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ROTATOR CUFF REPAIR (M TAO AND M TEUSINK, SECTION EDITORS)

The Repaired Rotator Cuff: MRI and Ultrasound Evaluation

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Abstract

Purpose of Review The purposes of this review were to provide an overview of the current practice of evaluating the postoperative rotator cuff on imaging and to review the salient imaging findings of the normal and abnormal postoperative rotator cuff, as well as of postoperative complications.

Recent Findings The repaired rotator cuff frequently appears abnormal on magnetic resonance imaging (MRI) and ultrasound (US). Recent studies have shown that while the tendons typically normalize, they can demonstrate clinically insignificant abnormal imaging appearances for longer than 6 months. Features of capsular thickening or subacromial-subdeltoid bursal thickening and fluid distension were found to decrease substantially in the first 6-month postoperative period. MRI and US were found to be highly comparable in the postoperative assessment of the rotator cuff, although they had a lower sensitivity for partial thickness tears. Imaging evaluation of newer techniques such as patch augmentation and superior capsular reconstruction needs to be further investigated.

Summary MRI and US are useful in the postoperative assessment of the rotator cuff, not only for evaluation of the integrity of the rotator cuff, but also for detecting hardware complications and other etiologies of shoulder pain.

Keywords Rotator cuff repair · Magnetic resonance imaging · Ultrasound · Rotator cuff re-tear

Introduction

The rotator cuff plays an important role in shoulder abduction and rotation, with the supraspinatus aiding in abduction [1] and the infraspinatus and subscapularis functioning as the main external and internal rotators, respectively [2]. After repair of rotator cuff tendon tears, approximately 25% of patients may experience persistent or new pain and disability [3]. In the symptomatic patient after rotator cuff repair, the primary etiologies to consider include, but are not limited to, rotator cuff re-tear, impingement, and postoperative synovitis. Hardware dislodgement can also be an unexpected finding on imaging, which may cause significant pain and impairment [4, 5].

The rate of re-tears reported in the literature varies tremendously, ranging from 9 to 94% [6–8], with re-tears typically occurring within the first three postoperative months [9]. The risk of re-tear increases with patient age [6] and size of the preoperative rotator cuff tear [7]. Additional risk factors associated with re-tears include preoperative fatty infiltration of the rotator cuff musculature [4] and double-row repairs [8]. Magnetic resonance imaging (MRI) and ultrasound (US) are both used in evaluating pathology after rotator cuff repair. Our goal is to highlight both expected postoperative and abnormal findings on MRI, while underscoring the use of static and dynamic ultrasound as a complementary exam, particularly when a high likelihood of re-tear is suspected clinically.

MRI Evaluation of the Postoperative Rotator Cuff

After clinical and physical examination, radiographs are typically obtained for first-line evaluation [4, 10•]. If radiographs do not answer the clinical question, MRI can be performed to evaluate the rotator cuff integrity and assess for complications such as re-tear of the tendon or displacement of suture

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anchors. A recent study by Collin et al. found inter-observer agreement regarding MRI interpretation of the postoperative rotator cuff to range from 0.76 to 0.90 [11•]. At our institution, MRI of the repaired rotator cuff is acquired on a 1.5-T (Tesla) system (GE Healthcare, Waukesha, Wis) with our imaging parameters described in Table 1. To overcome artifacts from metallic shavings, the bandwidth can be increased to 80 kHz. In our experience, 3-T magnets have not provided additional diagnostic benefit over 1.5-T units in assessing the postoperative shoulder, while accentuating susceptibility artifact from metal [12].

MRI Appearance of the Repaired Rotator Cuff Tendon

Normal, native tendons on MRI should demonstrate homogenous low signal intensity without tendon thickening or attenuation, interposed fluid-intensity high signal, or discontinuity [13]. Repaired rotator cuff tendons, on the other hand, commonly demonstrate increased signal intensity on MRI; such appearance can be attributable to postoperative granulation tissue and inflammation or preexisting tendinosis, rather than a re-tear [14]. A small study by Spielmann et al. determined that only 10% of asymptomatic patients who had undergone rotator cuff repair had a normal MRI appearance of the rotator cuff tendon [15]. Patients who are asymptomatic with good function of their rotator cuff may still demonstrate tendon thinning on imaging [10•]. The repaired tendon may continue to appear thin or hyperintense up to a year after surgery (Fig. 1a–d) [14]. At the site of debridement, the tendon may have a smooth defect that is classically wider than it is deep, which should not be mistaken for a re-tear [16, 17]. Intermediate to low signal intensity foci may be identified within the repaired tendon, typically from either suture material, granulation tissue, fibrosis, or metal artifact from instrumentation [10•, 15, 16]. After the first postoperative year, the repaired tendon will begin to have a more normal appearance, but may demonstrate abnormal characteristics even years after surgery [14]. Additionally, it is important to be aware that portions of the rotator cuff may not have been repaired secondary to poor tissue quality, therefore continuing to demonstrate features of partial or full-thickness tear similar to the prior study; these should not be mistaken for re-tears [10•].

In irreparable or chronic, massive rotator cuff tears, surgical augmentation with graft may be performed to bridge the rotator cuff defect, or a superior capsular reconstruction to stabilize the humeral head [18•, 19, 20]. Dermal allograft, fascia lata autograft, or synthetic material may be used [18•, 21]. On MRI, the grafts typically demonstrate low signal intensity on proton density images; however, the literature on the MRI evaluation of rotator cuff and superior capsular reconstruction grafts is sparse [18•, 21, 22]. In patch augmentation, the two ends of the torn rotator cuff may not be in complete apposition, but the graft should bridge the rent in the rotator cuff; in superior capsular reconstruction, the graft should be continuous from the superior glenoid to the greater tuberosity for stabilization of the glenohumeral joint (Fig. 2a–f) [18•, 22, 23].

Increased signal within the greater tuberosity may also be a normal finding at the site of suture anchor placement, as this is seen even in asymptomatic patients [15]. Subacromial bursitis may be a finding after rotator cuff repair and can be seen in both symptomatic and asymptomatic patients (Fig. 3a, b) [17]. Causative factors of subacromial bursal fluid include leakage of joint fluid through a repaired tendon, synovitis inciting a bursitis, or postoperative scarring [17].

At our institution, intra-articular gadolinium is not used in the setting of prior rotator cuff repair. In our experience, optimized high-resolution noncontrast MRI on 1.5T units is accurate for identifying clinically significant re-tears of the rotator cuff. A study by Duc et al. came to a similar conclusion, as did a recent meta-analysis by Roy et al., finding that MR arthrography does not provide improved diagnostic performance when compared to standard unenhanced MRI [24, 25•].

Table 1 MRI protocol for imaging of the shoulder

PPlane/sequence	FOV (cm)	Matrix (frequency × phase)	Slice thickness/gap (mm)	TE (msec)	TR (msec)	TI (msec)	Bandwidth (kHz)	NEX
3 plane localizer SS FSE	20	256 × 128	7/0	Min	Min	–	31	1
Oblique coronal IR FSE	17	288 × 288	3.5/0	17	4000	150	31	2
Oblique coronal PD FSE	16	512 × 384	3/0	24	4000	–	31	2
Axial PD FSE	15	512 × 384	3/0	24	4000	–	31	2
Oblique sagittal PD FSE	15	512 × 320	4/0.5	24	4000	–	31	2

FOV field of view, *TE* time to echo, *TR* time to repetition, *TI* inversion time, *NEX* number of excitations, *ETL* echo train length, *SS FSE* single shot fast spin echo, *IR* inversion recovery, *FSE* fast spin echo, *PD* proton density

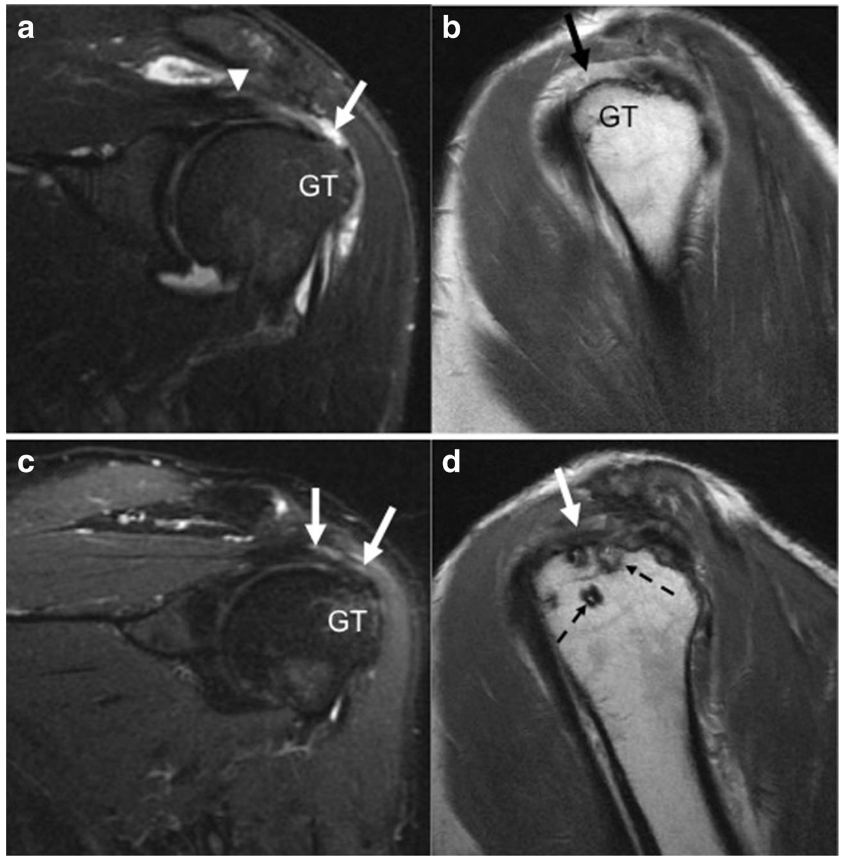


Fig. 1 **a**–**d** Fifty-six-year-old man initially presenting with rotator cuff tear: preoperative and postoperative imaging. Preoperative oblique coronal IR (**a**) and oblique sagittal PD (**b**) images demonstrate the supraspinatus tendon (arrowhead) with a fluid-filled gap (arrow) and no normal fibers inserting onto the greater tuberosity (GT), consistent with a full thickness tear. Ten months after rotator cuff repair, oblique coronal IR (c) and oblique sagittal PD (d) images demonstrate somewhat irregular and slightly hyperintense supraspinatus tendon fibers (arrows) inserting onto the greater tuberosity, without a fluid filled gap to suggest a re-tear. Suture anchors (dashed arrows) are noted within the greater tuberosity

Complications of Rotator Cuff Repair on MRI

Familiarity with the typical appearance of the postoperative tendon is important when approaching the repaired rotator cuff, as most repaired tendons demonstrate irregularity on MRI and US in the 1-year postoperative period, which should not be mistaken for a failed tendon repair or re-tear [14]. Re-tears are typically thought to be a result of failed tendon healing due to inadequate tissue quality or failure of fixation, either at the bone-tendon interface or from suture breakage [10•, 26, 27]. A re-tear typically manifests as a full-thickness discontinuity with gap of tendon fibers where there is intersecting fluid signal, reflecting a large rotator cuff defect usually occurring at the supraspinatus tendon (Fig. 4a–c) [14, 15, 17, 28]. Medial retraction of the proximal tendon and muscle edge can be seen as a secondary sign of re-tear [28]. However, as stated already, a full-thickness or partial-thickness defect of the cuff may be a normal postoperative appearance if that portion of the tear could not be successfully repaired intraoperatively. This can pose a challenge for interpretation and knowledge of the exact surgical technique as well as comparison to prior MRI becomes critical. Additionally, similar findings of discontinuity with hyperintense, fluid intensity signal within the gap indicate a failure of surgical grafts [18•].

While one of the limitations of MRI includes artifact from metallic material, bioabsorbable suture anchors are well demonstrated on MRI and result in minimal artifact in contradistinction to older metallic screws [11•, 29]. Partial or complete dislodgement of the rotator cuff anchors from the humeral head is yet another complication of the repaired cuff (Fig. 5a–b). In a small study by Magee et al., 13 of 30 patients who presented with pain after rotator cuff repair demonstrated dislodgement of the rotator cuff anchors, all presenting in the first 6-month postoperative period [30]. As bioabsorbable anchors are not visible on radiographs, MRI is important for assessing their integrity [30, 31]. Anchors displaced into the glenohumeral joint can incite a synovitis, causing new pain after arthroscopy or result in chondral injury and decreased range of motion (Fig. 6a–d) [5, 30]. If displaced into the glenohumeral joint, suture anchors can also cause a locking sensation of the shoulder [4, 5]. One case study found a suture anchor displaced into the acromioclavicular joint [29]. MRI can determine the number of anchors that are displaced and their location and can aid in surgical planning. Anchor dislodgement may or may not be accompanied by a cuff tear, and the rotator cuff tendons should be closely examined when there is identification of suture anchor failure [30].

Even without dislodgement, certain implants including suture anchors can incite an inflammatory reaction or result in

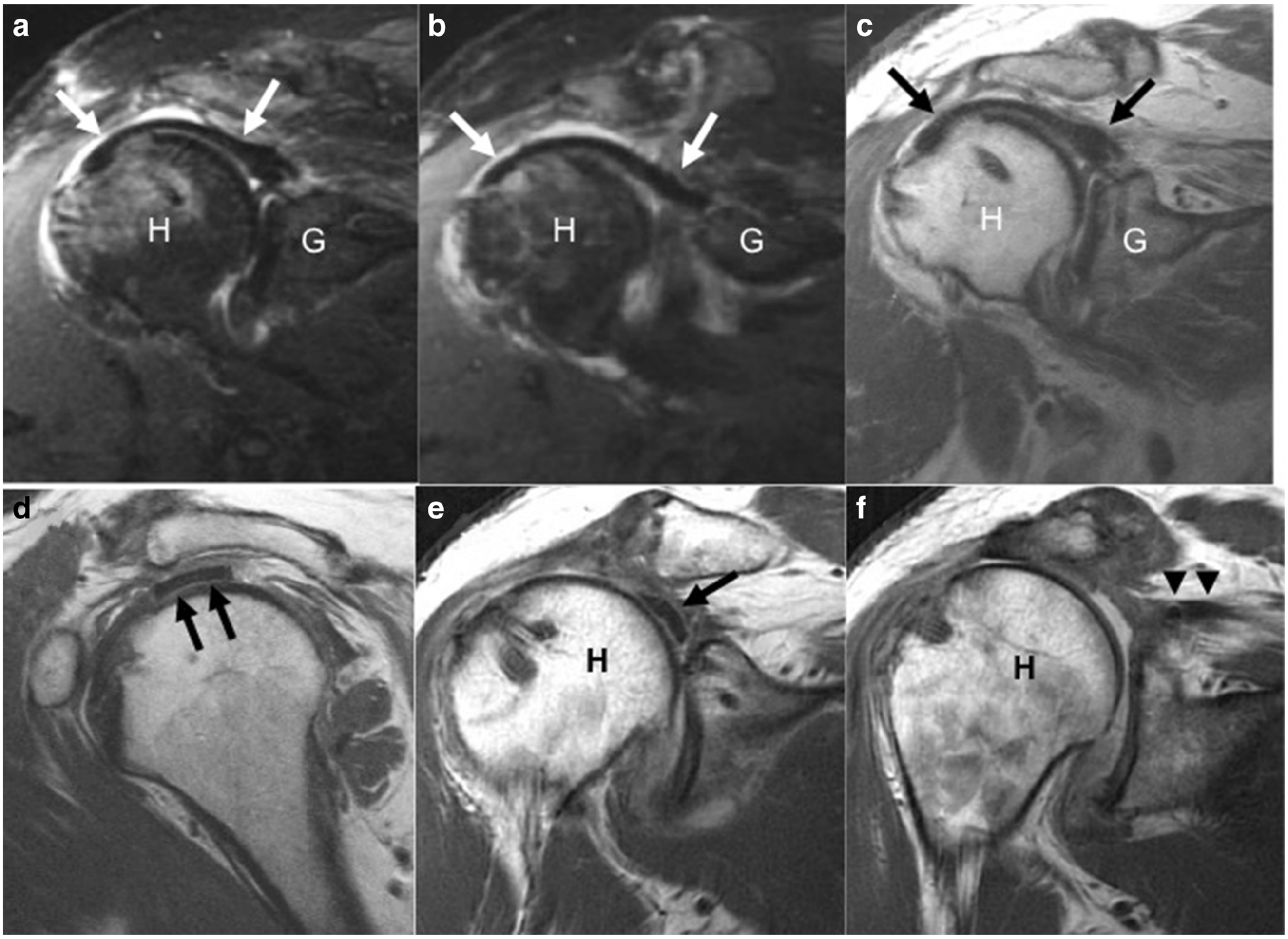
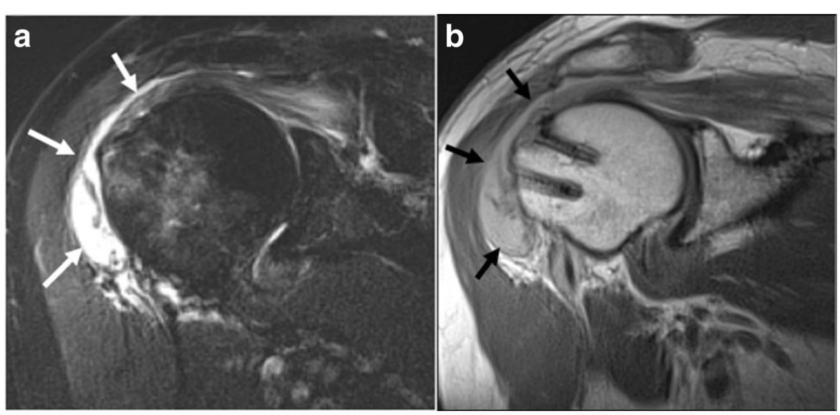


Fig. 2 **a**–**f** Sixty-year-old man, 4 months after superior capsular reconstruction. Oblique coronal IR (**a**, **b**), oblique coronal PD (**c**), and oblique sagittal PD (**d**) images demonstrate low signal intensity of the dermal allograft (arrows). The graft is closely apposed to both the greater tuberosity at the humeral head (H), as well as the glenoid (G). In a different patient (**e**, **f**), there is discontinuity of the low signal intensity graft (arrow) seen far anteriorly, with detachment from both the humeral head (H) and the medially retracted supraspinatus tendon (arrowheads). Previously, the graft had been surgically placed from the humeral head to the torn supraspinatus tendon

foreign body granulomas in the susceptible host [32–34]. On MRI, prominent and persistent bone marrow edema around the anchors associated with bony resorption is suspicious for an inflammatory reaction (Fig. 7a–c) [33]. The imaging features can overlap with infection particularly if these are accompanied by soft tissue edema, subacromial bursitis, and synovitis. While subacromial-subdeltoid bursitis can be seen in asymptomatic patients after rotator cuff repair (Spielman et al. found 67% of asympatomatic patients to have subacromial-subdeltoid bursitis), in the absence of focal

Fig. 3 **a**, **b** Fifty-year-old man with shoulder pain, 9 months after rotator cuff repair. Oblique coronal IR (**a**) and oblique coronal PD (**b**) demonstrate marked subacromial-subdeltoid bursitis (arrows) with fluid distension and debris



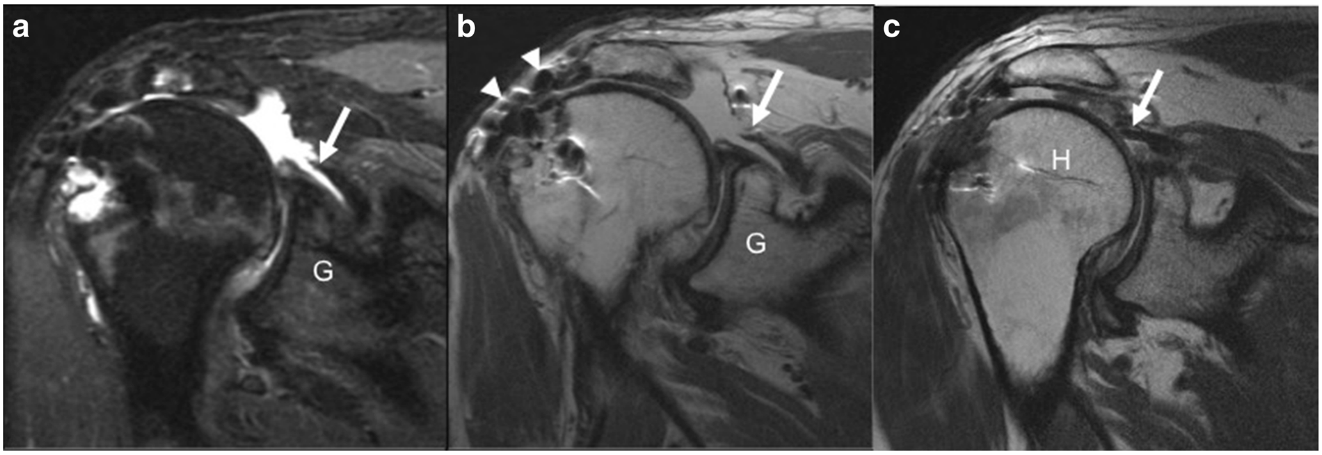


Fig. 4 **a**–**c** Forty-seven-year-old man, 5 months after most recent rotator cuff repair. Oblique coronal IR (**a**) and oblique coronal PD (**b**) images demonstrate a fluid filled defect with retraction of the supraspinatus tendon (arrow) to the level of the glenoid (G), consistent with complete rotator cuff re-tear. There is susceptibility artifact (arrowheads) from prior repair. In a different patient, oblique coronal PD (c) image demonstrates a complete tear of the repaired supraspinatus tendon (arrow) with retraction of the tendon fibers to the level of the humeral head (H)

tendon abnormality, a large amount of fluid in the bursa should raise suspicion for other etiologies such as infection or bursitis related to bioabsorbable surgical anchors [15, 28].

Other postoperative complications and etiologies of pain include acromial fracture, suprascapular or axillary nerve injury, deltoid dehiscence, capsular scarring, and biceps tendon subluxation or rupture [4, 10•, 28]. The glenohumeral joint should be examined for articular damage, either from dislodged suture anchors or post-arthroscopic glenohumeral chondrolysis [35–37]. Of course, other causes of pain such as labral tears and pathology unrelated to rotator cuff repair can also be identified on MRI [10•].

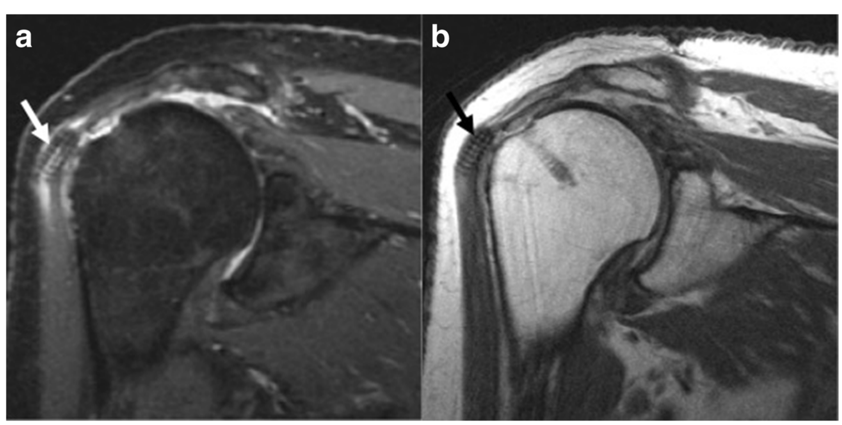
US Evaluation of the Postoperative Rotator Cuff

Indications for US

As US possesses high spatial resolution and allows the performance of dynamic maneuvers in real time, it can be very useful in the postoperative evaluation of the rotator cuff, particularly in the setting of metal artifact making MRI non-diagnostic [10•, 38]. Recent meta-analysis by Roy et al. found similar diagnostic accuracies between US and MRI in the evaluation for re-tears, with sensitivities and specificities over 0.90 for both imaging modalities in their detection of full-thickness tears, and over 0.90 specificities but somewhat lower sensitivities of 0.67–0.83 for partial-thickness tears [25•]. A more recent study by Okoroha et al. showed that MRI demonstrated greater inter-observer reliability in the evaluation of tear size, retraction, and muscle atrophy as compared to US [39]. In patients with contraindications for MRI, such as cardiac pacemakers, US is a valuable tool in assessing the repaired rotator cuff tendons [40].

A systematic approach should be taken when performing real-time diagnostic US of the postoperative shoulder. While US is highly operator dependent, a standardized examination can be useful in guiding treatment. At our institution, US is performed with the patient in a seated position using a high-frequency (6–15 MHz) linear broad-array transducer. The anterior structures (long head of the biceps tendon and

Fig. 5 **a**, **b** Seventy-nine-year-old woman, 6 months after rotator cuff repair, presents with clicking and soreness of the shoulder. Oblique coronal IR (**a**) and oblique coronal PD (**b**) images demonstrate a screw (arrow) displaced into the substance of the proximal deltoid muscle, inciting surrounding soft tissue edema, and subacromial-subdeltoid bursitis



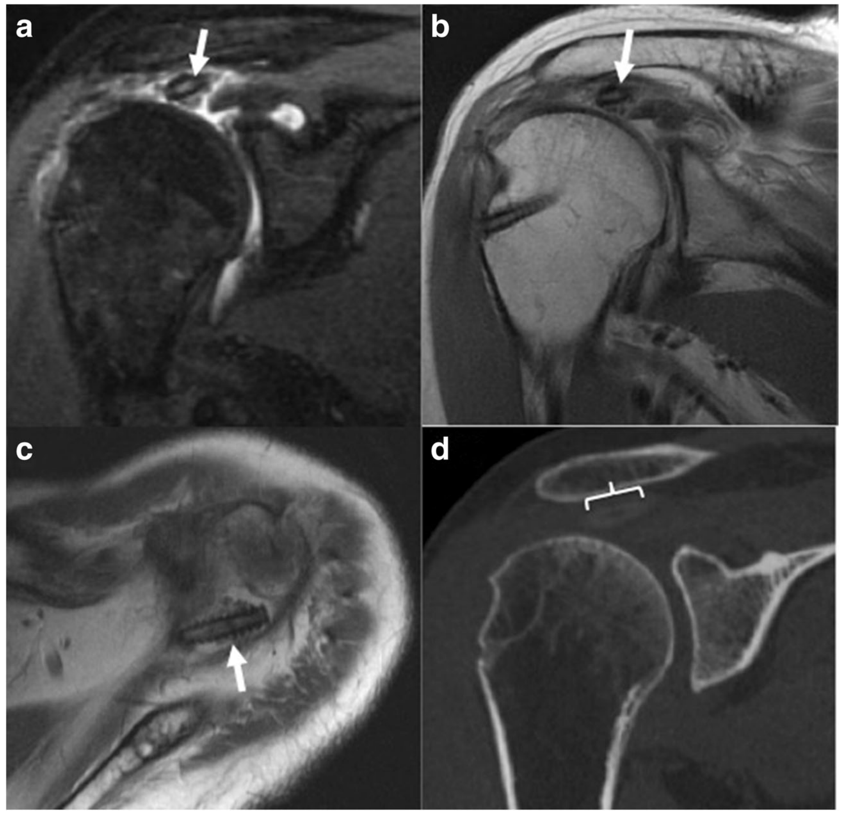


Fig. 6 **a**–**d** Fifty-six-year-old woman, 9 months after rotator cuff repair, presents with shoulder pain. Oblique coronal IR (**a**) and oblique coronal PD (**b**) images demonstrate a screw (arrow) displaced into the glenohumeral joint, generating a reactive synovitis. Axial PD (**c**) image best shows the entirety of the screw (arrow) within the joint, superior to the level of the humeral head. Oblique coronal CT image (**d**) again shows the faintly radiopaque screw (bracket) displaced superior to the humeral head

subscapularis tendon) are examined first, followed by superior structures (acromioclavicular joint, supraspinatus tendon, and subacromial-subdeltoid bursa), and the posterior structures (infraspinatus and teres minor tendons and posterior glenohumeral joint). While sonographic evaluation of the rotator cuff tendons is dependent on patient cooperation, such as the ability to maneuver into the Crass and modified Crass positions for evaluation of the supraspinatus tendon footprint [41], complete supraspinatus tears at the footprint can still be identified with the patient imaged in the neutral position. Unlike an MRI, which is a static exam, the ability to perform dynamic maneuvers is an advantage of US. Abduction of the shoulder during real-time scanning of the supraspinatus tendon can assess for subacromial impingement [42].

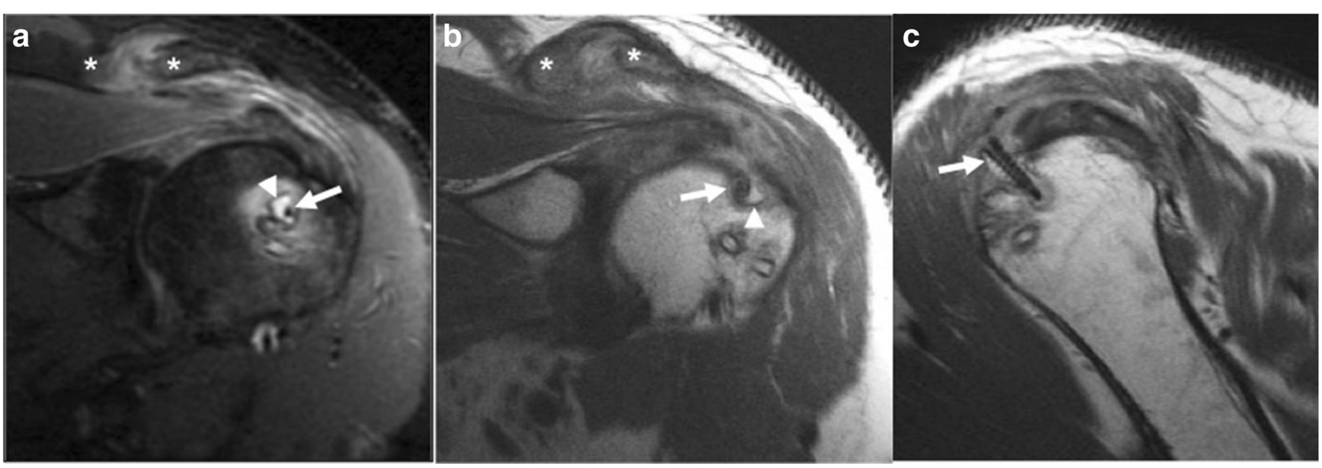


Fig. 7 **a**–**c** Forty-nine-year-old man, 4 months after rotator cuff repair, presents with shoulder pain. Oblique coronal IR (**a**) and PD (**b**) images demonstrate hyperintense signal (arrowhead) surrounding a screw (arrow), reflecting bony resorption with reactive bone marrow edema. The supraspinatus muscle belly and adjacent acromioclavicular joint (asterisks) demonstrate hyperintense signal, reflecting inflammatory changes. Sagittal PD (**c**) image demonstrates the same screw (arrow) proud to the humeral cortex

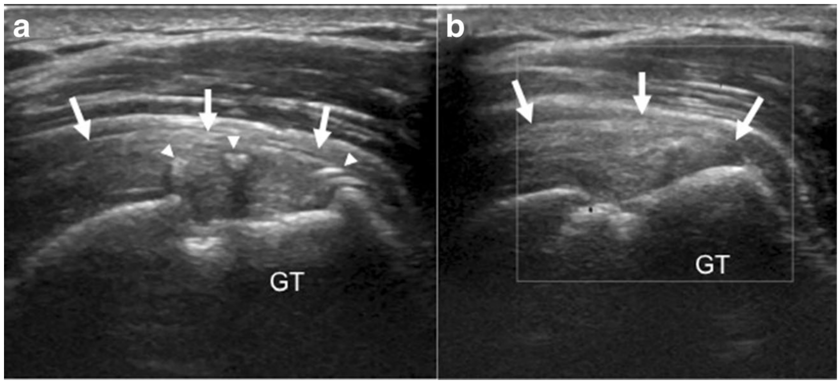


Fig. 8 **a**, **b** A 51-year-old man, 1 year after rotator cuff repair, demonstrates a normal appearance on ultrasound after rotator cuff repair. The supraspinatus tendon (arrows) appears thickened and slightly hypoechoic, but there is no fluid filled defect disrupting its insertion onto the greater tuberosity (GT). Hyperechoic sutures (arrowheads) with posterior acoustic shadowing are identified within the substance of the supraspinatus tendon (arrows), and there is no increased vascularity seen on doppler images (b)

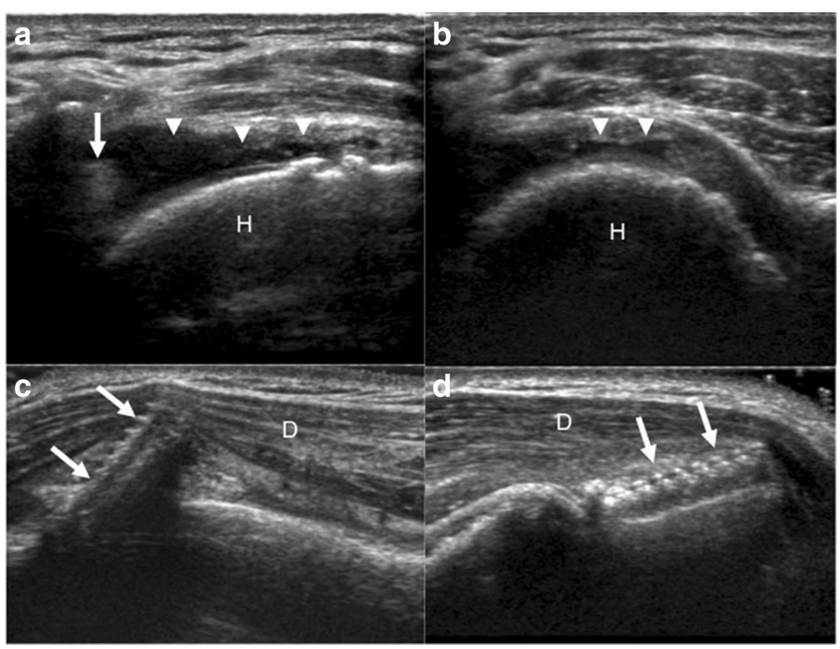
US Appearance of the Repaired Rotator Cuff

A normal tendon such as the rotator cuff should have a homogeneously hyperechoic (bright) and fibrillar appearance on US [43]. However, as on MRI, an intact postoperative rotator cuff may exhibit a varied and abnormal appearance on US [40]. Serial ultrasound evaluation of postoperative rotator cuff tendons has shown that the tendons may appear abnormal for years after surgery [10•, 44]. Gulotta et al. found defects within 20–50% of the repaired tendons using sonography [44]. The repaired tendons demonstrate abnormal echogenicity and thickness: the tendons may appear hyper or hypoechoic from disorganization of the tendon fibers and healing mechanisms and may demonstrate varying degrees of thickening or attenuation (Fig. 8a, b) [10•, 38, 40, 44, 45•]. A study by Yoo et al. following tendons up to 6 months after surgery determined that postoperative tendon echotexture and fibrillar architecture normalized over time, as did irregularities along the tendon surface [45•]. However, the normal fibrillar architecture of the tendon may remain abnormal for up to 5 years after surgery [44]. Increased peritendinous vascularity of the repaired tendon should also decrease by approximately 6 months after surgery [46].

Complications of Rotator Cuff Repair and Features on US

Yoo et al. found that recurrent tears occurred within the first 3 months of surgical repair, confirming results from Miller et al. [45•, 47]. Tears were defined as an absence of continuous tendon fibers visualized over the humeral head and attaching to the greater tuberosity (Fig. 9a, b) [45•]. Dynamic

Fig. 9 **a**–**d** Sonographic images of a 76-year-old man (**a**, **b**), 10 years after rotator cuff repair with shoulder pain after lifting boxes. Longitudinal (**a**) and transverse (**b**) to the supraspinatus tendon demonstrate a full thickness tear with retraction of the supraspinatus tendon (arrow) to the level of the humeral head (H) and fluid filled gap (arrowheads). Sonographic images (**c**, **d**) of a 38-year-old woman, 1 month after rotator cuff repair with shoulder pain, demonstrate a screw (arrows), backing out of the greater tuberosity and into the deltoid musculature (D)



sonographic imaging with shoulder abduction may also be performed to confirm tendon continuity; identification of fibers moving in tandem with the greater tuberosity upon abduction typically confirms preserved tendon integrity [48]. The greater tuberosity should also be examined for dislodged screws (Fig. 8e, f). Additionally, sutures, appearing as thin curvilinear, hyperechoic structures sometimes with posterior acoustic shadowing or reverberation artifact (Fig. 8a, b) [48], should also be evaluated for displacement. As on MRI, full-thickness or partial-thickness defects in the cuff on US may represent a re-tear or may represent a normal postoperative appearance if that portion of the tear was irreparable. Differentiation of the two may not be possible without knowing how the repair was performed. However, if a full-thickness defect of the cuff is associated with a bare suture anchor in the greater tuberosity, this is indicative of a new tear (Fig. 9c, d).

Subacromial-subdeltoid bursal abnormalities can also be identified on ultrasound. Fluid collection superficial to the supraspinatus tendon is indicative of subacromial-subdeltoid fluid distension [43]. Yoo et al. found that 58 and 34% of patients had bursal thickening and fluid distension, respectively, in the 3-month postoperative period, although the study did not determine pain status [45•]. The posterior glenohumeral capsule may also appear thickened [49]. However, over time, there is typically a significant decrease in bursal and capsular thickness, as well as subacromial-subdeltoid fluid distension, shoulder stiffness, and pain [45•, 49].

Role of Contrast in Imaging the Rotator Cuff After Repair

In patients with contraindications to MRI in whom there are further clinical concerns for rotator cuff abnormality after sonographic evaluation, computed tomography (CT) arthrogram may be obtained [50, 51]. Conventional arthrogram, however, has been considered unreliable because contrast material may leak through a repaired, incompletely healed tendon, and arthrography has been shown to have a lower sensitivity, specificity, and accuracy compared to ultrasound [40]. While CT arthrogram may be able to detect full thickness rotator cuff tears, sensitivity and specificity for partial thickness tears are significantly lower [51]. Even in the setting of a full thickness tear, postoperative scar formation and anatomic distortion may prevent contrast from dispersing into the subacromial bursa [26, 40]. MRI in this instance would better characterize the location and size of a defect, reveal postoperative scar tissue, and allow for preoperative planning if a tear is identified.

Conclusion

Familiarity with the typical imaging appearance of the postoperative tendon is important when evaluating the repaired rotator cuff, as tendons commonly demonstrate an abnormal appearance on both MRI and US in the 1-year postoperative period that should not be mistaken for a failed tendon repair or re-tear. Imaging appearance of the postoperative rotator cuff is variable and should be correlated with clinical symptoms and the operative history, inclusive of graft utilization. Not only can imaging be used to diagnose re-tear and integrity of the rotator cuff, but it can also identify other etiologies for pain, such as hardware dislodgement, infection, or capsular scarring/synovitis. Identification of suture anchor dislodgement or displacement of suture wires themselves can be helpful in aiding surgical planning.

Compliance with ethical standards

Conflict of Interest All authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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