistent. With these findings, it was possible to conclude that, surgeons often deal with more extensive tears during surgery when compared with pre-operative MRI. Therefore, pre-operative planning should take these differences into account, as well as the possibility of change in tear type.

Author contribution All authors declare that they were involved in designing the study, collecting the data, analyzing the data, writing the manuscript, and confirming the accuracy of the data and the analyses.

Compliance with ethical standards

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

Institutional review board approval The study protocol was approved by the Medical Ethics Committee of the Koç University, Istanbul, Turkey (2015.149.IRB2.054).

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