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SCIENTIFIC ARTICLE

Diagnosis of superior labral lesions: comparison of noncontrast MRI with indirect MR arthrography in unexercised shoulders

Philip A. Dinauer · Donald J. Flemming · Kevin P. Murphy · William C. Doukas

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Abstract
Objective To prospectively compare the accuracy of noncontrast magnetic resonance imaging (MRI) with indirect MR arthrography (I-MRa) of unexercised shoulders for diagnosis of superior glenoid labral lesions.
Materials and methods Institutional Review Board approval and patient informed consent were obtained for this prospective study. Superior labral findings on shoulder MRI and unexercised I-MRa studies of 104 patients were correlated with findings at arthroscopic shoulder surgery. Two musculoskeletal radiologists independently reviewed the two sets of MR images while blinded to arthroscopic results. For each radiologist, the McNemar test was used to detect statistically significant differences between techniques.
Results The superior labrum was intact in 24 and abnormal in 80 subjects. For detection of superior labral lesions by each radiologist, I-MRa was more sensitive (84–91%) than MRI (66–85%), with statistically significant improvement in sensitivity for one reader ($p=0.003$). However, I-MRa was less specific (58–71%) than MRI (75–83%). Overall, accuracy was slightly improved on I-MRa (78–86%) compared with MRI (70–83%), but this difference was not statistically significant for either reader.
Conclusion Compared with noncontrast MRI, I-MRa was more sensitive for diagnosis of superior glenoid labral lesions. However, the diagnostic value of I-MRa in shoulders remaining at rest is potentially limited by decreased specificity of the technique.

Keywords Arthrography · Shoulder joint · Magnetic resonance imaging · Diagnosis

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P. A. Dinauer
Department of Radiology, Walter Reed Army Medical Center,
Washington, DC 20307, USA

D. J. Flemming
Department of Radiology, H066 MSHMC,
P.O. Box 850, 500 University Drive,
Hershey, PA 17033-0850, USA

K. P. Murphy · W. C. Doukas
Orthopaedic Surgery Service Department of Orthopaedics
and Rehabilitation, WRAMC,
Building 2, Clinic 5A,
Washington, DC 20307, USA

Present address:
P. A. Dinauer (✉)
Department of Radiology, Hospital of Saint Raphael,
1450 Chapel Street,
New Haven, CT 06511, USA
e-mail: padinauer@yahoo.com

Introduction

The indirect shoulder magnetic resonance arthrography (I-MRa) technique typically involves intravenous (i.v.) administration of a standard dose of 0.1 mmol/kg of gadopentetate dimeglumine and the addition of 10–15 min of shoulder exercise to promote contrast diffusion into the glenohumeral joint [1–3]. The arthrogram-like effect achieved with I-MRa may improve detection of glenoid labral tears compared with noncontrast MR imaging (MRI) [4–6]. Furthermore, if some labral tears contain fibrovascular tissue as a repair response [7, 8], it seems possible that contrast enhancement at sites of intralabral fibrovascular tissue may increase sensitivity of labral tear detection.

In relatively small study populations, several investigators have described improved sensitivity in diagnosis of superior labral tears with I-MRa compared with conventional, noncontrast MRI [4–6, 9]. However, in symptomatic shoulders, it remains unclear whether I-MRa performed without a delay for shoulder exercise can significantly improve definition of glenoid labral tears. The diagnostic potential of I-MRa in defining superior labral tears without the addition of joint exercise has not been adequately described in prospective clinical studies. Our objective was to prospectively compare the accuracy of noncontrast MRI with indirect MR arthrography for diagnosis of superior glenoid labral tears in shoulders remaining at rest.

Materials and methods

Subjects

Institutional Review Board (IRB) approval was obtained for performance of this prospectively designed study. For study inclusion, subjects had to be at least 18 years of age with clinical findings of subacromial impingement, glenohumeral instability, or mechanical symptoms of labral tear warranting treatment with arthroscopic or open shoulder surgery, as determined to be standard of care by the orthopedic surgeons. Subjects with a history of prior surgery on the affected shoulder or chronic pain from osteoarthritis were excluded. The participating surgeons and one orthopedic nurse case manager informed eligible subjects about the research study. Preoperative planning for each patient was based on clinical data and any available radiological studies performed prior to the optional, research MRI. Volunteers interested in obtaining the research MRI were required to provide informed, written consent before completing a brief questionnaire and scheduling the MRI examination. Data collected on the questionnaire included patient gender, age, and duration and type of symptoms.

Over a 2-year period, 135 volunteers were gathered, which based on review of surgical schedules during that period reflected an approximately 50% recruitment rate of all potentially eligible participants. Although all 135 volunteers completed the research MRI, only 106 of the 135 subjects underwent arthroscopic shoulder surgery by one of the participating surgeons. Data were incomplete on 29 enrolled subjects who were lost to follow-up or did not undergo shoulder surgery at our institution due to military deployments, clinical improvement, or surgery completed at other medical facilities. Two patients were excluded from data analysis due to a delay of more than 6 months between MRI and surgery. Six other patients had a delay of more than 3 months, but chart review revealed no new episodes of shoulder trauma between the time of MRI and surgery.

MR imaging

All MRI examinations were performed on a 1.5 Tesla GE Signa magnet (Milwaukee, WI, USA) using a dedicated phased-array shoulder coil and fast spin echo (FSE) sequences. The technical parameters for the noncontrast MRI pulse sequences were as follows: axial fat-suppressed scan, repetition time (TR)/echo time (TE) of 2,800/34 ms, 12 cm field of view (FOV), 3.5 mm section thickness, 0 mm intersection gap, echo train length (ETL) of 8, two signals averaged, and 224×256 image matrix; axial scan at TR/TE of 3,450/34 ms, 14 cm FOV, 3.5 mm thickness with 0.3 mm gap, ETL of 8, two signals averaged, and 512×384 image matrix; axial fat-suppressed scan, TR/TE 4,500/34 ms, 14 cm FOV, 3.5 mm thickness with no gap, ETL of 8, two signals averaged, and 512×256 matrix; coronal oblique scan, TR/TE 3,950/36 ms, 14 cm FOV, 3.5 mm thickness with no gap, ETL of 8, two signals averaged, and 512×256 matrix; coronal oblique fat-suppressed scan at TR/TE 3,500/70 ms, 14 cm FOV, 3.5 mm thickness with no gap, ETL of 6, two signals averaged, and 256×224 matrix; and sagittal oblique scan at TR/TE 3,000/70 ms, 12 cm FOV, 4 mm thickness with no gap, ETL of 8, three signals averaged, and 256×224 matrix.

After receiving an i.v. injection of a 0.2 ml/kg dose (0.1 mmol/kg) of a paramagnetic contrast agent (Magnevist, Berlex Laboratories, Wayne, NJ, USA), subjects remained at rest for 5 min before T1-weighted FSE fat-suppressed images were initiated. Axial images were acquired first, followed by coronal oblique and sagittal oblique scans at an ETL of 2, FOV of 13 cm, 4 mm slice thickness, 0 mm intersection gap, two signals averaged, and 192×256 image matrix.

Interpretation and data analysis

Two musculoskeletal radiologists, each with more than 5 years of subspecialty experience, and with experience interpreting shoulder I-MRa in clinical practice, completed separate, independent reviews of the noncontrast and contrast-enhanced examinations while blinded to clinical and surgical data. The IRB required that a radiologist provide an official report of findings on one of the image sets for potential patient care purposes. To meet this requirement, one of the readers interpreted noncontrast MR images of the first 20 enrolled subjects, interpreted I-MRa images of the next 20 consecutive subjects, and continued this alternating pattern, later reviewing the other image sets in a random, blinded fashion. The second reader also alternated the sequence of MRI/I-MRa review in sets of 15–20 patients with a delay of at least 1 week between review sessions. For research purposes, the readers graded the labrum as either intact or torn on data sheets saved in research files. The MRI and I-MRa images were not combined in rendering a final clinical or research interpretation.

The radiologists treated the glenoid rim as an analog clock face, with the superior labrum occupying the 11 to 1 o'clock position. The labrum was considered abnormal if it showed surface irregularity, increased signal intensity (or contrast enhancement) extending to its surface, or detachment from the glenoid rim not meeting criteria for a sublabral recess or foramen [10–13]. The readers regarded a normal sublabral recess to be a sulcus containing fluid or contrast at the bicipital-labral junction and following a medial orientation in parallel with underlying articular cartilage. Abnormal superior labral detachment was diagnosed if there was labral surface irregularity, hyperintense T2 signal or contrast enhancement that extended laterally into the labrum, or fluid in a deep sublabral sulcus that extended centrally beyond visible articular cartilage or posterior to the level of biceps attachment. The readers considered a normal sublabral foramen to be a sulcus separating a well-defined labrum from the glenoid rim in the region of 2 o'clock, anterior to the bicipital-labral junction. The readers attempted to subcategorize the superior labral anteroposterior (SLAP) tears with reference to the Snyder classification [14]. However, for data analysis, the labrum was considered either normal or torn.

Data were analyzed using SPSS statistical software (Statistical Package for the Social Sciences, version 11.0). For each radiologist, sensitivity, specificity, and accuracy were calculated, and the McNemar test was applied to detect significant differences between MRI and I-MRa interpretations. A p value of less than 0.05 was considered statistically significant. Using the modified Wald method, 95% confidence intervals were determined, as well.

Arthroscopic evaluation

The reference standard was arthroscopic shoulder surgery performed by two fellowship-trained orthopedic surgeons, each with extensive experience in joint arthroscopy. The surgeons were not consistently blinded to MRI reports or images, which were widely available on the institution's image network. In the arthroscopic procedure, a routine posterior portal was created for inspection of the glenohumeral joint and, if needed, additional portals were established for additional viewing and completion of arthroscopic surgery. Sixty-five patients also underwent bursoscopy. The surgeons provided written summaries regarding integrity of the glenoid labrum, presence of normal anatomic variants, and treatment administered. The superior labrum was considered normal if intact and untreated at surgery and abnormal if treated with débridement or repair. Superior labral injuries were described, when deemed appropriate, with reference to the Snyder classification system [14] or using additional subtypes of labral injury [15, 16]. Our surgeons describe two subtypes of type II SLAP tears: those with a stable biceps anchor that are treated with débridement and others that are unstable with a positive peel-back sign (often seen in throwers) that require labral repair [17].

Results

The 104 subjects consisted of 82 men and 22 women with a mean age of 40 years (range: 18–65 years). The average length of shoulder symptoms was 39 months, with duration of symptoms ranging from 1 month to 19 years. Pain was the most common symptom, described by all volunteers. The interval between the time of MR imaging and surgery ranged from 1 to 175 days, with a mean of 30 days. Of the 104 subjects with MR imaging and arthroscopic correlation, 80 had abnormalities of the superior labrum that were either débrided or repaired, and 24 had an intact superior labrum.

With arthroscopy as the standard, the most common type of superior labral lesion was fraying (n=44) without disruption of biceps-labral anchor stability; these stable lesions were treated with labral débridement alone. Three subjects in this group had a sublabral recess with fraying at

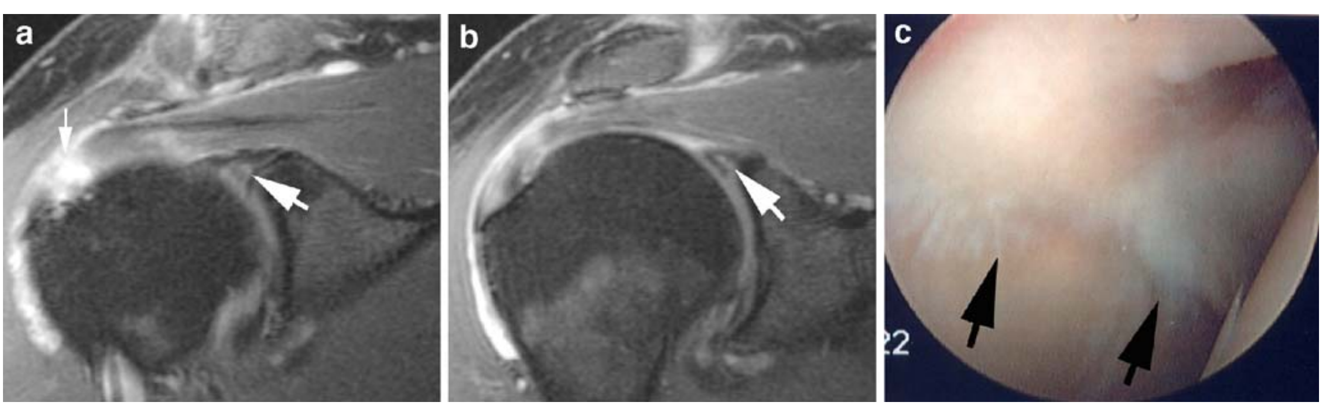

Fig. 1 a–**c** Frayed superior labrum (*arrows*) with sublabral recess misinterpreted as type II SLAP injury by both readers on contrast-enhanced T1-weighted MR images (**a**,**b**) in this 46-year-old male with a full-thickness supraspinatus tear (*small arrow* in **a**). **c** At arthroscopy, the biceps anchor was intact and a frayed meniscal-like superior labrum (*arrows*) was débrided

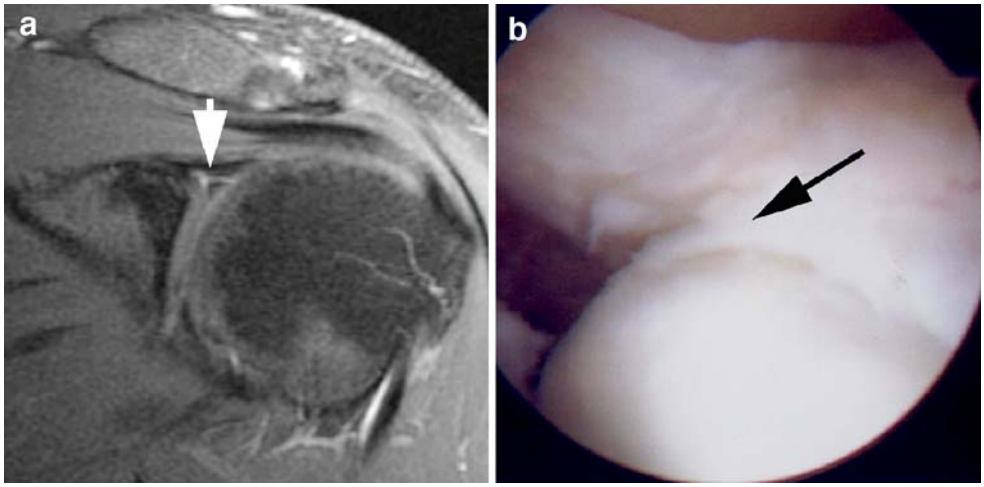

Fig. 2 **a**, **b** Type III SLAP tear correctly diagnosed by both readers on contrast-enhanced images. **a** Coronal oblique fat-suppressed T1-weighted MR image with contrast shows the bucket-handle tear (*arrow*). **b** Arthroscopic view shows torn labral fragment (*arrow*)

the free edge of a normal variant meniscoid-type superior labrum, in which the labrum had a triangular shape similar to a knee meniscus, with a free edge and loose attachment to the underlying superior glenoid (Fig. 1) [18]. One subject had labral fraying with a sublabral recess and foramen. Of the 44 subjects in this group, 34 had associated rotator cuff tears diagnosed with arthroscopy: partial articular surface rotator cuff tendon tears (n=21), partial bursal surface cuff tears (n=2), and full-thickness rotator cuff tears (n=11).

Thirty-two superior labral injuries were classified as type II SLAP tears and four as type III tears (Fig. 2). Of the 32 patients with type II SLAP tears, 7 had a stable biceps anchor as determined with direct visualization, probing, and absence of a superior labral peel-back sign. The 25 subjects with unstable type II SLAP injuries underwent arthroscopic labral repair. Of the 32 subjects with type II SLAP tears, 2 had anteroinferior extension of the labral tear in the form of a Bankart injury (i.e., type V SLAP tear), 1 had circumferential injury (i.e., type IX SLAP tear), and 4 had posterior extension (i.e., type VIII SLAP tear) [15, 19]. One subject had a Buford complex. Associated injuries to the rotator cuff included partial articular surface tendon tears (n=11) and full-thickness tears (n=2). Of the four subjects with type III SLAP tears, associated findings included a sublabral foramen (n=1) and partial articular surface rotator cuff tears (n=2). There were no subjects with a type IV SLAP tear.

Table 1 Sensitivity, specificity, and accuracy for diagnosis of superior labral lesions

	MRI		I-MRa	
	Reader A	Reader B	Reader A	Reader B
Sensitivity (n=80)[a]	85 (68)	66 (53)	91 (73)	84 (67)[b]
95% CI	75–91	55–76	83–96	74–90
Specificity (n=24)[a]	75 (18)	83 (20)	71 (17)	58 (14)
95% CI	55–88	64–94	51–85	39–76
Accuracy (n=104)[a]	83 (86)	70 (73)	87 (90)	78 (81)
95% CI	74–89	61–78	79–92	69–85

[a] Numbers are percentages. Numbers in parentheses were used to calculate the percentages. 95% CI=95% confidence interval using adjusted Wald method

[b] p=0.003 McNemar

Twenty-four subjects had a surgically intact superior glenoid labrum in which the superior labrum was left untreated. Based on the arthroscopic data, nine of these subjects also had a normal labrum and capsule throughout the remainder of the joint. Of the remaining 15 subjects, 3 had a sublabral foramen in the anterosuperior quadrant as well as fraying of the anterior labrum in the region of 1–4 o'clock; in addition, 1 of the subjects with a sublabral foramen had a meniscoid shape of the superior labrum with a sublabral recess. There was a heterogeneous collection of findings in the other remaining subjects, including a Buford complex (n=1), minimal fraying of a meniscoid superior labrum with sublabral recess (n=1), minimal labral fraying alone (n=1), superior glenohumeral ligament tear with anterior labral fraying (n=1), meniscoid superior labrum with sublabral recess, sublabral foramen and anterior labral fraying (n=1), anterior labral fraying (n=3), anterior labral tear with a stretched inferior glenohumeral ligament (n=1), Bankart injury (n=1), partial tearing of the posterior labrum (n=1), and glenohumeral ligamentous laxity without labral injury (n=1). Of the 24 subjects with an intact superior labrum, 13 had tears of the rotator cuff: partial articular surface (n=7), partial bursal surface (n=2), and full-thickness (n=4) tendon tears.

Each reader demonstrated improved sensitivity and accuracy, but decreased specificity, with I-MRa compared with noncontrast MRI (Table 1). The readers showed more success in recognizing the presence of superior labral tears than in correctly classifying the injuries to exactly match the arthroscopic findings. One reader correctly classified 59 of 104 superior labra on MRI and I-MRa. The other reader correctly classified 51 of the 104 superior labra with noncontrast MRI and 46 labra with I-MRa. For example, of the 44 subjects with stable, nonspecific tears or type I

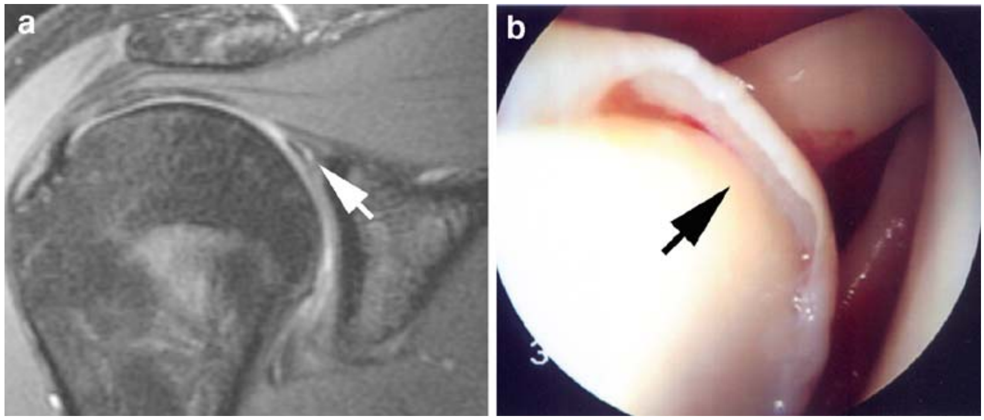

Fig. 3 **a**, **b** Type II SLAP tear (*arrow*) in a 26-year-old male was misinterpreted as type III SLAP injury by both readers. **a** Labral tear (*arrow*) on contrast-enhanced T1-weighted coronal oblique image. **b** Arthroscopic view of type II SLAP tear (*arrow*)

SLAP tears at arthroscopy, one reader incorrectly classified 9 as normal and 10 as type II SLAP tears with noncontrast MRI and classified 6 as normal and 12 as type II SLAP tears with I-MRa. In the group of 32 subjects with type II SLAP tears at arthroscopy, one reader correctly identified the presence of labral abnormality on 28 noncontrast (sensitivity of 88%) and 30 I-MRa (sensitivity of 94%) examinations, but only 60% were correctly classified as type II SLAP tears with each MR technique (Fig. 3). Of the four subjects with type III SLAP tears at arthroscopy, one reader used I-MRa to correctly classify two of the injuries, whereas the other two were misinterpreted as type II tears. With noncontrast MRI, this reader misinterpreted three of the four tears as type II SLAP injuries.

Discussion

The I-MRa technique, as described by Vahlensieck et al., involves an i.v. injection of gadopentetate dimeglumine followed by at least 10 min of joint exercise to promote contrast enhancement and diffusion, to achieve an effect similar to direct MR arthrography [1, 2]. Compared with conventional MRI, I-MRa with fat-suppressed MR sequences can improve contrast resolution between the joint cavity and surrounding structures, resulting in higher diagnostic accuracy for detection of glenoid labral tears [4, 5]. Several published reports suggest that I-MRa has diagnostic superiority compared with noncontrast MRI for detection of glenoid labral lesions. However, these studies have included relatively small numbers of patients [4–6, 9]. The largest group studied with glenohumeral I-MRa and surgical correlation is 35 patients [5].

For rotator cuff imaging, Allmann et al. determined that I-MRa without shoulder exercise might serve as a valuable, less time-consuming alternative [20]. In shoulders remaining at rest, these investigators found that definition of rotator cuff tears was improved on contrast-enhanced fat-suppressed T1-weighted gradient echo images compared with conventional MR images as early as 4 and 8 min after contrast injection [20]. For the glenoid labrum, Vahlensieck et al. have suggested that I-MRa may improve detection of labral tears when performed following joint exercise compared with no exercise [1], but the resting joints studied by Vahlensieck et al. were those of healthy volunteers, not patients with joint injuries. Therefore, in clinical practice, it has not been shown whether diagnostic performance of I-MRa is significantly improved with the addition of a time delay for joint exercise. It is possible that internal derangement of a joint may promote diagnostically signif-

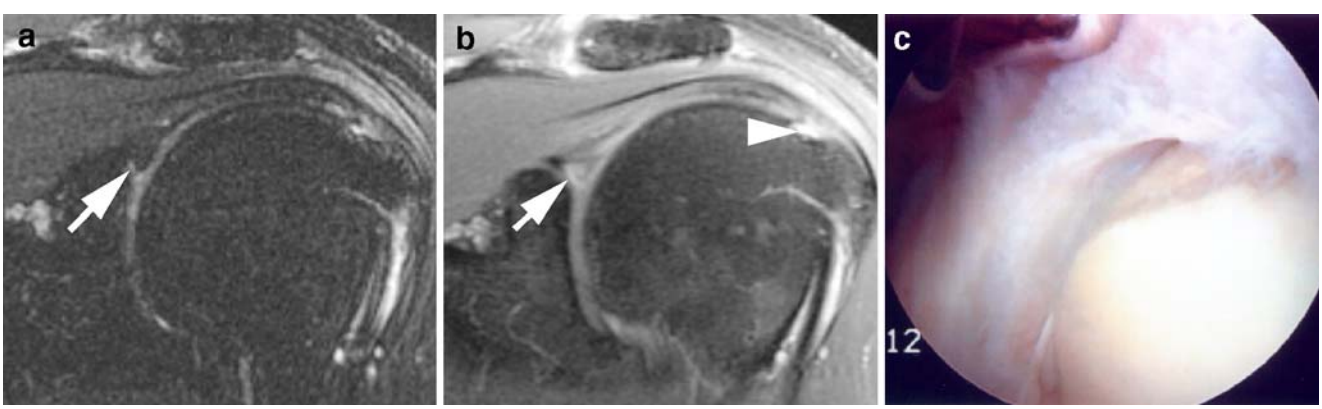

Fig. 4 **a**–**c** Type II SLAP tear, 53-year-old male. **a** Coronal FSE T2-weighted image with hyperintense signal at base of superior labrum (*arrow*), falsely considered a sublabral recess by one reader. **b** Coronal oblique T1-weighted image with contrast shows labral tear (*arrow*) detected by both readers. Note articular surface supraspinatus tendon tear (*arrowhead*). **c** Arthroscopic view of detached superior labrum

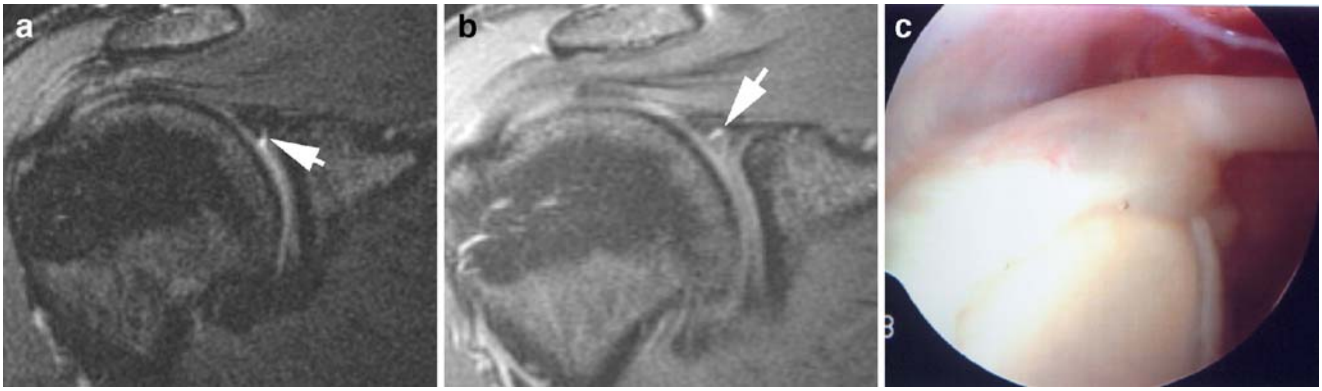

Fig. 5 **a**–**c** Normal superior labrum, 26-year-old male. **a** Normal superior labrum on FSE T2-weighted coronal oblique MR image, with hyaline cartilage undercutting (*arrow*). **b** Contrast-enhanced T1-weighted MR image shows a focus of labral enhancement (*arrow*), interpreted as labral tear by both readers. **c** Arthroscopy performed 7 days later showed normal biceps-labral junction

icant enhancement within minutes after intravenous injection of gadolinium contrast secondary to hyperemia, or fibrovascular tissue repair response, at sites of injury [3, 7, 8].

However, intravenous contrast enhancement may result in diagnostic dilemmas from enhancing vessels, or enhancing fibrovascular tissue, within structures of interest [1, 3]. Periosteal and capsular vessels provide blood supply to the glenoid labrum [18]. Blood supply is greatest at the periphery of the labrum, with decreased vascularity at the free edge; however, the degree of vascular penetration into the labral substance can be variable [18]. In a histopathological study of ten cadaveric shoulders with MRI correlation, Loredo et al. described the presence of fibrovascular tissue within labra of five shoulders [8]. Fibrovascular tissue may partly fill a labral tear defect or may develop in response to severe degeneration or injury at the base of a sublabral recess [7]. Therefore, a potential challenge in diagnostic interpretation of I-MRa is determining whether labral enhancement reflects normal vascularity, degenerative change, or underlying injury.

In our study of 104 symptomatic patients, we directly compared the diagnostic performance of noncontrast MRI with I-MRa of shoulders remaining at rest. However, we did not compare the diagnostic performance of various I-MRa techniques. Several studies have already shown that with the addition of joint exercise I-MRa improves detection of superior labral lesions compared with unenhanced shoulder MRI [4–6, 9]. For example, in a prospective study of 22 SLAP lesions in 35 patients, Herold et al. discovered that sensitivity improved from 73 to 91% and accuracy improved from 77 to 89% with I-MRa [5]. Our results were similar to previously published reports in that I-MRa was more sensitive for diagnosis of superior labral lesions than noncontrast MRI. In fact, for one radiologist, there was a statistically significant difference. These results suggest that some labral tears become more conspicuous on fat-suppressed I-MRa images from the improved contrast resolution provided by i.v. gadolinium (Fig. 4).

However, in our experience, the major drawback to I-MRa performed without preceding shoulder exercise is decreased specificity. The relatively small number of subjects with intact labra (n=24) in the study population may have contributed to this result. In addition, the study design likely affected performance of I-MRa. In order to eliminate interpretation bias, I-MRa images were reviewed without benefit of the pre-contrast imaging data. Consequently, an isolated finding of enhancement within or near the surface of the labrum on I-MRa may have been misinterpreted as labral injury in some of the subjects (Fig. 5). The misinterpretation of a sublabral recess as a labral tear could decrease specificity, as well, especially if I-MRa improves detection of labral variants, if labral tissue enhances at the base of a recess, or if there is an

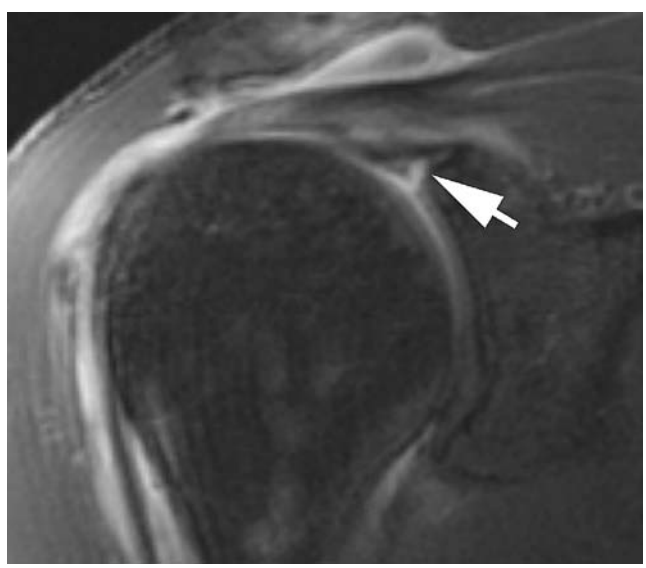

Fig. 6 Full-thickness supraspinatus tendon tear and sublabral recess in 43-year-old male. Coronal oblique T1-weighted contrast-enhanced MR image shows sublabral recess (*arrow*), which could not be firmly distinguished from a type II SLAP tear by either reader

associated tear of the anterior supraspinatus tendon (Fig. 6). The finding of an anterior rotator cuff injury in the setting of a questionable labral abnormality could bias a radiologist to diagnose a combined superior labrum anterior cuff (SLAC) lesion [21].

Selection bias is another limitation that likely affected our results. The radiologists may have been tempted to overdiagnose questionable findings in the population studied, as there was high likelihood of a surgical lesion in each enrolled patient. Selection bias may account for the high percentage of subjects with concomitant labral and rotator cuff lesions, many in whom the rotator cuff pathology could have been the primary source of shoulder pain. In some patients, superior labral fraying may have been “incidentally” noted and débrided at arthroscopy, accounting for the relatively high prevalence (77%) of superior labral lesions in this study. In our study population, all subjects described shoulder pain. At surgical inspection, the majority of subjects (62 of 104) had rotator cuff tears. Fraying or tearing of the superior labrum without compromise of biceps-labral anchor stability was a common finding. In those subjects with combined rotator cuff and labral lesions, the degree to which the labral lesion contributed to shoulder symptoms could not be precisely measured.

With direct MR arthrography, superior labral tears can be correctly classified in 66–76% of cases [22, 23]. In our study performed with I-MRa, the readers had limited success in correctly classifying superior labral lesions to match the arthroscopic results. There are several potential reasons for the MR imaging and arthroscopic discrepancies. In our study, the MR images may have lacked sufficient resolution to consistently and accurately define labral fraying. With MRI, there can be instances in which severe labral fraying and type III SLAP tears are difficult to distinguish from type II tears, or vice versa. Furthermore, it can be difficult to consistently distinguish normal anatomic variants from labral injury [24]. As reported in the surgical literature, anatomic variants in the anterosuperior quadrant have a statistically significant association with injury to the superior glenohumeral ligament, fraying of the anterosuperior labrum, and SLAP lesions [25, 26]. This association could negatively affect accuracy of MRI interpretation. For example, fraying of a sublabral recess or sublabral foramen may be incorrectly interpreted as a type II SLAP lesion or anterior variant of the type II SLAP tear [16].

In conclusion, our study shows that indirect shoulder MR arthrography performed without a time delay for shoulder exercise is more sensitive for superior glenoid labral lesions than noncontrast MR imaging. However, in our experience, the main drawback of I-MRa is a potential overdiagnosis of superior labral tears, resulting in decreased specificity of the technique. Radiologists using I-MRa in clinical practice must be cautious if they predominantly rely on fat-suppressed T1-weighted images for labral tear diagnosis, especially if they do not perform the MR examination with a time delay for shoulder exercise or carefully compare findings on fat-suppressed T1-weighted images with coronal oblique intermediate- or T2-weighted images.

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