## Title

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SCIENTIFIC ARTICLE

# Gradient-recalled echo sequences in direct shoulder MR arthrography for evaluating the labrum

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**Abstract**
*Objective* The purpose of this study was to determine the utility of fat-suppressed gradient-recalled echo (GRE) compared with conventional spin echo T1-weighted (T1W) sequences in direct shoulder MR arthrography for evaluating labral tears.
*Materials and methods* Three musculoskeletal radiologists retrospectively reviewed MR arthrograms performed over a 12-month period for which surgical correlation was available. Of 180 serial arthrograms, 31 patients had surgery with a mean of 48 days following imaging. Paired coronal oblique and axial T1W or GRE sequences were analyzed by consensus for labral tear (coronal oblique two-dimensional multi-echo data image combination, 2D MEDIC; and axial three-dimensional double-echo steady-state, 3D DESS; Siemens MAGNETOM Sonata 1.5-T MR system). Interpretations were correlated with operative reports.
*Results* Of 31 shoulders, 25 had labral tears at surgery. The GRE sequences depicted labral tears in 22, while T1W images depicted tears in 16 (sensitivity 88% versus 64%; $p<0.05$). Subdividing the labrum, GRE was significantly more sensitive for the posterior labrum (75% versus 25%; $p<0.05$) with a trend toward greater sensitivity at the anterior labrum (78% versus 56%; $p=0.157$) but not significantly different for the superior labrum (50% versus 57%; $p>0.7$). Specificities were somewhat lower for GRE.
*Conclusion* Thin section GRE sequences are more sensitive than T1W for the detection of anterior and posterior labral tears. As the specificity of GRE was lower, it should be considered as an adjunctive imaging sequence that may improve depiction of labral tears, particularly smaller tears, in routine MR arthrography protocols.

**Keywords** Shoulder MR arthrography · Magnetic resonance · Pulse sequences · Labrum

Preliminary results of this study were presented at the Annual Meeting of the Society of Skeletal Radiology, Orlando, FL, USA, on 21 March 2007.

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## Introduction

Direct shoulder MR arthrography with intra-articular contrast is the most commonly utilized imaging technique for evaluation of the labroligamentous structures and cartilage. It is frequently performed in the diagnostic evaluation of shoulder pain or instability, particularly in the subacute to chronic phase when joint effusion is often absent. Symptoms and physical examination in the setting of labral tear may be nonspecific, and labral pathology may be the source of chronic pain. As this is often relied upon as the definitive imaging examination, findings at MR arthrography often influence the decision to pursue arthroscopic evaluation and treatment and aid in preoperative planning.

Conventional MRI is limited for evaluating the glenoid labrum due to the presence of cartilage undercutting, apposition of the glenohumeral ligaments, and normal variants including the sublabral sulcus and foramen. As such, direct arthrography distends the joint, separating and coating these small structures to optimize evaluation.

To date, studies that have evaluated the accuracy and sensitivity of this technique have relied upon multiplanar spin echo or fast spin echo T1-weighted imaging (T1W) with fat saturation as the primary sequences on which to

evaluate the labrum. Indeed, multiple recent reviews advocate triplane conventional T1W imaging as the staple of a standard shoulder arthrogram protocol [1–3].

While MR arthrography has been compared with and shown to be favored over conventional MRI, little research has been done to determine which pulse sequences best depict glenoid labral pathology in arthrography. To our knowledge, no previous studies have directly compared two-dimensional (2D) and three-dimensional (3D) gradient-recalled echo sequences (GRE) with T1W sequences in direct MR shoulder arthrography. The purpose of this study is to compare the diagnostic performance of 3D double-echo steady-state (DESS) versus fat-suppressed T1-weighted sequences in MR arthrography of the shoulder.

## Materials and methods

This study was approved by the Institutional Review Board of the David Geffen School of Medicine at UCLA; informed consent for this review was waived. The study is compliant with the Health Insurance Portability and Accountability Act.

We retrospectively reviewed consecutive MR shoulder arthrograms performed at a single institution over a 12-month period (April 2006 to April 2007). Cases for which subsequent surgical correlation was available were then retrospectively reviewed. Inclusion criteria for the study group included having no surgery prior to MRI, arthroscopic or open surgical exploration following MRI, and availability of both the GRE and T1W sequences at the time of retrospective review. Subjects of all ages were included and were referred by the sports medicine and orthopedic faculty for the examinations. Surgeons were aware of the prospective MR interpretations at the time of surgery.

Written informed consent was obtained from the participants before undergoing the procedure. Direct shoulder arthrography was performed from an anterior approach over the lower third of the glenohumeral joint under fluoroscopic guidance with a 22-gauge, 3.5-inch needle. After confirmation of needle placement with less than 1 cc of iodinated contrast material (Conray, iothalamate meglumine; Mallinckrodt, St. Louis, MO, USA), 14–18 cc of a dilute gadolinium solution (1:200) was instilled into the joint (Omniscan, gadodiamide; GE Healthcare, Oslo, Norway).

Imaging was performed within 30 min of joint injection on a Siemens MAGNETOM Sonata 1.5-T magnet. A dedicated phased-array shoulder surface coil (Siemens) was utilized with the extremity in neutral position. All sequences were performed with a 16-cm field of view.

Spin-echo T1W fat-saturated sequences were obtained in the coronal oblique, sagittal oblique, and axial planes. Axial sequences were performed with TR/TE 434/11 ms, slice thickness 4 mm with an interslice gap of 0.8 mm, matrix 192×256, number of excitations (NEX) 2, and an imaging time of 4 min, 17 s. Coronal oblique T1W images were obtained with TR/TE 492/11, slice thickness 4 mm with a gap of 0.8 mm, matrix 256×256, NEX 2, and imaging time 5 min, 33 s.

The fat-suppressed GRE sequence in the axial plane was a 3D DESS sequence with the following parameters: TR/TE 22/6 ms, slice thickness 1.2 mm with interslice gap of 0.2 mm, bandwidth 140 Hz/pixel, flip angle 25°, matrix 168×256, NEX 1, and an imaging time of 9 min, 16 s. The coronal oblique fat-saturated GRE sequence utilized was a 2D multi-echo data image combination (2D MEDIC) with the following parameters: TR/TE 883/23 ms, slice thickness 4 mm with gap of 0.8 mm, bandwidth 241 Hz/pixel, flip angle 25°, matrix 192×256, NEX 1, and an imaging time of 4 min, 16 s.

Review of the images was performed by three musculoskeletal radiologists with varying levels of experience (19, 5, and 2 years). The radiologists were presented with either the paired axial and coronal GRE or the axial and coronal T1W sequences. For purposes of this study, only the T1W and GRE sequences were retrospectively reviewed, although in clinical practice additional information may be obtained from other sequences, such as fat-saturated proton density sequence. Reviewers were not provided with the sagittal T1W sequence for review in this study.

Paired sequences were presented in random order. Interpretation was done in a consensus fashion with the reviewers blinded as to patient identifiers, clinical history, or the operative reports. Tears were diagnosed if there was abnormal imbibition of contrast into the labrum, if the labrum was absent, if there was abnormal morphology, or if the labrum was detached. Anterior and posterior labral tears were primarily evaluated on the axial images and superior labral tears predominantly on the coronal images. Recognized normal variants, including the sublabral sulcus and foramen, were disregarded.

The presence or absence of tearing of the labrum was scored in each of three regions—anterior, posterior, and superior—using a standardized analog clockface method. With this method, for example in the right shoulder, the anterior labrum is from 1 to 6 o'clock, posterior from 6 to 11 o'clock, and superior from the 11 to 1 o'clock region (Fig. 1). This method has been utilized previously [4]. Severity of the tearing was not scored.

Subsequently, the retrospective interpretations were correlated with the operative reports and scored, using the surgical findings as reference standard. All abnormalities of the labrum described at surgery, including descriptions such as "mild fraying," were considered positive surgical results. The locations of the tears reported in the operative descriptions were as closely matched to the above clockface method insofar as possible, with most reports also utilizing

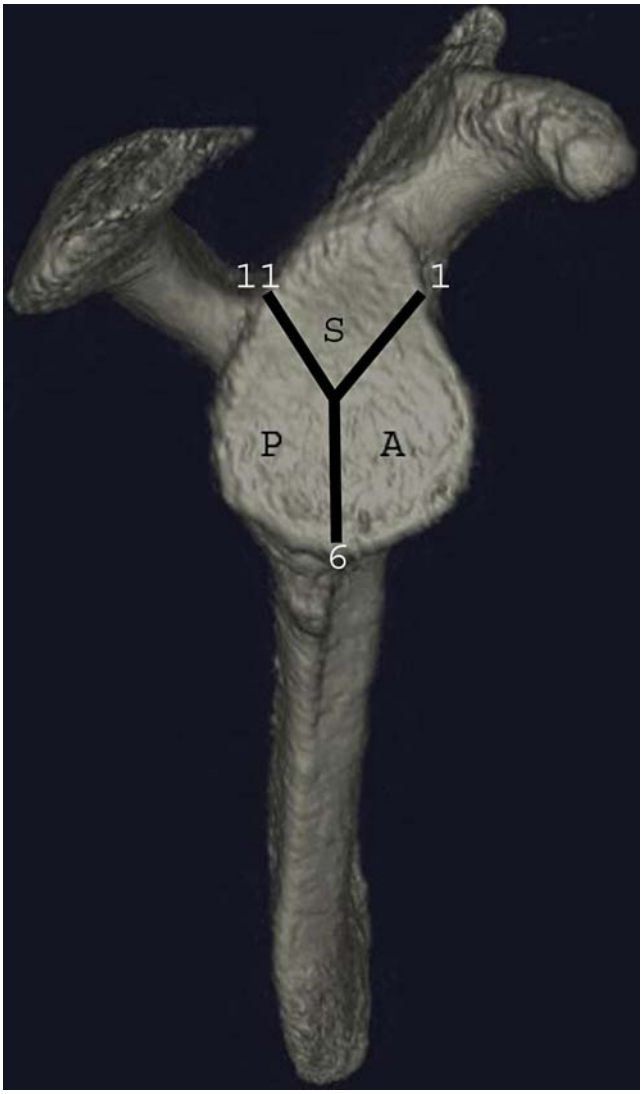


**Fig. 1** The glenoid labrum was subdivided into unequal thirds for analysis using an analog clockface method. On this 3D computed tomography image of the right glenoid, the superior labrum (*S*) extends from 11 to 1 o'clock, anterior (*A*) from 1 to 6 o'clock, and posterior (*P*) from 6 to 11 o'clock

a clockface method. Statistical analysis was performed using a Chi-squared test [5, 6].

## Results

A total of 180 MR shoulder arthrograms were performed over the 12-month period. Of these, 31 patients had had either arthroscopic (28) or arthroscopic-to-open (3) surgery following MRI, and these patients comprised the study population.

The study group ranged in age from 18 to 60 with a mean age of 33 years. Of the 31 patients, 28 were under the age of 50. Indications for surgery as gleaned from the operative reports were: chronic pain (18), instability (11), and impingement (2). The time from MRI to surgery ranged from 7 days to 160 days with a mean of 48 days. In 23 patients (74%) surgery was performed within 60 days of the MRI. Surgery was performed by four experienced orthopedists, each performing 20, 6, 3, and 2 operations. Twenty were carried out in right shoulders and 11 in the left, with 23 males patients and 8 female.

At surgery, a total of 25 of the 31 labra were torn. Dividing the labrum by region, 18 tears involved the anterior labrum, 8 the posterior labrum, and 14 the superior labrum. Within a shoulder, either the presence of multiple separate tears or an extensive tear spanning more than one region accounts for the greater number of tears upon subdividing the labrum.

The GRE sequences identified 22 of the 25 tears with a sensitivity of 88%, compared with the T1W sequences, which showed 16 of the 25 for a sensitivity of 64% ($p<0.05$). Of the 6 labra that were not torn at surgery, GRE identified tears in 3 of these, while there were no false-positives on the T1W images, giving specificities of 50% and 100% respectively ($p<0.05$).

In the anterior labrum, the GRE sequences identified 14 of the 18 tears, compared with 10 out of 18 for the T1W sequences (sensitivity 78 vs. 56%; $p=0.16$; see Figs. 2, 3). Of the 13 labra without an anterior tear at surgery, tearing was identified in 4 of these on the GRE sequences, while the T1W suggested tear in 1 (specificity 69% vs. 92%; $p=0.14$).

Of 8 posterior labral tears at surgery, the GRE sequences depicted 6, while the T1W showed 2 (sensitivity 75% vs. 25%; $p<0.05$; see Fig. 4a,c). Of 23 labra without a posterior tear at surgery, tears in 6 labra were identified on the GRE sequences compared with 3 for the T1W images (specificity 74% vs. 87% ; $p=0.27$).

Superior labral tears were shown in 14 labra at surgery. The GRE sequence showed a tear in 7 of these for a sensitivity of 50%, and the T1W, similarly, showed tears in 8 (sensitivity 50% vs. 57%; $p>0.7$; see Fig. 5). Of 17 superior labra that were intact at surgery, a tear was depicted in 3 cases on the GRE and in none of the cases on T1W imaging (specificity 82% vs. 100%; $p>0.06$).

## Discussion

In this study, 3D GRE DESS was significantly more sensitive than the T1W images for the detection of anterior and posterior labral tears. The axial 3D GRE sequence showed significantly increased sensitivity for posterior tears, with a strong trend toward increased sensitivity in detecting anterior tears. The coronal oblique 2D GRE sequence was not significantly better than the T1W images for depiction of superior tears.

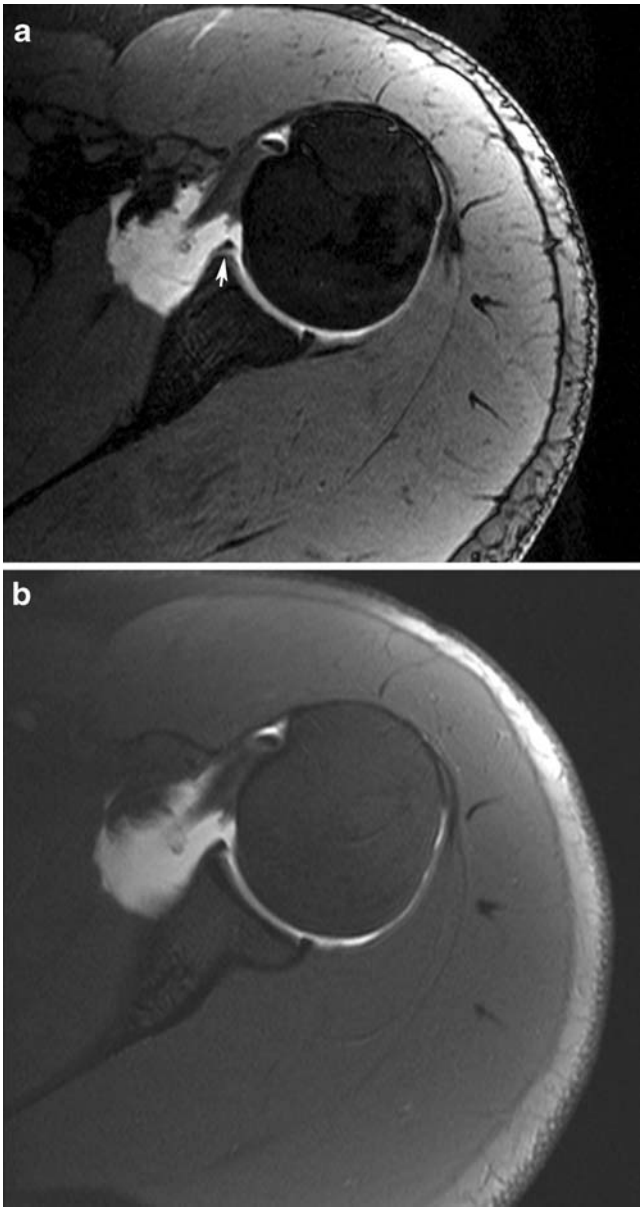


**Fig. 2** **a** On the axial fat-saturated gradient-recalled echo (GRE) 3D double-echo steady-state (DESS) sequence, linear contrast was appreciated extending across the base of the anteroinferior labrum without displacement (*arrow*), while the **b** tear was not appreciated on fat-saturated T1-weighted imaging. Tear with significant fraying was reported at arthroscopy

The overall sensitivity of the combined GRE sequences was 88% compared with 64% for the T1W images. Ultimately, the determination that the labrum is either normal or torn, regardless of site, is the fundamental concern of the examination. That said, in light of the retrospective nature of this study, sensitivities of the subdivided anterior, posterior, and superior labrum may be less accurate given difficulties in correlating the imaging compared with the surgical location of tears.

While MR arthrography is generally preferred over conventional unenhanced MRI for labral tears and has been shown to be more sensitive [7, 8], previous studies evaluating MR arthrography, including T1W sequences, have reported a wide range of sensitivities. Palmer et al. reported a sensitivity for labral tear of 92% [9, 10]. Studies evaluating specific labral regions have reported sensitivities for superior and superior labrum anterior–posterior (SLAP) tears ranging from 50 to 100% [11–15]. Anteroinferior labral tears have been reported with a sensitivity of 88% [16], anterior tears 86–95% [11], and posterior tears 7.7%.

To our knowledge, there have been no previous studies directly comparing GRE sequences with widely used T1W

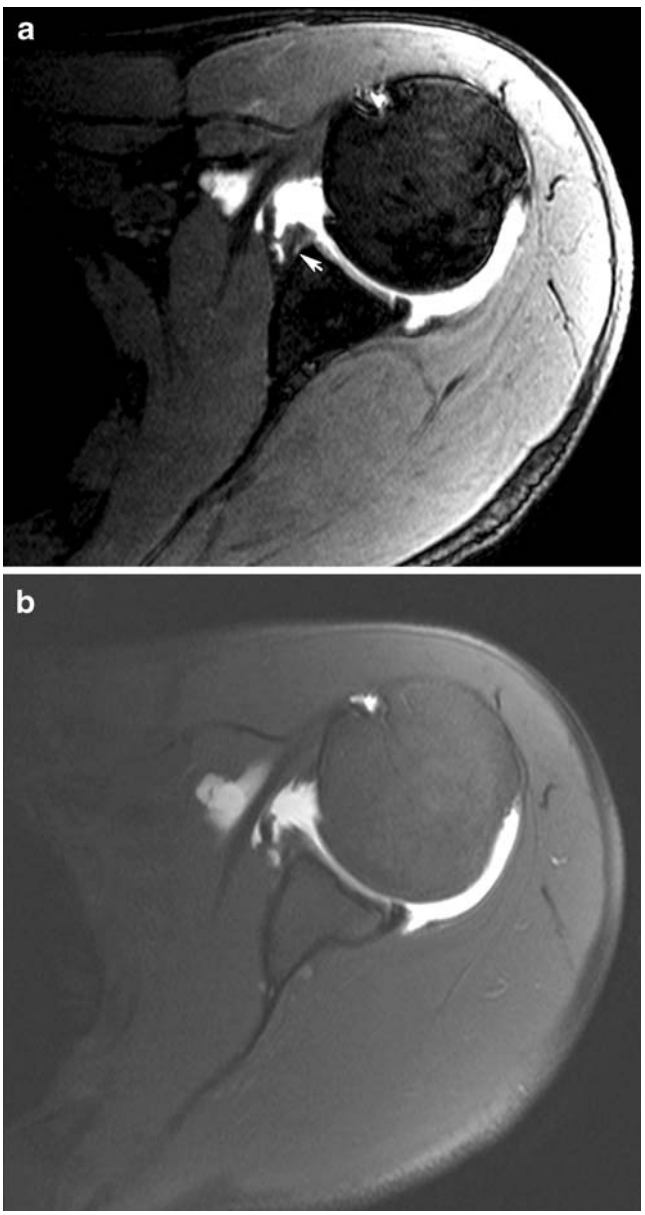


**Fig. 3** **a** Axial GRE 3D DESS image more clearly shows abnormal morphology of the anteroinferior labrum with a tiny amount of contrast imbibing into the base (*arrow*) compared with **b** the T1-weighted image at a comparable level. Surgery showed a Bankart lesion with avulsed labrum that was scarred down medially

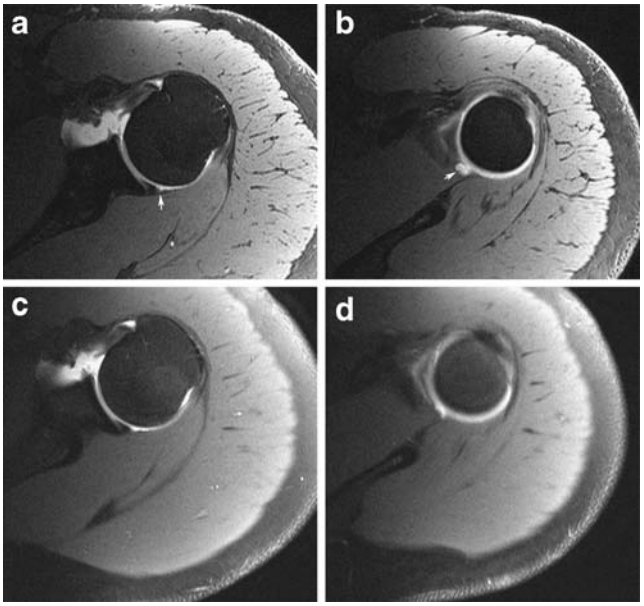


**Fig. 4** **a** Axial GRE 3D DESS image shows the irregular contour of the posterosuperior labrum (*arrow*), as well as **b** a small paralabral cyst (*arrow*) at a more superior level. **c** No abnormality was appreciated on the T1-weighted images on which the labrum appears smooth, and **d** the paralabral cyst was inconspicuous owing either to greater slice thickness or lack of filling of the cyst with contrast. Extensive posterosuperior labral fraying was reported at arthroscopy

fat-saturated sequences in direct MR shoulder arthrography. In one recent review of MR arthrographic techniques of multiple joints, the authors indicated that they included a fat-saturated T1-weighted 3D fast spoiled gradient echo sequence in one imaging plane in every joint, in addition to T1W spin echo or fast spin echo, to obtain thin sections that increased the depiction of small tears [17]. However, the authors did not provide data evaluating these sequences with regard to the glenoid labrum.

A recent study compared axial 2D with 3D GRE sequences in direct shoulder arthrography, reporting slightly superior detection of anterior but not posterior tears on 3D GRE compared with 2D GRE [18]. The authors, however, did not compare these sequences directly with T1W sequences.

The potential benefits of GRE in this study were particularly shown with the 3D DESS sequence used in the axial plane, which affords thinner sections and thereby likely improves conspicuity of tears. On this sequence, primarily the anterior and posterior sections of the labrum are evaluated. Slices measuring 1.25 mm were used in this study compared with 4-mm slices for the T1W images in the same plane, and there is also a thinner interslice gap of nonsampled tissue with the GRE sequence. Therefore, smaller tears in which only a thin band of contrast extended into the labrum were more optimally detected with GRE. As a matter of fact, comparing the coronal 2D GRE MEDIC with coronal T1W images, with the exact same image thickness and spacing, there was no statistical advantage in using the GRE sequence. The choice of larger slice thickness and gap for T1W images may also be partially responsible for decreased sensitivities for this sequence in comparison to the published literature. The majority of publications utilized a 3-mm slice thickness with no gap or just a 0.1-mm gap. In addition, optimizing various T1W image parameters, such as a longer TR, may have improved image quality and thus T1W sensitivity as well. On the other hand the higher sensitivity for axial GRE

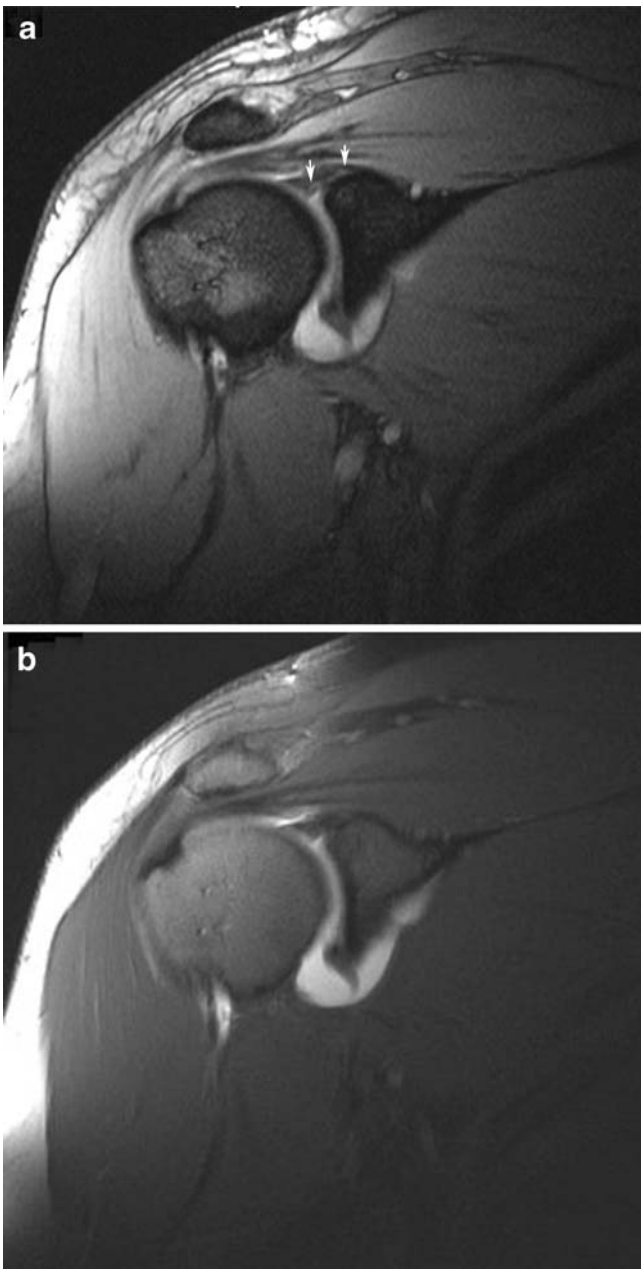


**Fig. 5** **a** Coronal GRE 2D multi-echo data image combination (MEDIC) image shows linear signal in the superior labrum directed laterally (*arrows*), inconspicuous on **b** the fat-saturated T1-weighted image. At arthroscopy, a superior labral tear was found

images may partially be due to the radiologists' comfort with interpreting the anterior and posterior labrum on GRE sequences included in the majority of routine shoulder MRI.

In addition, more subtle irregularities in labral contour were more conspicuous with GRE. This finding may be partially responsible for the low accuracy of the T1W images in our study, as GRE would more readily demonstrate mild fraying, in our institution regarded as a tear, whereas T1W images may be more sensitive for detecting "true symptomatic" tears. A follow-up study may be designed to separate labral fraying from "true symptomatic" tears (SLAP type II and above). A differentiation between these two categories in this study would have resulted in much lower total numbers and inability of a statistically significant analysis. In one case, a small paralabral cyst was evident on the axial GRE sequence, but completely inconspicuous on the T1W, likely due to the thinner slice of the 3D GRE sequence or possibly to the lack of filling of the cyst with contrast (Fig. 4b,d). GRE also enables greater contrast resolution.

An additional theoretical advantage of a 3D sequence is the potential for multiplanar imaging via post-processing of the 3D dataset, although the data may not prove isotropic to obtain high-quality images reliably.

The axial 3D GRE sequence was significantly more sensitive for the detection of posterior labral tears, but only a trend toward greater sensitivity for tears of the anterior labrum. This is likely due to the more subtle appearance of posterior tears in this patient population, which were more conspicuous with GRE. Anterior tears in the study population were often larger tears and commonly in association with obvious bony Bankart fractures well seen with both GRE and T1W, such that a statistically significant difference between the sequence types was not achieved with the study sample size.

In this study with a high prevalence of labral tears at surgery, there were only 6 cases in which no labral tear was present. The GRE sequences had a higher false-positive rate than T1W images in this small subset of patients. One possible explanation for the false-positive results is that not all portions of the labrum may be visualized at the time of surgery. Additionally, the intralabral signal abnormality that may have been identified on imaging is not evaluated at surgery, and therefore the labrum would be rendered intact at arthroscopy.

Gradient-recalled echo sequences have been faulted in the literature for possibly producing spurious intralabral signal that may confound the analysis of tears [19]. Intralabral signal abnormalities could result from histologic entities including fibrovascular tissue or mucoid or eosinophilic degeneration [20]. Multiplanar gradient-echo sequences in one study showed linear or globular signal in normal labra, although analysis was possibly confounded because the proposed normal population included asymptomatic healthy subjects without surgical correlation [20].

As such, when signal abnormality is identified on GRE that is not of contrast intensity or does not alter morphology of the labrum, the T1W images can be helpful in corroborating or dissuading a diagnosis of a tear.

One likely explanation for the lack of improved sensitivity on GRE over T1W images for the detection of superior labral tears is that the slice thickness of the coronal oblique 2D MEDIC GRE sequence in this study was the same as for the T1W images, 4 mm. As the glenoid is narrower in the anteroposterior than in the craniocaudal dimension, particularly at the superior portion of the pear-shaped glenoid, the coronal oblique sequence may particularly benefit in future protocols from thinner sections in order to improve spatial resolution and increase the number of slices on which the superior tears are delineated.

Limitations of this study include the retrospective nature of its design, which may limit the exact correlation of the location of tears by imaging and surgery. There was also a time lag between the imaging study and surgery, during which intercurrent injury to the labrum could occur and thereby confound the results. However, this would likely pose only a minor aberrance, if any. In 12 cases, surgery was performed within 30 days and in 23 cases under 60 days. In only 6 cases was surgery performed greater than 90 days after the imaging examination.

One additional consideration is the acceptance of the surgical findings as a true "gold standard." Arthroscopists may vary in their criteria as to what constitutes a torn compared with an intact labrum, and there may be significant interobserver variability regarding the grade of the tear. A recent description of a study utilizing video case vignettes reported significant interobserver variability amongst experienced arthroscopists in the diagnosis of SLAP tears, including difficulty in distinguishing normal shoulders from those with low-grade SLAP tears [21]. This phenomenon could account for imperfect correlation between the imaging examination and surgical findings, but would not necessarily explain any difference between the sequence types.

As this study was performed using a Siemens MAGNETOM Sonata 1.5T scanner, results may not be applicable to centers using scanners from other manufacturers. Reproducibility of these results and GRE sequences on other equipment should be further investigated as well. Likewise, GRE sequences at 3 T also warrant further consideration.

Incorporating a 3D DESS sequence into the routine protocol requires consideration of the time allotted for the examination, as the sequence, as it was performed in this study, requires just over 9 min for coverage from above the acromioclavicular joint through the proximal humeral diaphysis. One viable modification of the sequence that

would reduce the imaging time would be to scan only through the level of the glenohumeral joint. An additional adjustment that may improve signal-to-noise ratio would be to increase the flip angle in the gradient sequences, as performed in this study.

In summary, GRE sequences—particularly with the 3D GRE sequence that allows one to obtain thin sections—showed increased conspicuity of labral tears over conventional spin echo T1W fat-saturated sequences. It is our subjective experience that tears can be diagnosed with greater confidence on this sequence, and we have included it in our routine MR shoulder arthrography protocol. While the specificity was lower than for T1W images, GRE may be an important adjunctive sequence that will improve the clinical accuracy of this examination.

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