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Supraspinatus tendon tears: comparison of US and MR arthrography with surgical correlation

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Abstract The aim of this study was to compare the diagnostic reliability of US with MR arthrography in diagnosing supraspinatus tendon tears. Surgical findings were used as the gold standard in detecting tears. A total of 44 patients were assessed with transverse and longitudinal US scans with respect to the long axis of the rotator cuff tendons and then examined with MR arthrography. This technique involved free-hand injection of contrast medium into the shoulder joint. At surgery 20 incomplete and 24 complete tears were observed. Ultrasound offered good results for the large tears, but its sensitivity decreased proportionally with the size of the tears. Magnetic resonance arthrography correctly diagnosed 43 tears, whereas only one false-negative diagnosis of tendinosis was made for a partial tear on the bursal side. Since it improves the diagnosis of small tears, MR arthrography must be performed on all patients for whom surgical repair is necessary in order to restore normal functions.

Keywords MR arthrography · Shoulder · Tendons · Supraspinatus · US

Introduction

The incidence of tearing in the supraspinatus tendon is much higher than in other rotator cuff tendons [1, 2, 3, 4, 5]. Except for a small percentage of supraspinatus tears attributable to acute trauma, the cause of such tears is still unclear. Generally, the pathogenesis of supraspinatus tears is considered to be multifactorial and includes intrinsic degeneration and impingement syndrome [2, 3, 4, 6]. Nevertheless, the subsequent development of the pathology is much the same whatever its origin, since it is self-sustaining [6].

The diagnosis of tears is often difficult because the intensity of clinical findings does not correspond to the severity of the lesion [5, 7, 8] and the identification of a tear is a fundamental feature with regard to the proper diagnosis and treatment of cuff pathology [1, 6, 8]; thus, an instrumental diagnosis is essential in order to recognise the type of supraspinatus tear as well as evaluate the quality of the residual tissue [6, 8]. Plain radiographs display soft tissues only to a limited extent and can demonstrate solely superior migration of the humeral head, an indirect sign of cuff failure [6, 9, 10]. Ultrasound is a useful and inexpensive means of assessing the rotator cuff but has numerous limitations and its level of accuracy, which is great only in large tears, is otherwise reported as variable [1, 4, 6, 9, 11]. Magnetic resonance imaging is effective in evaluating rotator cuff and is highly accurate in detecting complete tears, whereas it is less effective in revealing partial tears [1, 4, 11, 12, 13]. Diagnostic accuracy is improved for small full-thickness tears and underface partial tears when intra-articular contrast medium is used (MR arthrography) [1, 6, 8, 12, 13, 14].

Materials and methods

From February 1999 to April 2000, 273 patients with signs and symptoms suggesting lesions of the rotator cuff were assessed with US and MR arthrography. Our study comprised only the 44

Table 1 MR arthrography protocol. *FA* flip angle; *FOV* field of view; *GE* gradient echo

Sequence and plane[a]	TR/TE (ms)	FA	Matrix	Section/gap (mm)	FOV (cm)	Imaging time (min:s)
T2 GE axial	680/12	60°	256×256	4/0.4	18×18	4:15
T1 GE oblique coronal	550/9.2	80°	256×256	4/0.4	16×16	6:27
T1 GE oblique sagittal	500/17	80°	256×256	4/0.4	16×16	7:11

[a] All sequences with fat suppression

patients who underwent open surgery, given that we used surgical findings as the standard of reference for US and MR arthrography. The same orthopaedic surgeon performed all surgical repairs. The study did not include those patients with diagnosed tears who refused surgery or those patients displaying normal imaging who did not undergo surgery due to disappearance of symptoms.

The study included 23 men and 21 women whose ages ranged from 22 to 74 years (mean age 55.7 years); none had previously undergone shoulder surgery. Informed consent was obtained from the patients prior to MR arthrography.

All MR arthography was performed and evaluated by the same radiologist; all dynamic US was performed and evaluated by another radiologist. Each physician had more than 4 years of experience with the examination technique. The reports were made by each reader without knowledge of the results of the other imaging method.

Ultrasound observation and diagnoses were made during real-time imaging using General Electric Logiq 500 (General Electric, Milwaukee, Wis.) and Hitachi EUB 8000 (Hitachi, Tokyo, Japan) equipment. Ten-megahertz linear-array transducers were routinely used with both. During examination, the patients were seated on a stool and the radiologist stood behind the patient during the scan.

Ultrasound of the shoulder [2, 4, 15, 16] begins with a transverse and longitudinal image of the biceps tendon within the bicipital groove. Next, longitudinal and transverse scans of the subscapularis tendon are made with the patient's arm externally rotated. Images of the supraspinatus tendon are made with the arm in internal rotation in order to expose as much of the supraspinatus tendon as possible from beneath the acromion. This position is best achieved by placing the patient's arm behind his back. The supraspinatus tendon may be scanned perpendicular and parallel to its fibers. The thickness and echogenicity of the tendon, the segmental or complete loss of rotator cuff substance, the presence and amount of joint and bursal fluid, the loss of convex contour of tendon on the bursal side, and greater tuberosity changes [2, 4, 15, 16, 17, 18] are observed. In addition, it is important to use the transducer to compress the deltoid muscle against the cuff in an attempt to separate the torn tendon ends at the site of a non-retracted tear [2, 4, 15].

In MR arthrography, an MR imager with a 1.5-T magnet (Gyroscan ACS NT Powertrak 6000, Philips, Eindhoven, The Netherlands) and one surface coil was used. Our procedure involves direct intra-articular injection of a contrast agent prior to MRI. We inject the contrast medium into the articular cavity with a simple-to-perform, free-hand technique. The left hand explores the anterior shoulder area to locate the extremity of the coracoid process. The groove separating it from the humeral head is then identified and the needle is inserted at the bottom of this groove in a slightly medio-lateral direction (Fig. 1). A sudden decrease in elastic resistance indicates without doubt that the needle has moved beyond the articular capsule and has assumed the correct position in the articular cavity. Instead, in some cases the needle may meet interference, indicating that it has entered the humeral head cartilage. In this case the needle must be retracted a few millimeters and reinserted, pointing the needle in a more medial direction.

Depending on articular capacity, 15–20 ml of contrast medium (0.1 ml of gadolinium-DTPA (Magnevist, Schering, Berlin, Germany) in approximately 20 ml of saline dilution) is injected into

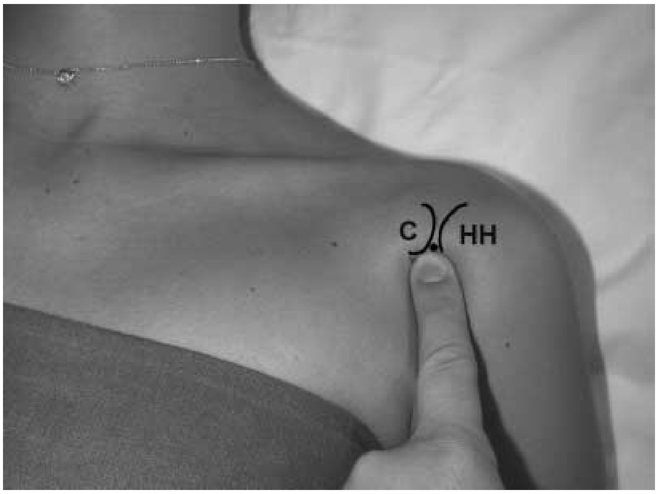

Fig. 1 Free-hand injection technique with anterior approach. Landmarks: *HH* humeral head; *C* coracoid. The *black dot* indicates the needle entrance

the shoulder by means of a 19-G spinal needle and low-resistance syringe. This syringe makes it possible to sense if the contrast medium is injected within the articular space or in the surrounding soft tissue according to the quantity of resistance felt against the piston. This criteria, in addition to the above-mentioned sudden decrease in needle resistance upon entrance into the articular cavity, further ensures correct intra-articular positioning of the needle. Following injection, the shoulder is gently moved prior to imaging in order to achieve satisfactory distribution of the contrast medium and distension of the articular capsula. During MRI examination the patient lies supine with his adduct arm in a neutral position and thumb pointing upward.

We employ T2-weighted, gradient-echo (GE) Spectral Presaturation Inversion Recovery (SPIR) sequences in true axial scans and T1-weighted, GE SPIR sequences in oblique coronal planes that are parallel to the course of the supraspinatus muscle, and oblique sagittal planes that are parallel to the glenoid fossa (Table 1). Imaging time is approximately 18 min.

All tears observed are described as follows: full thickness or complete tears are distinguished from incomplete tears; in the former, the paramagnetic contrast medium is always evident in the bursal space because it exits the articular cavity through a side-to-side tendon tear [12, 13]. Complete tears are either focal, sub-total, or total (Fig. 2). Focal tears display a piercing tendon hole; in sub-total tears only a few fibers are regularly inserted, whereas in total tears all tendon fibers are torn and the stump is retracted under the acromion. In incomplete tears there is no communication between the glenohumeral joint and the subacromial bursa; they are either partial or intratendinous (Fig. 3). In intratendinous tears the split is only within the tendon itself and there is no communication with the subacromial/subdeltoid (SA/SD) bursa or the shoulder joint [2, 7, 16]. In partial tears some tendinous fibers on the articular or bursal surface are interrupted. In MR arthrography the con-

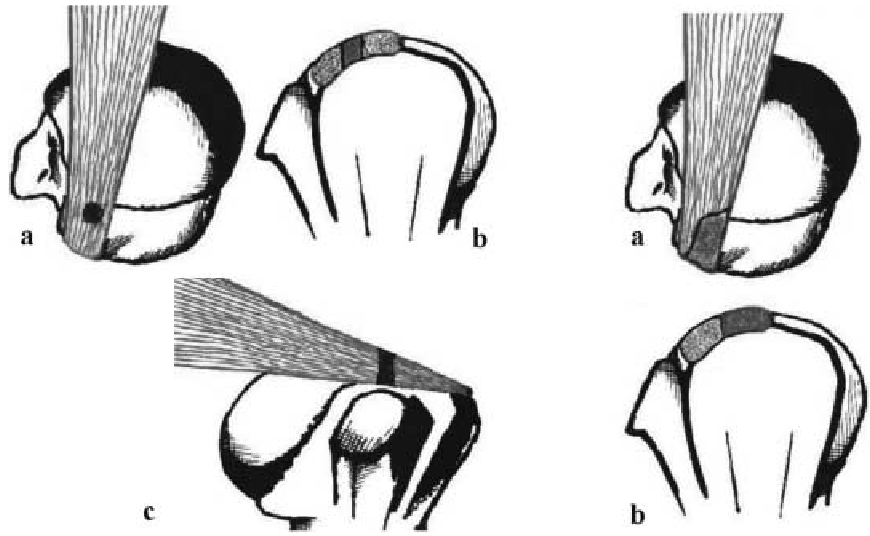

Fig. 2 Full-thickness tears. On the left: focal tear. Supraspinatus tendon section on **a** axial, **b** sagittal, and **c** coronal planes. On the right: sub-total tear. Supraspinatus tendon section on **a** axial and **b** sagittal planes

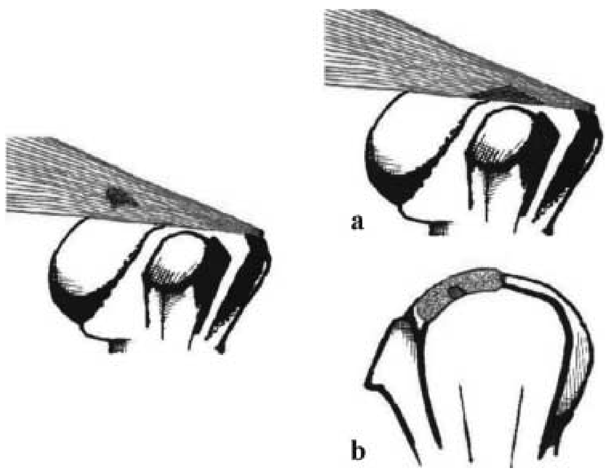

Fig. 3 Incomplete tears. On the left: intratendinous tear. Supraspinatus tendon section on coronal plane. On the right is a partial tear on the articular side. Supraspinatus tendon section on **a** coronal and **b** sagittal planes

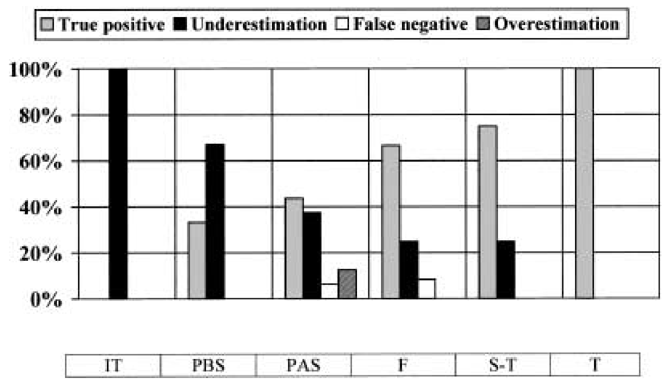

Fig. 4 Agreement between US and surgical findings. Note that the diagnostic reliability of US increases with tear size. *IT* intratendinous; *PBS* partial on the bursal side; *PAS* partial on the articular side; *F* focal; *S-T* subtotal; *T* total

Table 2 Supraspinatus tendon tears at surgery

		No. of cases at surgery
Incomplete tears	Intratendinous	1 (2.3)
	Partial bursal side	3 (6.8)
	Partial articular side	16 (36.4)
Complete tears	Focal	12 (27.2)
	Sub-total	4 (9.1)
	Total	8 (18.2)

Numbers in parentheses are percentages

trast medium traces only the outlines of partial tears on the articular side, whereas the visualization of partial tears on the bursal side and intratendinous tears is no better than with conventional MRI.

Results

Surgical findings were used as the gold standard in detecting supraspinatus tendon tears (Table 2). Twenty incomplete tears were observed: one was intratendinous (2.3%) and 19 partial (43.2%; 16 on the articular side and 3 on the bursal side); complete tears were found in 24 shoulders: 12 were focal (27.2%), 4 sub-total (9.1%) and 8 total (18.2%).

Ultrasound and surgical findings coincided in 27 cases (61.3%), whereas US underestimated 13 tears (29.6%) and overestimated only one (2.3%). Moreover, 3 false-negative diagnoses (6.8%) were made.

Magnetic resonance arthrography and surgical findings coincided in 43 cases (97.7%). Only one false-negative diagnosis of tendinosis was made for a partial tear on the bursal side.

Regarding partial incomplete tears (Fig. 4), for the three partial tears on the bursal side, US correlated with surgery in 1 case (33,3%), whereas it underestimated the other 2 cases as tendinosis (66.7%).

For the 16 partial tears on the articular side (Fig. 4), US correlated with surgery in 7 cases (43.7%), whereas it underestimated 6 tears as tendinosis (37.5%) and overestimated one tear as focal (6.3%). Moreover, in 2 patients a false-negative diagnosis was made (12.5%).

Our sole intratendinous case displayed no agreement between US and surgical findings and was underestimated as tendinosis (Fig. 4).

Magnetic resonance arthrography correlated with surgery in all 16 partial tears on the articular side (100%), whereas it correlated with surgery for two partial tears

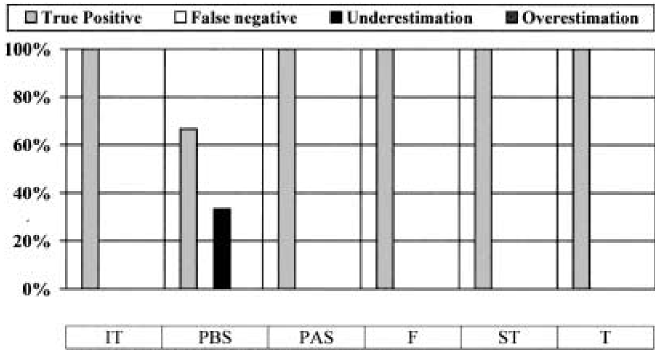

Fig. 5 Agreement between MR arthrography and surgical findings

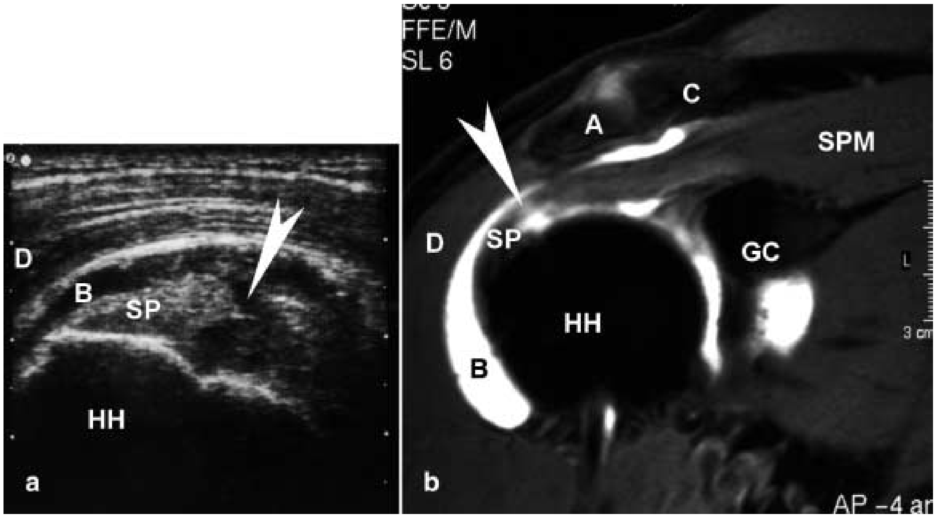

Fig. 6a, b Oblique coronal scans: the diagnosis of a supraspinatus focal tear with **a** US is confirmed by **b** MR arthrography. *SP* supraspinatus tendon; *SPM* supraspinatus muscle; *B* SA/SD bursa; *D* deltoid muscle; *HH* humeral head; *arrowhead*: tendon tear; *A* acromion; *C* clavicule; *GC* glenoid cavity

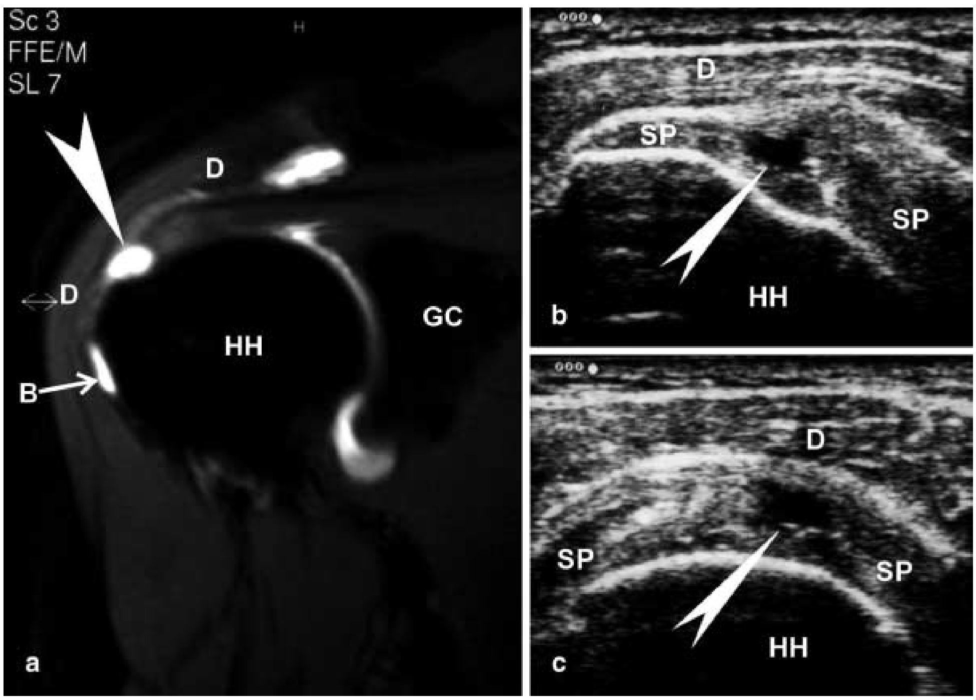

Fig. 7 **a** Supraspinatus focal tear underestimated as a partial-thickness tear with **b, c** US. *SP* supraspinatus; *D* deltoid; *HH* humeral head; *GC* glenoid cavity; *B* SA/SD bursa; *arrowhead*: tendon tear

on bursal side (66.7%) and it underestimated the tear diagnosed with US (33.3%) as tendinosis (Fig. 5).

With regard to complete (or full-thickness) tears (Fig. 4), in the focal type (Fig. 6) there was agreement between US and surgery in 8 patients (66.6%), whereas in 3 patients the focal tear was underestimated as a partial tear (Fig. 7) or tendinosis (25%). A false-negative diagnosis was made only in 1 patient (8.4%). In sub-total tears, agreement was found in 3 patients (75%), whereas in 1 patient (25%) the tear was underestimated as a focal lesion. Finally, the total tears displayed agreement between US and surgery in all 8 patients (100%).

Magnetic resonance arthrography and surgery coincided in all complete tears (100%; Fig. 5).

It is noteworthy that in 3 cases (2 obese patients and 1 with a highly developed muscle structure who experienced intense pain) two injections proved necessary, given that the contrast medium was injected outside the articular cavity (in the anterior muscle layers) during the first attempt. This in no way hampered diagnosis, however. Furthermore, contrast medium was never injected into the bursae surrounding the shoulder joint.

Discussion

Tears of the supraspinatus tendon have a multifactorial etiopathogenesis [2, 3, 4, 6] and occur more frequently than in other rotator cuff tendons [1, 2, 3, 4, 5]. From a biomechanical perspective, the supraspinatus tendon is affected by stress to a greater extent than other tendons because of its short size and wide range of motion [3]. The incidence of partial-thickness tears is much higher on the undersurface of the supraspinatus tendon [2, 3, 13, 19] and this is partially due to the hypovascularity which has been observed near the insertion of the supraspinatus tendon, especially on its articular side [3, 20].

The treatment of patients with symptoms attributed to supraspinatus pathology depends on the type of tear [1, 6, 8]; thus, imaging procedures represent an important step in accurate diagnosis and proper therapy [6, 8].

Plain-film radiography still remains the basis of all imaging studies in the shoulder joint [11], but poorly visualizes soft tissues and is therefore ineffective in detecting tendon tears [5, 6].

Great variation of sensitivity and specificity of US detection of rotator cuff tears is reported in the literature [4, 5, 6, 11]. Ultrasonographic reproducibility of standard views is difficult and changes in echogenicity within the tendon due to artifacts or malpositioning of the transducer occur with considerable frequency; thus, the success of US depends heavily on the experience of the operator [1, 15, 17] and on the use of machines with high resolution [4, 17]. The limited acoustic window resulting from adjacent bone structures is an additional factor which makes US technically difficult. For this reason, knowledge of the complex three-dimensional anatomy of the rotator cuff and its normal US appearance is crucial to successful rotator cuff tear diagnosis [21].

Several reports present US as clearly displaying complete tears of the supraspinatus tendon [1, 4, 15, 17], although its sensitivity and specificity for partial lesions is low, since areas of focal echogenicity may also appear in calcific tendonitis or hemorrhagic and fibrotic bursitis [1, 4, 6, 15]. In accordance with other authors, we found that US is highly sensitive in diagnosing large full-thickness tears (total and subtotal) but is less sensitive for partial and small (focal) full-thickness tears [1, 4]. On the other hand, the accuracy of conventional MRI in detecting small tears is also reported to be low. In the international literature, US is at least as sensitive and specific as conventional MRI in detecting full-thickness tears [4, 15, 16, 22], whereas both methods were less effective in distinguishing small full-thickness tears, partial-thickness tears, and tendinosis [1, 4, 13, 23]. Although MRI, due to its wide field of view, is suitable for diagnosing other pathologies of the shoulder joint and allows for assessment of rotator cuff muscle atrophy [5, 20], no single method has been definitively proven superior in diagnosing rotator cuff tendon tears. Since US is economical and fast, it should be the primary diagnostic method in shoulder pain screening [1, 4, 22].

In MR arthrography, intra-articular gadolinium outlines the inferior supraspinatus surface, fills partial-thickness tears and, in complete tears, leaks from the gleno-humeral joint into the SA/SD space (Fig. 8) [5, 12, 13]. Although MR arthrography is invasive, it is superior to conventional MRI [1, 13, 14] and indirect MR arthrography with intravenous administration of gadolinium [12, 13]. Indirect MR arthrography has been investigated as an alternative to direct intra-articular injection. It is obviously less invasive than direct arthrography. Moreover, joint structures may be homogeneously enhanced following 5–10 min of light exercise. The rate of diffusion may be accentuated as a result of articular flogosis or overly intense exercise following injection. Diagnostic inaccuracy may result from enhancement of the supraspinatus tendon caused by inflammation, thus leading to a false-positive diagnosis of rotator cuff tears. Moreover, indirect MR arthrography does not offer the most essential benefits of intra-articular injection because the capsule does not become distended. Furthermore, fewer cases of adverse effects are reported using direct MR arthrography than with intravenous MR arthrography [13].

In the international literature direct MR arthrography is not generally suggested during routine shoulder examination [1, 4, 23] since the exact positioning of the needle within the articular space requires a small amount of iodinated contrast medium to be injected into the articular cavity under fluoroscopic guidance [8, 12, 13]. Moreover, upon completion of this procedure, the patient must

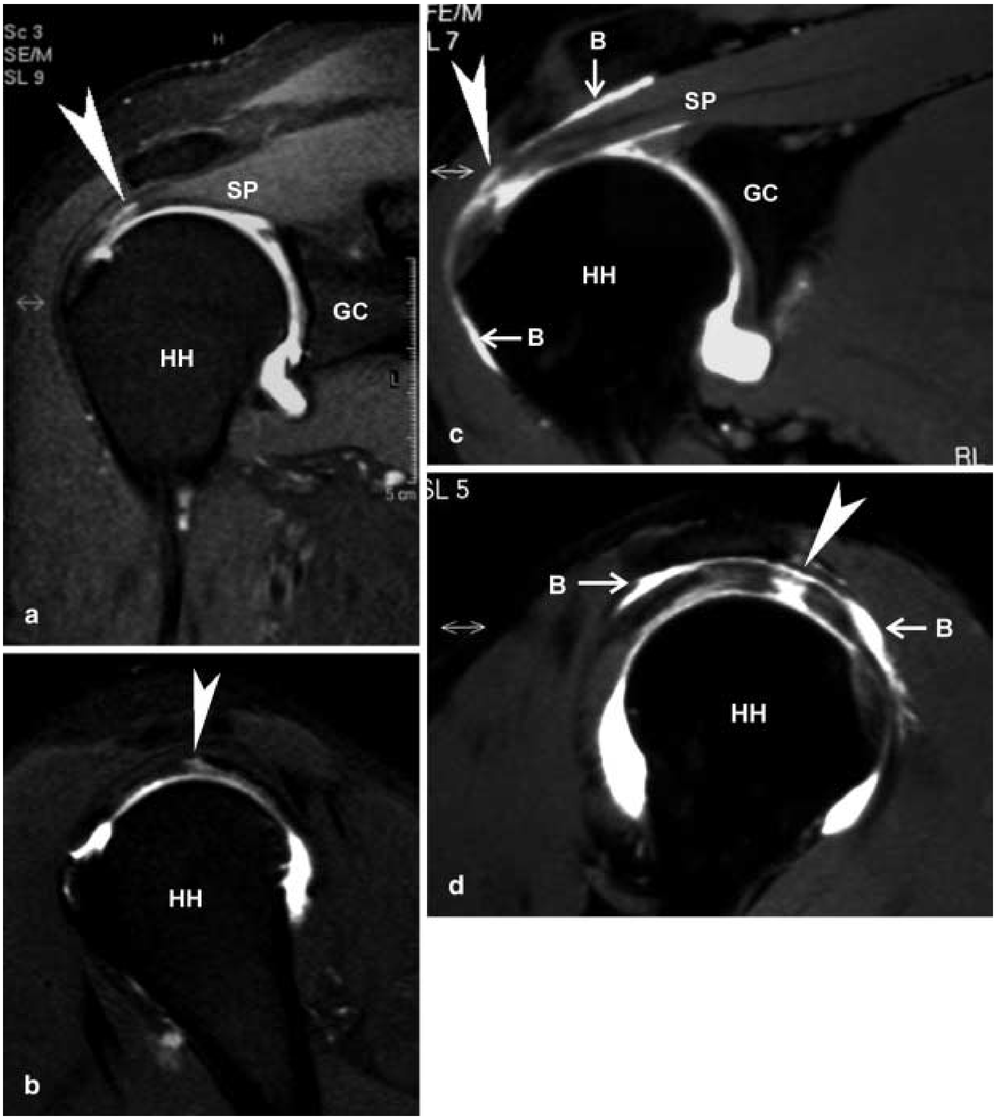

Fig. 8 Oblique coronal and sagittal scans comparing a partial-thickness tear with fraying of **a, b** the supraspinatus tendon and **c, d** a focal tear in which the presence of contrast medium in the subdeltoid space is evident. *SP* supraspinatus; *arrowhead*: tear; *B* SA/SD bursa; *HH* humeral head; *GC* glenoid cavity

be transferred from the fluoroscopic room to the MR imager. It follows that the procedure is charged through the use of ionizing radiation and iodinated contrast, provoking adverse reactions and requiring longer examination time [12, 13, 23].

In our procedure the contrast medium is injected into the articular cavity with a simple-to-perform, free-hand technique, so that iodinated contrast medium and fluoroscopy are not employed. Moreover, the gadolinium solution is injected in the room beside the MR imager. All our sequences are performed with fat suppression in order to distinguish fat from gadolinium, given that they display similar signal intensities on standard T1-weighted images. This similarity may create difficulty in the differential diagnosis of partial- and full-thickness tears when the supraspinatus tendon reveals contrast solution extending toward the bursal surface, but it is unclear if the medium passes entirely through it. On fat-suppressed T1-weighted images, the signal from the contrast solution remains unvaried, whereas the signal from the normal fat is selectively decreased; thus, low signal intensity in the SA/SD space indicates a partial-thickness tear, whereas persistent high-signal intensity indicates communication with the shoulder joint through a full-thickness tear [12, 13]. Imbibition of contrast medium into the substance of the tendon is sometimes recognizable in partial-thickness tears on the articular surface. In our study MR arthrography proved to be sensitive with small full-thickness tears and undersurface partial tears. No improvement in diagnosing bursal surface partial-thickness and intratendinous tears has been documented with MR arthrography because no communication exists between these lesions and the articular joint [5, 12, 13, 23]: in such cases these tears appear as they would with conventional MRI. In our study two of the three tears on the bursal side were correctly diagnosed with MR arthrography (in practice, conventional

MRI), whereas the third was correctly diagnosed with US due to the compression technique. Our results, although of statistically limited value due to the small number of cases observed, are in agreement with those in the literature, confirming the difficulty presented by both techniques (US and conventional MRI) in diagnosing small tears [1, 4, 6, 13, 15, 23].

During MR arthrography the contrast medium was never found to cause adverse effects in patients. In terms of pitfalls, it was necessary to inject the contrast medium a second time in only three cases: the first attempt had failed since the needle had been incorrectly inserted into the particularly thick periarticular soft tissues. The extra-articular contrast medium was no hindrance to diagnosis, however. Furthermore, the contrast medium was never injected into the bursae surrounding the shoulder joint. Moreover, due to the free-hand technique, MR arthrography proves to be cost-effective in the clinical management of patients.

In conclusion, from our experience, we consider US the screening technique of choice for patients with shoulder pain or clinical findings suggesting a supraspinatus tendon lesion, due to its ease of use and diagnostic sensitivity. It must, however, be noted that small tears may be misdiagnosed [1, 4]. Magnetic resonance arthrography represents the most suitable technique for achieving an accurate diagnosis when US produces unclear findings, non-surgical therapy is unsuccessful, or with patients destined for surgery. We have found MR arthrography to be superior to conventional MRI, given that the international literature reports this latter technique as presenting the same diagnostic weaknesses as US for detection of small tears. Magnetic resonance arthrography (performed with our free-hand injection technique) furthermore requires only slightly greater examination times and costs than conventional MRI. At the same time it offers significantly greater diagnostic sensitivity for small full-thickness tears and for partial tears on the articular side (the most frequently occurring partial tears) while it offers equal resolution of the bursal side.

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