

Tears at the rotator cuff footprint: Prevalence and imaging characteristics in 305 MR arthrograms of the shoulder

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Abstract

Objectives To evaluate the prevalence, imaging characteristics and anatomical distribution of tears at the rotator cuff (RC) footprint with MR arthrography (MR-A) of the shoulder.

Methods MR arthrograms obtained in 305 patients were retrospectively reviewed. Partial articular-sided supraspinatus tendon avulsions (PASTA), concealed interstitial delaminations (CID), reverse PASTA lesions and full-thickness tears (FT) at the humeral tendon insertion were depicted. Anatomical locations were determined and depths of tears were classified.

Results 112/305 patients showed RC tears, including 63 patients with 68 footprint tears. 34 PASTA lesions were detected with 20/34 involving the anterior supraspinatus (SSP) tendon and 17/34 PASTA lesions were grade I lesions. Most CID lesions (14/23) occurred at the posterior SSP and 20/23 were classified as grade I or II. 9 FT and 2 reverse PASTA lesions were found. Statistical analysis revealed no

difference in anatomical location ($p=0.903$) and no correlation with overhead sports activity ($p=0.300$) or history of trauma ($p=0.928$). There were significantly more PASTA lesions in patients <40 years of age ($p=0.029$).

Conclusions Most RC tears detected with MR-A involve the SSP footprint and are articular-sided with predominance in younger patients, but concealed lesions are not as uncommon as previously thought.

Keywords Magnetic resonance imaging · Arthrography · Shoulder joint · Tendon injuries · Rotator cuff

Introduction

Rotator cuff (RC) disease is the most common cause of shoulder pain and dysfunction in adults [1, 2]. Multiple aetiological factors have been postulated, including age-related degeneration, major trauma, repetitive microtrauma, and extrinsic or intrinsic impingement [3]. Tears occurring at the RC tendons can be classified in partial-thickness or complete tears, whereas partial-thickness tears can be located either bursal- or articular-sided. Lesions involving the midsubstance of the tendon are called interstitial or intrasubstance tears [3, 4]. The majority of RC tears occur at the tendon of the supraspinatus (SSP) muscle, especially at its anterior portion [5]. Owing to a zone of reduced vascularity within the tendon and/or increased tensile loads on the undersurface tendon fibres, it is described that, particularly in degenerative lesions, most of the tears occur in a region about 1 cm medial to the tendon insertion, the so-called “critical zone” [6–9]. In 1934, Codman described a type of tear, where tendon fibres were “torn-out” of the bony attachment at the greater tuberosity, which he termed rim-vents [10]. A more anatomical description of this type

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of tear is a partial articular-sided supraspinatus tendon avulsion (PASTA) lesion, which is virtually synonymous with rim-rent tears. These tears occur at the RC footprint, which represents the region of the humeral tendon insertion of the SSP and infraspinatus (ISP) muscles [11]. Understanding the biomechanical importance of the RC footprint is the basis for anatomical surgical repair of RC tears. This is of special clinical relevance in athletes where even small partial tears require more active and earlier intervention to enable the athlete to return to a pre-injury level of sport [12, 13]. Hence specific assessment of the RC footprint on MR images is required.

Magnetic resonance arthrography (MR-A) has been used with increasing frequency to diagnose internal derangement of the glenohumeral joint. It has proven to be superior to conventional MR imaging (MRI) and ultrasound in the assessment of full- and partial-thickness rotator cuff tears [14]. Previous studies by Tuite et al. [15] and Vinson et al. [16] have evaluated rim-rent tears using conventional MRI and MR-A of the shoulder but intrasubstance tears at the RC footprint were not mentioned in these studies. However, MR-A has the potential to safely differentiate partial-articular-sided defects from concealed intrasubstance tears [17]. If undercalled on imaging reports, concealed interstitial delamination (CID) lesions can be difficult to detect at arthroscopic shoulder surgery.

The purpose of the study was to evaluate the prevalence, imaging characteristics and anatomical distribution of RC tears involving the humeral insertion of the SSP and ISP tendon with MR-A of the shoulder.

Materials and methods

Patients

The study was performed with approval from our institutional review board. The requirement for informed consent was waived.

Between February 1, 2004 and May 31, 2009, 362 MR arthrograms of the shoulder were performed at our institution. Inclusion criteria were: (a) no history of previous shoulder surgery and (b) performance of a standardised protocol for MR arthrography. Therefore, 50 patients were excluded because of previous shoulder surgery and four patients were excluded because a non-standardised MR imaging protocol was used. Furthermore, three patients had two consecutive MR arthrographies of the same shoulder. In these cases only the first examination was included. Patients who underwent MR arthrography of the left and right shoulder were counted as two unique subjects. None of the patients was excluded from the study on the basis of age, sex, severity of shoulder injury, or

quality of the MR imaging examination. Therefore, MR arthrographies of 305 patients were included, consisting of 211 male and 94 female patients with a mean age of 33.0 years (standard deviation (SD): 11.9 years). The indications for MR arthrography were the evaluation of: Superior labral anterior posterior (SLAP) lesion ($n=121$), instability or labral pathological features ($n=92$), RC tear ($n=50$), clinically suspected posterosuperior glenoid impingement (PSI) ($n=23$), injury to the pulley system ($n=14$) and frozen shoulder ($n=4$).

MR arthrography

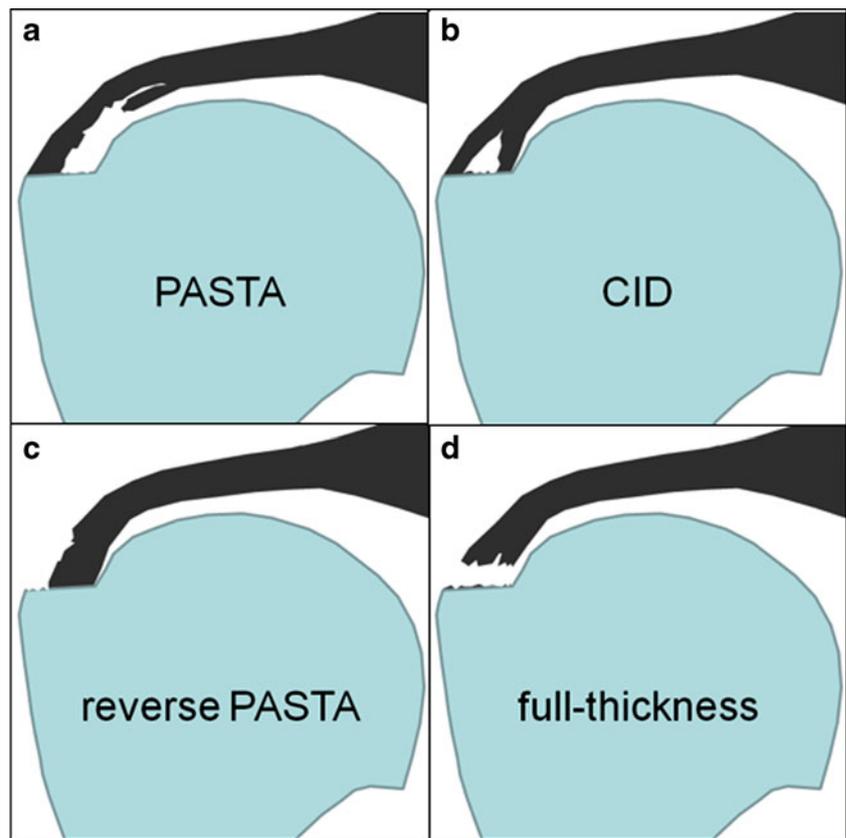
All MR arthrograms were performed using 1.5-T MR (Sonata, Espree or Avanto, Siemens Medical Solutions, Erlangen, Germany) and a dedicated shoulder coil (MRI devices, USA). The MR arthrographic examinations were performed after the injection of approximately 8–12 ml of gadopentetate dimeglumine (Magnevist[®], Bayer Healthcare, Berlin, Germany) at a concentration of 2.5 mmol/l via an anterior approach. The intraarticular position of the 20 G needle (TSK Supra[®], TSK Laboratory, Tochigi, Japan) was confirmed in all patients with fluoroscopic guidance by injecting 1–2 ml of iodinated contrast material (Ultravist[®] 300, Bayer Healthcare). MR imaging was commenced within 15 min after intraarticular contrast agent injection. The patients underwent imaging with the shoulder in neutral position. T1-weighted spin-echo images (TR range/TE range, 537–790 ms/10–14 ms) were obtained in the coronal oblique plane (parallel to the long axis of the SSP tendon) with fat suppression, the sagittal oblique plane (perpendicular to the glenohumeral joint) and the transverse plane. Proton density-weighted images (TR/TE, 2620–3370 ms/33–45 ms) with fat suppression were acquired in the coronal oblique plane. Parameters for all sequences were a section thickness of 3 mm with an intersection gap of 0.3 mm, a field of view of 16 cm and an in-plane resolution of 0.5×0.4 mm.

Image interpretation

All MR images were retrospectively reviewed by two radiologists in consensus, who had 2 and 15 years' experience in musculoskeletal radiology. MR arthrograms were assessed on a conventional PACS workstation for the occurrence of four different types of tears at the humeral tendon insertion of the SSP and ISP (Fig. 1):

- A. Partial articular-sided supraspinatus tendon avulsion (PASTA) lesions were diagnosed if there was a discontinuity of undersurface tendon fibres with contrast material extending into the tendon from the articular side on T1-weighted sequences. Articular-

Fig. 1 Drawings of the shoulder in the coronal oblique plane show different types of tendon tears at the rotator cuff footprint. **a** Partial articular-sided supraspinatus (SSP) tendon avulsion (PASTA) lesion with tendon failure on the articular side. As shown on the drawing an associated horizontal delamination of tendon fibres is possible. **b** Concealed interstitial delamination (CID) lesion which is covered by intact tendon fibres on both the articular and the bursal side. **c** Reverse PASTA lesion with a bursal-sided defect of the tendon, continuous to the subdeltoid bursa. **d** Full-thickness tear with continuous extension of the defect from the joint space to the subdeltoid bursa



- sided ISP tendon tears at the RC footprint were summarised under the term “PASTA lesion” as well.
- B. Concealed interstitial delamination (CID) lesions were diagnosed if there was a lesion with focal high signal intensity, isointense to fluid on fat-saturated intermediate-weighted images and without contrast material extending into the defect on T1-weighted images.
 - C. Bursal-sided tendon avulsion (reverse PASTA) lesions were diagnosed, if a tendon lesion with focal high signal intensity, isointense to fluid on fat-saturated intermediate-weighted images and continuous extension to the subdeltoid bursa was found.
 - D. Full-thickness tears (FT) were diagnosed if contrast agent extended through the entire articular-to-bursal thickness of the tendon on T1-weighted images.

The anatomical location was determined by four different categories: (1) anterior SSP tendon (anterior half of the superior facet of the greater tuberosity), (2) posterior SSP tendon (posterior half of the superior facet of the greater tuberosity), (3) SSP/ISP tendon transition zone (superior half of the middle facet of the greater tuberosity), (4) ISP tendon (inferior half of the middle facet of the greater tuberosity) [11].

The vertical depth of concealed and non-concealed partial-thickness tears was classified on coronal oblique

images according to the Ellman classification [18] (Fig. 2). Furthermore the extent of horizontal delaminations was measured in millimetres. In addition, all MR arthrograms were evaluated for the presence of SLAP lesions, labral tears, a pattern of lesions indicating PSI, injuries to the pulley system and tears of the subscapularis (SSC) tendon. The presence of bone marrow oedema or cysts at the greater tuberosity was also documented.

Review of clinical data

The clinical records of the patients were reviewed for a history of trauma, the type of trauma, performance of overhead sports, shoulder pain, and performance of shoulder arthroscopy. Arthroscopic reports were available in only 33 out of 63 patients included to the study. Therefore, we did not perform further correlation with arthroscopic results.

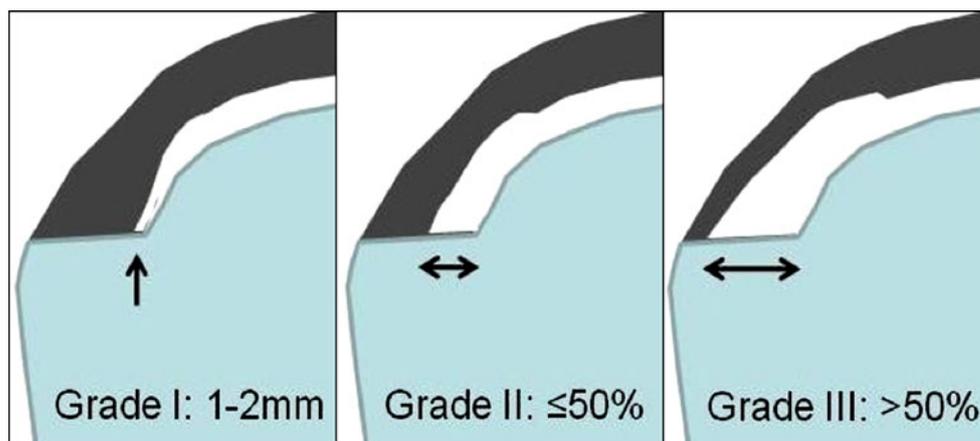
The clinical data were correlated with different types of footprint tears.

Statistical analysis

Statistical analysis was performed using PASW software (version 17.0, SPSS Inc., Chicago, IL, USA).

Continuous data are presented as mean and standard deviation, categorical data as absolute and relative frequencies.

Fig. 2 Schematic illustration of the classification system used to describe the vertical extension of rotator cuff tears according to Ellman [18]. Grade I: Partial tear involving 1–2 mm of the tendon insertion at the greater tuberosity. Grade II: Partial tendon tear with a vertical defect involving $\leq 50\%$ (3–6 mm) of the footprint. Grade III: Partial tendon tear and an extension $>50\%$ (>6 mm) of the tendon insertion at the greater tuberosity



To evaluate the association between the kind of lesion and relevant clinical and demographic parameters the generalised estimation equation (GEE) approach was used. This was done to account for correlations between repeated measures in the same subject, since some patients had more than one lesion. Ignoring the correlation of measures in the same subject may lead to overly optimistic results by producing too small *p*-values.

All statistical comparisons were made using a two-sided 0.05 level of significance.

Results

Among the 305 MR arthrographies that were included in our study 112 (36.7%) patients with tears at the tendon of the SSP or ISP tendons were observed. In 63 (56.3%) of these 112 cases 68 tears involving the rotator cuff footprint were found. Therefore, the overall incidence of RC tears involving the footprint was 20.7% in our series.

Thirty-four out of 68 (50.0%) footprint lesions were articular-sided tendon tears. Most of the PASTA lesions were located at the anterior SSP tendon ($n=20/34$; 58.8%). Eleven out of 34 (32.4%) PASTA lesions were found at the posterior SSP tendon or the SSP/ISP tendon transition zone. Only three (8.8%) involved the ISP tendon exclusively. Seventeen out of 34 (50%) PASTA lesions were small tears, classified as Ellman grade I tears. Nine out of 34 (26.5%) tears were grade II lesions and only 8 of 34 (23.5%) articular-sided tears were extensive partial ruptures classified as Ellman grade III (Fig. 3a–c).

Concealed tears accounted for 23 out of 68 (33.8%) footprint lesions. CID lesions were predominantly located at the posterior SSP tendon or the SSP/ISP tendon transition zone ($n=14/23$; 60.9%). However, nine out of 23 (39.1%) intrasubstance tears were identified at the anterior SSP tendon. The majority of CID lesions were either grade I ($n=11/23$, 47.8%) or grade II ($n=9/23$,

39.1%) defects. Grade III lesions were only seen in 3 out of 23 (13.0%) cases (Figs. 4 and 5 a,b).

Reverse PASTA lesions were very rare. Only two (2.9%) bursal-sided tears of this type were found. These two lesions involved the anterior SSP tendon with a small tear (grade I) and the SSP/ISP tendon transition zone (grade II), respectively (Fig. 6).

Of the nine (13.2%) full-thickness tears detected, seven were identified at the anterior SSP tendon, whereas two complete tears were located at the SSP/ISP tendon transition zone (Fig. 7).

In five out of 34 (14.7%) PASTA lesions an associated horizontal delamination along the long axis of the tendon was observed, which showed an extension ranging from 8 to 45 mm. In each of the other subgroups only one tendon delamination could be found.

Because of the low number of reverse PASTA lesions and full-thickness tears these subgroups were not applicable for statistical evaluation. However, all statistical correlations were made in comparison of the two major subgroups with PASTA lesions ($n=34$) and CID lesions ($n=23$). There was no statistical difference between these two subgroups with respect to the anatomical location of the lesions at the rotator cuff tendons ($p=0.903$) or the vertical depth of tears in the coronal plane (0.077).

Among the 63 patients with tears at the RC footprint several associated pathological conditions were found: SLAP lesions ($n=11$), labral tears ($n=13$), injuries to the pulley system ($n=7$), PSI pattern ($n=5$) and SSC tendon tears ($n=5$). The different types of footprint lesions could not be statistically correlated with associated joint pathological features ($p=0.289$). Cysts at the greater tuberosity were found in 14 out of 68 (20.6%) cases and associated bone marrow oedema at the tendon insertion was depicted in 16 out of 68 (25.5%) cases. The appearance of neither cysts ($p=0.110$) nor bone marrow oedema ($p=0.065$) at the greater tuberosity was statistically significantly different between the subgroups. The review of clinical data showed that 24 out of 63 (38.1%) patients were

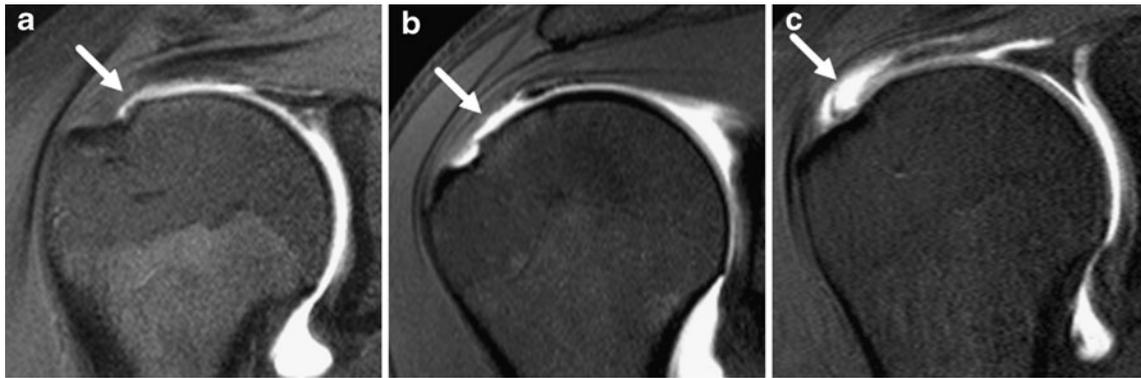


Fig. 3 T1-weighted fat-suppressed MR arthrograms in the coronal oblique plane show PASTA lesions at the SSP footprint. **a** Arthroscopically confirmed Grade I PASTA lesion at the right shoulder of a 17-year-old handball player. Intraarticular contrast agent fills the articular-sided tendon defect and extends down to the greater tuberosity (*arrow*). **b** Arthroscopically confirmed Grade II PASTA

lesion in a 35-year-old female kayak athlete. MR arthrogram shows a deep (<50%) articular-sided tendon defect at the humeral tendon insertion (*arrow*) outlined by intraarticular contrast agent. **c** Grade III PASTA lesion in a 36-year-old male patient. The MR arthrogram shows the contrast agent-filled, articular-sided defect of the tendon involving >50% of the SSP footprint

participating in overhead sports. Regarding the performance of overhead sports, there was no statistically significant predominance between the two subgroups ($p=0.300$). Furthermore, the review of clinical data revealed no statistically significant difference in the history of trauma to the shoulder (30/63 patients; 47,6%; $p=0.928$).

When divided into two subgroups with patients <40 or ≥ 40 years of age, we found a significantly higher incidence ($p=0.029$) of PASTA lesions in the younger population. On the other hand, there was no difference in CID lesions in the two subgroups ($p=0.608$) (Fig. 6). Patients suffering from full-thickness tears were significantly older (mean: 49.9 years, SD: 11.8) than patients with partial tears of the RC (mean: 37.7 years, SD: 12.0) ($p=0.003$).

Discussion

In the literature it is widely accepted that most rotator cuff tears occur on the articular side of the SSP tendon critical

zone [6–8, 15]. Since Codman first described rim-rent tears of the SSP tendon fibres at the humeral tendon insertion, only a few radiological publications have concentrated on imaging of tears at the rotator cuff footprint [10]. In contrast, the rotator cuff footprint is a major topic in literature on shoulder surgery and orthopaedics [19–21]. However, the pathogenesis and natural history of rotator cuff tears are not fully understood [22]. Theories abound as to why, how and where the tendons fail. For instance, Neer's theory of rotator cuff tears related to subacromial impingement is not applicable to the pathogenesis of humeral tendon avulsions in younger athletes [23].

Tuite and co-workers showed that articular-sided footprint tears detected with conventional MR imaging are significantly more frequent in patients younger than 36 years of age than tears at the critical zone of the tendon [15]. In their study rim-rent tears constituted 25% of tears found in the younger population. Based on the results of MR-A our data support these findings as RC footprint tears were the most common (56.3%) type of SSP and ISP tendon tears. Patients with

Fig. 4 Coronal oblique MR arthrograms of the right shoulder in a 44-year-old male patient. **a** Proton density-weighted fat-suppressed MR arthrogram shows an arthroscopically confirmed Grade I CID lesion (*arrow*) as hyperintense signal with horizontal delamination along the tendon. **b** Corresponding T1-weighted fat-suppressed MR arthrogram shows no extension of intraarticular contrast agent into the tendon tear (*arrow*)



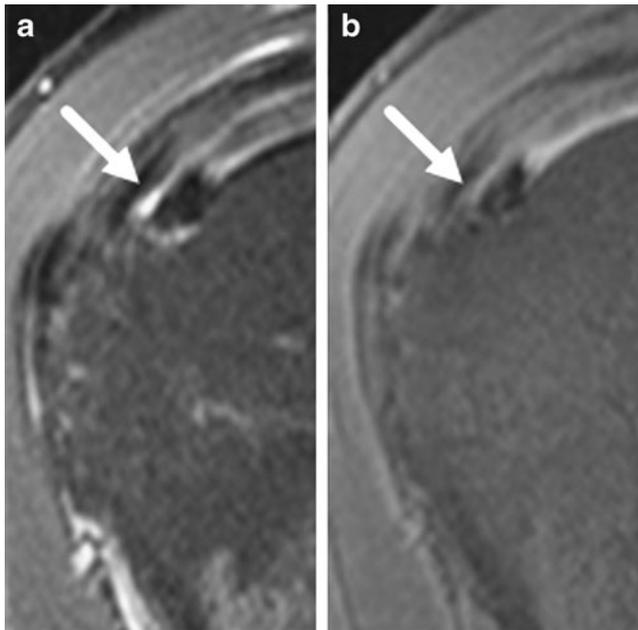


Fig. 5 Grade II CID lesion in a 26-year-old male patient. **a** Coronal oblique proton density-weighted MR arthrogram of the left shoulder shows a hyperintense SSP tendon lesion (*arrow*) with horizontal delamination involving 4 mm of the anterior facet of the greater tuberosity. **b** Corresponding T1w fat suppressed MR arthrogram shows no contrast agent extension into the tendon defect at the greater tuberosity (*arrow*)

PASTA lesions were significantly younger. However, Vinson et al. showed that 70% of partial rotator cuff tears are located at the tendon insertion and they postulated an overall incidence of articular-sided footprint tears of 24.5% in their study group [16]. Our data showed a similar incidence of footprint tears (20.7%). Additionally we found a high prevalence of concealed interstitial delamination lesions at the bony tendon insertion. CID lesions have not been described in imaging studies before. Most of the footprint

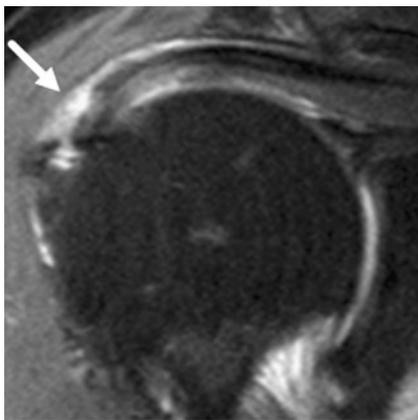


Fig. 6 Coronal oblique proton density-weighted MR arthrogram in a 67-year-old male patient. The image shows bursal-sided fluid-like signal intensity with continuous extension to the subdeltoid bursa (*arrow*) representing a reverse PASTA lesion of the SSP tendon

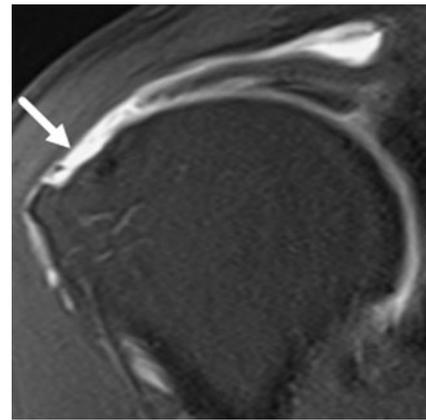


Fig. 7 Arthroscopically confirmed full-thickness tear at the SSP tendon footprint (*arrow*). Fat-suppressed coronal oblique T1-weighted MR arthrogram in a 51-year-old male patient shows contrast material extending from the joint through the entire SSP tendon into the subdeltoid bursa (*arrow*) with tendon retraction

lesions in our study were PASTA lesions but CID lesions accounted for one third (33.8%) of all lesions at the footprint. Even though intrasubstance tears of the SSP tendon have been well described on MR imaging of the shoulder, the frequency of this kind of lesion at the RC footprint has never been evaluated. Nakagawa et al. described concealed tears of the anterior SSP tendon in six out of 17 patients in an arthroscopically evaluated series of throwing athletes [24]. It was mentioned that preoperative MR imaging is helpful in drawing attention to the presence of a concealed tear, which might otherwise be missed on arthroscopic inspection. In contrast to their findings, our results show that CID lesions were predominantly located at the posterior SSP tendon or in the transition zone of the SSP/ISP tendons but we could confirm that CID lesions are more prevalent than previously assumed. However, the precise anatomic location of the different types of footprint lesions is less important for the decision between conservative or operative treatment.

Fukuda et al. histologically evaluated concealed rotator cuff tears in en bloc specimens. They asserted that intratendinous tears were caused by shearing forces within a degenerated tendon [25]. Budoff and coworkers postulated intrinsic factors as causes of intratendinous tears such as avascularity, aging, overuse and/or overload [26]. The results of the present study showed that CID lesions occur in almost equal measure in patients under 40 or patients over 40 years of age. This suggests that CID lesions more often develop on the basis of degenerative changes. On the other hand, our data showed that PASTA lesions were more frequent in younger patients, which suggests that degeneration is less important. However, we did not observe that PASTA or CID lesions showed a higher prevalence in athletes performing overhead sports.

Former studies seemed to indicate that partial rotator cuff tears can progress and do not heal on their own. The full-thickness tears in our study occurred in significantly older patients (mean age: 49.9 years) than partial tears (mean age: 37.7 years). During our study we observed one case of a patient with a CID lesion in the study group which was treated conservatively. Approximately 6 months later he showed a full-thickness tear at the identical location on MR imaging. This observation supports the progression theory and underlines the importance of diagnosing partial-thickness rotator cuff tears.

Our study has several limitations. First, the design of the study is retrospective. However, all MR arthrographies included to the study have been performed using a standardised protocol. In addition, the diagnostic criteria for detecting rotator cuff tears were defined precisely. Second, not all of our patients underwent arthroscopy. Therefore the findings of rotator cuff tears were not correlated with a gold standard. However, in previous studies MR arthrography has shown a high specificity and sensitivity in the evaluation of the rotator cuff tears using the same diagnostic criteria as the present study [14, 27]. Third, the patient population referred for MR arthrography of the shoulder is preselected and not representative of the general population suffering from shoulder pain. Rotator cuff tears related to outlet impingement in elderly patients are mostly evaluated with conventional MR imaging [28, 29]. In our study group MR arthrography was often performed for evaluating labral pathological conditions as well as lesions to the labral-bicipital complex. In such cases rotator cuff tears are not expected. Fourth, intrasubstance tears can be filled with granulation tissue, which might result in a signal that is increased but lower than that of fluid on T2-weighted images. Thus, such tears might be confused with tendinosis [25, 30]. This suggests that some concealed tears may not have been detected in our study. Hence tendon alterations with signal isointense to fluid show high specificity in diagnosing partial tears. Therefore, only these lesions were classified as concealed tears in the present study.

In conclusion, most rotator cuff tears in patients referred for MR arthrography of the shoulder involve the rotator cuff footprint. Most of these lesions are articular-sided (PASTA lesions) but a concealed type of tear (CID lesion) is a representative lesion and is not as uncommon as previously thought. The detection of concealed tears is of special importance as these lesions might be invisible at arthroscopic shoulder surgery. PASTA lesions tend to be more anterior at the SSP tendon than CID lesions. However, the incidence of PASTA lesions was significantly higher in a younger patient population. This suggests that the pathogenesis of PASTA lesions might be a more repetitive traumatic mechanism than in CID lesions, which appear to occur on the basis of degenerative changes. As a

result of the high prevalence of tears at the rotator cuff footprint radiologists should pay particular attention to the humeral tendon insertion of the rotator cuff.

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