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S. Waldt
M. Bruegel
D. Mueller
K. Holzapfel
A. B. Imhoff
E. J. Rummeny
K. Woertler

Rotator cuff tears: assessment with MR arthrography in 275 patients with arthroscopic correlation

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S. Waldt (✉) · M. Bruegel ·
D. Mueller · K. Holzapfel ·
E. J. Rummeny · K. Woertler
Department of Radiology,
Technische Universität München,
Klinikum rechts der Isar,
Ismaninger Strasse 22,
D-81675 Munich, Germany
e-mail: waldt@roe.med.tum.de
Tel.: +49-89-41402696
Fax: +49-89-41404834

A. B. Imhoff
Department of Sports Orthopedics,
Technische Universität München,
Klinikum, Rechts der Isar,
Conollystr 32,
D-80809 Munich, Germany

Abstract We assessed the diagnostic performance of magnetic resonance (MR) arthrography in the diagnosis of articular-sided partial-thickness and full-thickness rotator cuff tears in a large symptomatic population. MR arthrograms obtained in 275 patients including a study group of 139 patients with rotator cuff tears proved by arthroscopy and a control group of 136 patients with arthroscopically intact rotator cuff tendons were reviewed in random order. MR imaging was performed on a 1.0 T system (Magnetom Expert, Siemens). MR arthrograms were analyzed by two radiologists in consensus for articular-sided partial-thickness and full-thickness tears of the supraspinatus, infraspinatus, and subscapularis tendons. At arthroscopy, 197 rotator cuff tears were diagnosed, including 105 partial-thickness (93 supraspinatus, nine infraspinatus, three subscapularis) and 92 full-thickness (43 supraspinatus, 20 infraspinatus, 29 subscapularis) tendon tears. For full-thickness tears, sensitivity, specificity, and accuracy were 96%, 99%, and 98%, respectively, and for partial tears 80%, 97%, and 95%, respectively. False negative and positive assessments in the diagnosis of articular-sided partial-thickness tears were predominantly [78% (35/45)] observed with small articular-sided (Ellman grade1) tendon tears. MR arthrography is highly accurate in the diagnosis of full-thickness rotator cuff tears and is accurate in the diagnosis of articular-sided partial-thickness tears. Limitations in the diagnosis of partial-thickness tears are mainly restricted to small articular-sided tears (Ellman grade 1) due to difficulties in differentiation between fiber tearing, tendinitis, synovitic changes, and superficial fraying at tendon margins.

Keywords Shoulder arthrography · MRI shoulder · Rotator cuff tears · Magnetic resonance (MR)

Introduction

Rotator cuff disease is the most common cause of shoulder pain and appears to be the result of many contributing factors [1, 2]. Beside age-related intratendinous changes, subacromial impingement, shoulder instability, internal impingement, and acute or repetitive traumatic events represent extrinsic factors causing rotator cuff disease [1, 3–5]. Currently, conventional magnetic resonance (MR) imaging and ultrasonography (US) are regarded as the methods of choice for noninvasive diagnosis of rotator cuff lesions. Both imaging modalities proved to be highly accurate in the detection of full-thickness rotator cuff tears [6–11]. However, most studies on conventional MR imaging and US suggested considerable limitations in the diagnosis of partial-thickness tears [6–9, 12]. Since partial-thickness tears have increasingly been regarded as a source of surgically treatable shoulder pain, identification of even small tendon tears has recently become more important. Previous studies indicate that arthroscopic debridement of partial-thickness tears results in clinical improvement in a large percentage of athletes with refractory shoulder pain

[3, 13, 14]. In previous studies, direct MR arthrography showed significantly higher sensitivity in the detection of partial-thickness tears compared with conventional MR imaging and US techniques [8, 15]. Since results on the performance of direct MR arthrography in the diagnosis of partial-thickness tendon tears were predominantly obtained in small series, further investigations are required to verify and analyze limitations of this imaging modality [8, 15–17]. The purpose of our study was to assess the diagnostic performance of MR arthrography in the diagnosis of articular-sided partial-thickness and full-thickness rotator cuff tears in a large symptomatic population.

Materials and methods

Patients and control groups

Surgical records of patients who had been referred to the Department of Sports Orthopedics for evaluation of shoulder pain between May 1996 and October 2004 were reviewed in order to select patients for this study. Altogether, MR arthrograms of 275 patients (187 male and 88 female; age range 15–73 years; mean age 38.9 years) were evaluated retrospectively. The study group included 139 MR arthrograms obtained in 139 patients with arthroscopically proven rotator cuff tears, and the control group comprised 136 MR arthrograms obtained in 136 patients with an intact rotator cuff at arthroscopy. Inclusion criteria for the study group were: (a) a partial- or full-thickness rotator cuff tear (with information on tear depth, size, and location) as stated in the surgical record, (b) preoperative MR arthrography performed at our institution according to a standardized protocol, (c) the analyzing radiologist's unfamiliarity with the case, and (d) no history of previous shoulder surgery. All patients who met these criteria were included in this study. Included were 139 patients with a total of 197 rotator cuff tendon tears: 92 full-thickness (43 supraspinatus, 20 infraspinatus, 29 subscapularis) and 105 partial-thickness (93 supraspinatus, nine infraspinatus, three subscapularis) tears. Ninety-six patients had one-tendon tear, 34 patients had two-tendon tears, and 11 patients had three-tendon tears.

The control group comprised 136 patients who were recruited on the basis of the following criteria: (a) description of a rotator cuff without pathological findings as stated in the surgical records, (b) preoperative MR arthrography performed at our institution according to a standardized protocol, (c) the analyzing radiologist's unfamiliarity with the case, and (d) no history of previous shoulder surgery. Arthroscopic diagnoses of the control group comprised 74 patients with anteroinferior or posterior labral injuries, 34 patients with superior labral anterior-posterior (SLAP) injuries, five with coexisting SLAP and anteroinferior labral injuries, and 23 without any pathological findings.

Study group patients (93 male and 46 female; mean age 30.7 years) were significantly older (*t* test, $P<0.01$, level of statistical significance $P<0.05$) than patients of the control group (94 male and 42 female; mean age 41 years). There was no relevant difference in gender (χ^2 test, $P=0.792$, level of statistical significance $P<0.05$) between study and control group patients. All arthroscopies were performed by either one of two experienced orthopedic surgeons who knew the results of the MR examination. Partial-thickness tears were documented by measuring the depth of the tear in millimeters. In subscapularis tears, the craniocaudal extension of tears at the lesser tuberosity was documented. The average time interval between MR arthrography and shoulder arthroscopy was 47 (range, 1–136) days.

Imaging and Image Interpretation

Fluoroscopically guided injection of 12–18 ml of diluted gadopentetate dimeglumine (Magnevist; Schering, Berlin, Germany) with a concentration of 2.5 mmol/l was performed via an anterior approach. MR imaging was commenced within 15 min after contrast injection with a 1.0-T system (Magnetom Expert; Siemens, Erlangen, Germany) and a dedicated phased array shoulder coil (Siemens). Patients underwent imaging with the arm in neutral position. T1-weighted spin-echo images (TR range/TE range, 500–700/14–20) were obtained in the transverse plane, sagittal oblique plane (parallel to the glenohumeral joint), and coronal oblique plane (perpendicular to the glenohumeral joint space). T2-weighted fast spin-echo (FSE) images (3,000–4,200/90–120) were obtained in the coronal oblique plane. Parameters for all sequences were a section thickness of 3 mm with a 0.1-mm intersection gap, matrix size of 256×192, and field of view (FOV) 14–16 cm. For image analysis, all MR arthrograms were placed in random order. Examinations were analyzed by two experienced musculoskeletal radiologists in consensus who were blinded to clinical and arthroscopic findings. Articular-sided partial-thickness tears were categorized with a modified Ellman classification system based upon tear depth (grade 1, <3 mm; grade2, 3–6 mm; grade 3, >6 mm) (Fig. 1) [18]. Imaging criteria of articular-sided partial-thickness tears were disruption of the smooth undersurface of the tendon with accumulation of paramagnetic contrast within the substance of the tendon and no evidence of paramagnetic contrast present within the subacromial bursa [8, 16, 17]. Because there was no arthroscopic correlation in all patients with bursa-sided and intrasubstance partial-thickness tears, these tears were not further evaluated. Criteria of complete tears were extension of paramagnetic contrast through the entire thickness of the rotator cuff and/or presence of contrast medium in the subacromial bursa [8, 16, 17]. For more precise assessment of subscapularis tendon tears, these tears were categorized with an additional classification system [19]. A grade 1 lesion

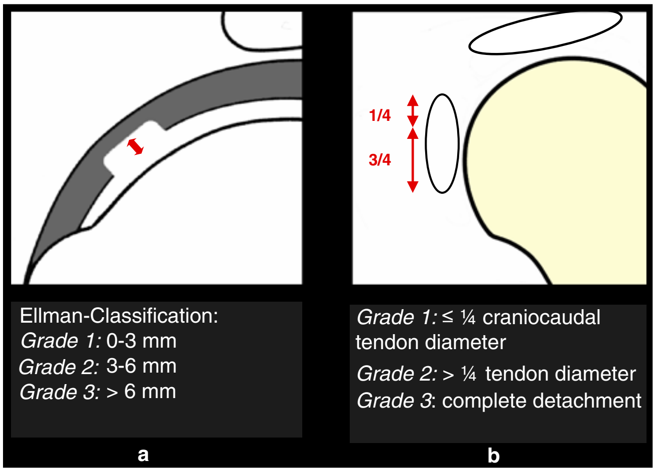

Fig. 1 Schematic illustration of the classification systems used for categorization of **a** articular-sided partial-thickness rotator cuff tears and **b** subscapularis tendon tears

was defined as a lesion of the upper margin of the tendon (less than one quarter of the craniocaudal diameter of the tendon), a grade two lesion as a tear with an extension of more than one quarter of the diameter of the tendon, and a grade 3 lesion complete detachment of the subscapularis tendon (Fig. 1).

Statistical analysis

With arthroscopy as the standard of reference, sensitivities, specificities, accuracy, negative and positive predictive values, and corresponding 95% confidence intervals were calculated in the overall detection of rotator cuff tears and in the detection of full- and partial-thickness tears. All statistical computations were performed with the SPSS 12.0.1 software package (SPSS, Chicago, IL, USA).

Results

Arthroscopy

Our results are summarized in Tables 1, 2 and 3. At arthroscopy, 197 rotator cuff tears in 139 patients were diagnosed, including 105 partial- and 92 full-thickness tendon tears. Distribution of tears is presented in Table 1. Of 105 articular-sided partial-thickness tears of the supraspinatus, infraspinatus and subscapularis tendon, 47 were arthroscopically categorized as grade 1 (Fig. 2); 42 as grade 2 (Fig. 3); and 16 as grade 3 (Fig. 4) tears according to the modified Ellman classification system. Subscapularis tears were additionally categorized as follows: 12 grade 1 (upper margin of the subscapularis tendon at the lesser tuberosity), including three articular-sided partial-thickness tears; 12 grade 2 (tear of more than one quarter of the craniocaudal diameter of the tendon); in three cases, the tendon was completely detached from the lesser tuberosity.

Synovitis in the Codman region, tendinitis, or degenerative fraying of the supra- and/or infraspinatus tendon without evidence of a tear of the rotator cuff tendons was documented in 47 surgical records. In 15 of 45 patients (athletes) with shoulder instability and secondary posterosuperior impingement, the diagnosis of partial-thickness tears was established. In seven of these patients, the partial-thickness tears were localized in the posterior portion of the supraspinatus tendon and/or the anterior portion of the infraspinatus tendon (Fig. 5).

Table 1 Distribution of articular-sided partial-thickness and full-thickness rotator cuff tears at arthroscopy

	Supraspinatus	Infraspinatus	Subscapularis
Articular-sided partial-thickness rotator cuff tears (n=105)	93	9	3
Full-thickness rotator cuff tears (n=92)	43	20	29

Table 2 Efficacy of magnetic resonance (MR) arthrography in the diagnosis of articular-sided partial-thickness and full-thickness rotator cuff tears

MR arthrography	Full-thickness tears	Articular sided partial-thickness tears
No. of true-positive cases	88	84
No. of true-negative cases	723	697
No. of false-positive cases	4	24
No. of false negative cases	10	21
Sensitivity	96% (88/92)	80% (84/105)
95% CI	0.92–1	0.72–0.88
Specificity	99% (723/733)	97% (696/720)
95% CI	0.98–1	0.96–0.98
Positive predictive value	90% (88/98)	78% (84/108)
95% CI	0.86–0–96	0.71–0.86
Negative predictive value	99% (723/727)	97% (696/717)
95% CI	0.98–1	0.96–0.98
Accuracy	98% (811/825)	95% (780/825)

Numbers of cases refer to the numbers of evaluated rotator cuff tendons

MR arthrography

Considering partial- and full-thickness tears of the rotator cuff together, MR arthrography had an overall sensitivity of 91% (179 of 197 cases; CI: 0.87–0.95), specificity of 95% (596 of 628 cases; CI: 0.93–0.97), accuracy of 94% (793 of 825 cases), negative predictive value of 97% (596 of 614 cases; CI: 0.96–0.98), and positive predictive value of 85%

Table 3 Correlation between findings at magnetic resonance (MR) arthrography and arthroscopy for articular-sided partial-thickness and full thickness tears of the supra- and infraspinatus tendon

Arthroscopy		MR arthrography				
		No rotator cuff tear (*n*=381)	Partial-thickness rotator cuff tear			Full-thickness tear (*n*=67)
			Grade 1 (*n*=49)	Grade 2 (*n*=38)	Grade 3 (*n*=15)	
No rotator cuff tear (*n*=385)		361	17	1	1	5
Partial-thickness rotator cuff tear (*n*=102)	Grade 1 (*n*=46)	14	31	1	0	0
	Grade 2 (*n*=40)	4	1	34	1	0
	Grade 3 (*n*=16)	1	0	1	12	2
Full-thickness tear (*n*=63)		1	0	1	1	60

Numbers refer to the numbers of rotator cuff tendons

(179 of 211 cases; CI: 0.77–0.93) in the detection of rotator cuff tears. The numbers of cases refer to the number of evaluated rotator cuff tendons. Eighteen rotator cuff tears were missed at MR arthrography (false-negative findings), and in 32 cases, the diagnosis was not confirmed at surgery (false-positive findings). Results on diagnostic efficacy of MR arthrography in the diagnosis of articular-sided partial-thickness tears are presented in Table 2. In 14 of 24 false-positive findings synovitis, tendinitis, or superficial degenerative fraying of the supra- and/or infraspinatus tendons without evidence of a tear was described in the corresponding surgical reports. At MR arthrography, 17 of 24 false-positive findings were categorized as grade 1 (Fig. 6) lesions of the supra-/or infraspinatus tendons according the modified Ellman classification system.

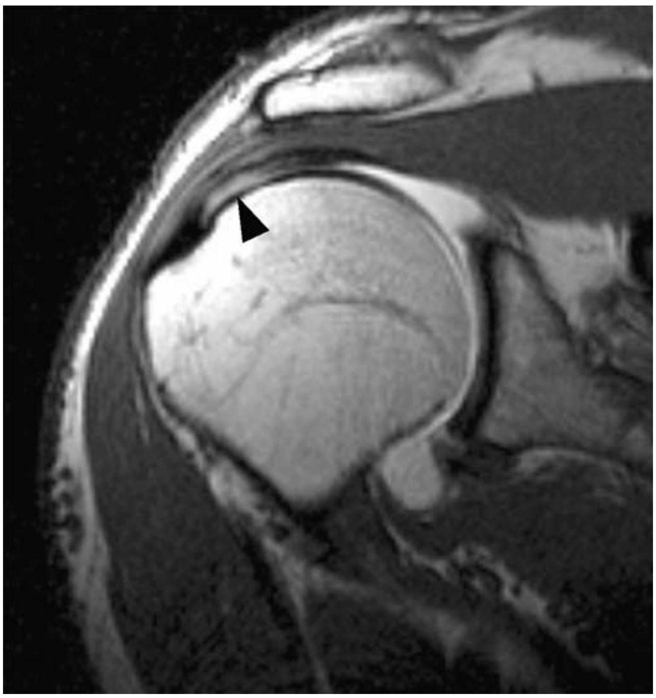

Fig. 2 Coronal oblique T1-weighted magnetic resonance (MR) arthrogram in a 36-year-old man demonstrates band-like accumulation of contrast media within the articular-sided supraspinatus tendon and loss of continuity of the tendon undersurface (*arrowhead*), correctly interpreted as grade 1 tear at image analysis

Considering full-thickness tears separately, MR arthrography proved to be highly effective. Detailed results are listed in Table 2. In eight patients with correctly depicted full-thickness tears of the supraspinatus tendon, the false-positive diagnosis of an additional full-thickness tear (five infraspinatus and three subscapularis tears) was established at MR arthrography whereas the tendons were considered to be normal at arthroscopy. In two false-positive cases where the MR arthrographic diagnosis was based on the evidence of contrast medium in the subacromial bursa, only partial-thickness tears were diagnosed at arthroscopy. The correlation between MR arthrographic and arthroscopic findings in the diagnosis of partial- and full-thickness tears of the supra-and infraspinatus tendon is shown in Table 3.

In the overall detection of subscapularis tears, there were seven false-positive findings (Fig. 7) and only two false-negative findings. Exact agreement between arthroscopic and MR arthrographic classifications regarding craniocaudal extension of subscapularis tears was present in 78% (25/32) of cases.

Discussion

Although no standardized treatment algorithm for partial-thickness rotator cuff tears in the general population exits, the current opinion is that surgical treatment in athletes should be performed at an early stage because of the unfavorable natural course of these lesions [3, 13, 14, 20]. Andrews at al. [3] achieved an 85% success rate in

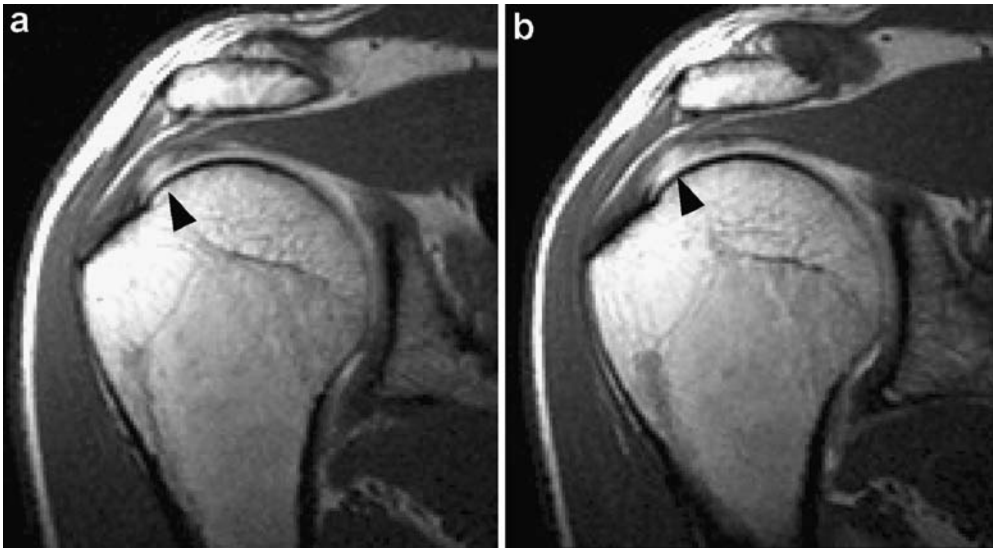

Fig. 3 Consecutive coronal oblique T1-weighted magnetic resonance (MR) arthrograms obtained in a 53-year-old man with subacromial impingement demonstrate contrast media extension into the supraspinatus tendon with a depth of 5 mm (*arrowhead*). The lesion was classified as grade 2 at MR arthrography as well as arthroscopy

returning young athletes to competitive overhead-throwing activities after simple arthroscopic debridement of articular-sided partial-thickness tears. As a result of advanced arthroscopic skills and improved understanding of the pathophysiology of rotator cuff lesions, several authors have suggested even more aggressive techniques for the treatment of partial-thickness tears in overhead athletes and recommend performing a formal repair of tears greater than 50% or 75% of tendon thickness [2, 20–22]. Since the intensity of clinical findings often does not reflect lesion severity, accurate imaging of partial-thickness tears in athletes is essential [23]. At present, MR arthrography is usually not indicated in patients with rotator cuff disease in the general population because preoperative information on the extent of partial-thickness tears does not influence the therapeutic approach in these patients [13, 24] and full-thickness tears can be sufficiently assessed with conventional MR imaging and US [6–11]. Since we included patients with outlet impingement as well as athletes with secondary internal impingement in this study, the results can be applied to both patient groups.

Fig. 4 Coronal oblique T1-weighted magnetic resonance (MR) arthrogram from a 46-year-old woman with subacromial impingement shows an extensive articular-sided partial-thickness tear of the supraspinatus tendon with a depth of more than 6 mm (*arrowhead*), correctly interpreted at MR arthrography as a grade 3 lesion. The lesion was classified as grade 3 at arthroscopy

Although conventional MR imaging and US are highly effective in the diagnosis of full-thickness tears, sensitivities for detection of partial-thickness tears with both image modalities vary widely in the literature [6–12, 25]. With sensitivity of 80% and specificity of 97%, MR arthrography was accurate in the detection of articular-sided partial-thickness tears in this study. Our results compare well with the results of a study by Meister et al. [16], who reported sensitivity of 84% and specificity of 96% in the diagnosis of articular-sided partial-thickness tears. Other authors who suggested the use of intra-articular contrast media to improve the depiction of partial-thickness tears have published sensitivities of 71% and 100% for detection of supra- and infraspinatus tears, respectively [8, 17]. These results are not directly transferable to our study since partial- and full-thickness tears were considered together in both studies, and the number of partial-thickness tears in both series was comparatively small.

Results of this study demonstrate that articular-sided Ellman grade 2 and 3 partial-thickness tears can be reliably detected and classified with MR arthrography (Table 3) whereas limitations in diagnosis of small (Ellman grade 1)

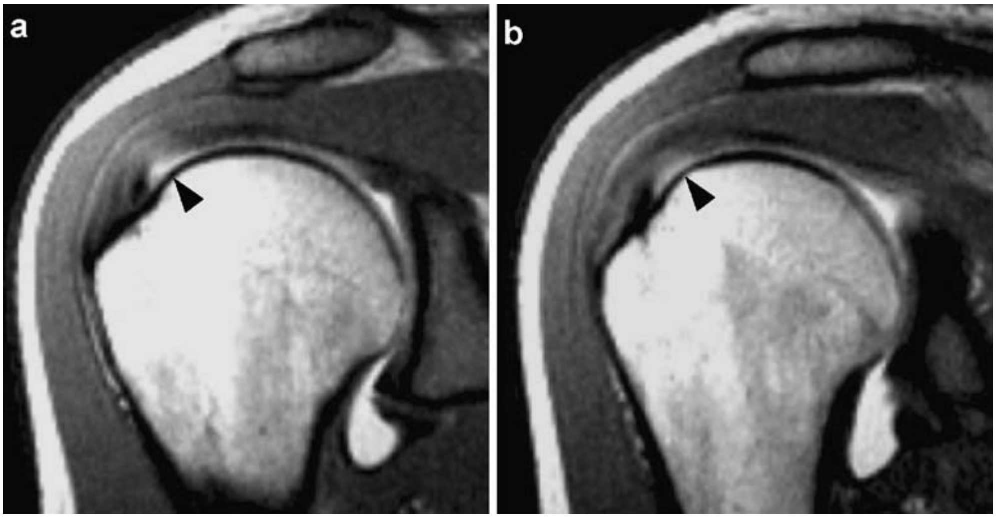

Fig. 5 Consecutive coronal oblique T1-weighted magnetic resonance (MR) arthrograms in a 23-year-old tennis player with posterosuperior impingement show a correctly detected articular-sided tear in the posterior aspect of the supraspinatus, with extension into the anterior aspect of the infraspinatus tendon (*arrowhead*)

tears were evident. Seventy-eight percent of false-positive and false-negative findings were observed with articular-sided partial-thickness tears of grade 1. Our results confirm the observation by Hodler et al. [8] that, due to limited spatial resolution, focal synovitis, tendinitis, and degenerative fraying may appear indistinguishable from small partial-thickness tears at MR arthrography. However, interpretation of subtle changes at tendon margins represents an inherent problem among orthopedic surgeons. Whereas some investigators do not establish diagnosis of a rotator cuff tear until torn tendon fibers are identifiable, others diagnose a grade 1 tear in the presence of fibrillations and superficial fraying, as suggested by the classification system by Snyder et al. [26].

As expected from previous investigations, MR arthrography proved to be highly reliable in the assessment of full-thickness tears [8, 15–17]. Only in a few cases was the extension of a correctly detected full-thickness tear into the abutted tendon overestimated. This might be explained by the circumstance that tendons of the supra- and infraspinatus muscles blend approximately 15 mm proximal to their insertion at the greater tuberosity to a confluent sheet. In anatomical studies, the tendons were not separable by blunt dissection in this location [27].

Since tears of the subscapularis tendon are most commonly located in the superior aspect of the tendon and involvement of the inferior aspect only occurs in more extensive tears, the classification system used in our study reflects the usual craniocaudal development of subscapularis tendon tears at the lesser tuberosity [19] and, therefore, appears to be more accurate in the evaluation of these tears than does the Ellman classification system. Tears of the subscapularis tendon can occur as components of large rotator cuff tears, as rotator interval lesions, or as isolated, usually traumatic, tendon tears [28–32]. In the literature, anterior extension of large supraspinatus tendon tears into the subscapularis tendon has been reported to be far more frequent than isolated traumatic tears [32]. Likewise, in our study, tears of the subscapularis tendon were predominantly found in association with tears of the supraspinatus tendon.

Analyzing our data, it has to be considered that the subscapularis tendon is more difficult to evaluate arthroscopically than the other two tendons. Tears in the superior portion of the subscapularis tendon may be overlooked at arthroscopy [31], and even if a tear has been detected, its

Fig. 6 False-positive finding in a 17-year-old woman with positive superior labral anterior-posterior (SLAP) tests. Coronal oblique T1-weighted magnetic resonance (MR) arthrogram shows circumscribed irregularity of the undersurface of the supraspinatus tendon and focal accumulation of contrast medium (*arrowhead*) interpreted as a grade 1 tear of at image analysis. The corresponding surgical record described synovitis at the undersurface of the supraspinatus tendon

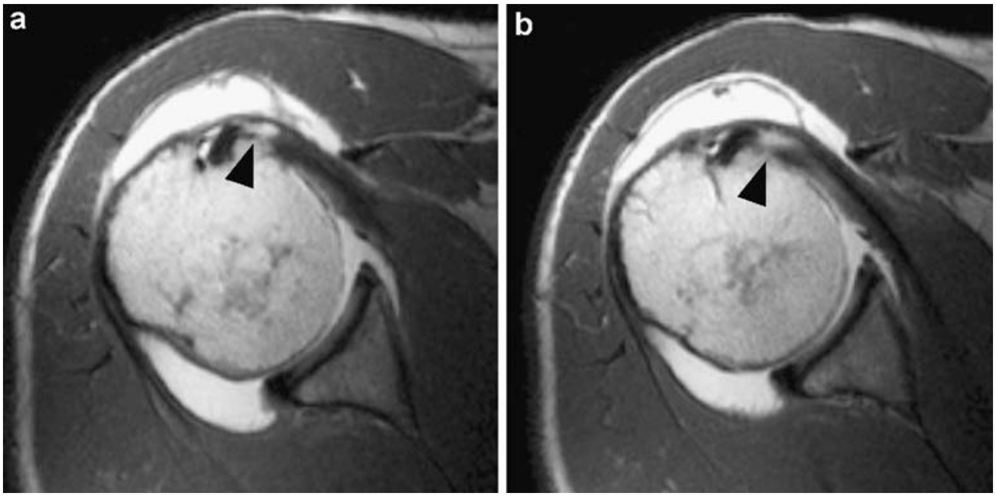

Fig. 7 False-positive finding in a 57-year-old man with subacromial impingement. Consecutive transverse T1-weighted magnetic resonance (MR) arthrograms demonstrate localized, articular-sided contrast media accumulation in the superior portion of the subscapularis tendon and slight subluxation of the long biceps tendon (*arrowheads*). At MR arthrography, the lesion was categorized as a grade 1 tear according the classification system of subscapularis tendon tears whereas the tendon was described without pathological findings at arthroscopy

extent may be underestimated because scar tissue may bridge the defect between the torn and medially retracted tendon and the lesser tuberosity [28]. This might be a possible explanation for the relatively high number of false-positive findings of subscapularis tears in this study.

Our study has several limitations. Although arthroscopy was the best standard of reference available in this study setting, it was imperfect because it is an operator-dependent method; arthroscopic findings cannot be reproduced in a retrospective analysis and, as discussed above, because of the potential to cause underestimation especially of subscapularis tendon tears. The fact that the decision to perform arthroscopy was not only based on clinical but also on imaging findings introduced a verification bias, and additionally, findings at arthroscopy could have been biased by the availability of MR reports. Interobserver variability was not assessed in this study. Our results regarding the diagnosis of partial thickness tears are only applicable to ruptures on the articular side of the rotator cuff. When dealing with bursa-sided and intrasubstance tears of the rotator cuff, the diagnostic accuracy of MR imaging is not improved by the use of intra-articular contrast media, which has to be taken into consideration when interpreting our data. A further limitation was that MR examinations were performed on a 1.0-Tesla scanner, which did achieve a lower spatial resolution compared with newer 1.5- or 3-Tesla scanners. Furthermore, all sequences were performed without fat saturation. Further improvements of the results might be expected with fat-saturated sequences, which has been indicated by previous studies [10, 17].

In conclusion, MR arthrography is a highly accurate method in the diagnosis of full-thickness rotator cuff tears and is accurate in the diagnosis of articular-sided partial-thickness tears. Limitations in the diagnosis of partial-thickness tears are mainly restricted to small articular-sided tears (Ellman grade 1). Due to the limited spatial resolution focal synovitis, tendinitis and degenerative fraying may appear indistinguishable from small, partial-thickness tears at MR arthrography.

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