

Rotator Cuff Injury and Repair

Laura A. Fitzpatrick, MD, FRCPC¹ Angela Atinga, MB BChir, FRCR, FRCPC²^{id}
 Lawrence White, MD, FRCPC^{1,3}^{id} Patrick D.G. Henry, MD, FRCSC⁴ Linda Probyn, MD, FRCPC, FCAR²^{id}

¹Joint Department of Medical Imaging, University of Toronto, Toronto, Ontario, Canada

²Department of Medical Imaging, Sunnybrook Health Sciences Centre, University of Toronto, Toronto, Ontario, Canada

³Sinai Health System, University Health Network, and Women's College Hospital, University of Toronto, Toronto, Ontario, Canada

⁴Division of Orthopaedic Surgery, Department of Surgery, Sunnybrook Hospital, University of Toronto, Toronto, Ontario, Canada

Address for correspondence Linda Probyn, MD, FRCPC, FCAR, Department of Medical Imaging, Sunnybrook HSC, University of Toronto, 2075 Bayview Ave., Toronto ON, M4N 3M5, Canada (e-mail: linda.probyn@sunnybrook.ca).

Semin Musculoskelet Radiol 2022;26:585–596.

Abstract

Rotator cuff pathology is a commonly encountered clinical and radiologic entity that can manifest as tendinopathy or tearing. Magnetic resonance imaging (MRI) and ultrasonography offer similar sensitivity and specificity for the evaluation of the native rotator cuff, and the chosen modality may vary, depending on local practice and accessibility. MR arthrography is frequently used in the postoperative setting as a problem-solving tool. Key findings to include in the preoperative MRI report include the size and location of the tear, thickness of the tendon involved (partial versus full thickness), and overall tendon quality. The report should also address features associated with poor surgical outcomes, such as fatty atrophy, a decreased acromiohumeral interval, and evidence of rotator cuff arthropathy. Musculoskeletal radiologists should be familiar with the various surgical techniques and expected postoperative imaging appearance of rotator cuff repairs. Imaging also plays a role in identifying recurrent tearing, graft failure, hardware loosening, infection, and other complications.

Keywords

- ▶ rotator cuff
- ▶ tendinopathy
- ▶ tear
- ▶ postoperative rotator cuff

The rotator cuff is a dynamic stabilizer of the shoulder, whereas the labrum, joint capsule, glenohumeral ligaments, and osseous structures are static stabilizers.¹ Loss of integrity of the rotator cuff leads to progressive instability and eventual degenerative changes at the glenohumeral joint, referred to as rotator cuff arthropathy. Rotator cuff arthropathy is a primary indication for reverse total shoulder arthroplasty.¹

Theories abound regarding the pathogenesis of rotator cuff injury, with extrinsic and intrinsic impingement most commonly described.^{2,3} In extrinsic impingement, rotator cuff tendinopathy and tearing is thought to result from subacromial impingement due to structural abnormalities of the coracoacromial arch, such as acromioclavicular (AC) joint osteophytes, enthesophytes, or abnormal acromial configuration (e.g., hooked acromion or os acromiale).³ Subcoracoid

impingement is another form of extrinsic impingement that may result from a narrowed coracohumeral interval, predisposing to tears of the subscapularis tendon.³

Internal impingement frequently involves entrapment of the posterosuperior rotator cuff tendons between the humeral head and posterior glenoid during abduction and external rotation, eventually leading to tendon degeneration. Other theories suggest that tendons simply undergo intrinsic degeneration due to repetitive use, causing destabilization of the joint, subluxation of the humeral head, and potential for further injury.²

This article reviews the normal anatomy of the rotator cuff and illustrates distinct types of rotator cuff tears. Key findings that should be included in the radiology report for rotator cuff tears are discussed, highlighting features that may change management. Finally, the various surgical techniques for

rotator cuff repair are described with example of cases to illustrate expected postoperative findings and complications.

Rotator Cuff Anatomy

The rotator cuff consists of the supraspinatus, infraspinatus, subscapularis, and teres minor tendon–muscle units. The supraspinatus tendon has an approximate width of 23 mm, inserting on the superior and middle facet of the greater tuberosity.⁴ The supraspinatus is primarily involved in shoulder abduction from 0 to 15 degrees, acting in conjunction with the deltoid to abduct the arm beyond 15 degrees. The infraspinatus tendon has a similar width and inserts on the middle facet with the anterior-most fibers interdigitating with the posterior supraspinatus tendon. The infraspinatus externally rotates the shoulder in conjunction with the teres minor that inserts on the inferior facet. The subscapularis is a strong adductor and internal rotator composed of four to six tendon slips inserting on the lesser tuberosity with a direct muscular attachment at the inferior third; some fibers of the subscapularis cross the bicipital groove to insert on the lesser tuberosity, forming the transverse humeral ligament.^{3,5}

The subacromial-subdeltoid bursa lies superficial to the rotator cuff tendons and deep to the acromion and deltoid. The subacromial-subdeltoid bursa can become distended with fluid in the setting of a full-thickness rotator cuff tear or due to subacromial-subdeltoid bursitis.

Imaging the Rotator Cuff: Pathology and Pitfalls

Radiographs

As described in the American College of Radiology Appropriateness Criteria, radiographs are an appropriate first-line investigation for the assessment of rotator cuff injury and demonstrate ancillary findings of rotator cuff disease.⁶ Typical views obtained include anteroposterior (AP) external rotation, internal rotation, and a scapular Y view. Radiographic findings of rotator cuff tear include superior migration of the humeral

head and narrowed acromiohumeral interval, <6 mm, best seen on the active abduction/AP external rotation view.⁷ Osseous irregularity and cystic changes at the greater tuberosity and lesser tuberosity are also an indicator of more chronic rotator cuff pathology.⁷ The modified AP views show subacromial enthesophytes or inferiorly oriented osteophytes from the AC joint, and a subscapular Y view is useful to assess acromial morphology. Radiographs are also helpful to exclude alternative sources of pain, such as fracture or osteoarthritis.

Ultrasonography

Ultrasonography (US) is a good first-line test for the assessment of rotator cuff pathology due to its widespread accessibility, low cost, and superior spatial resolution.⁶ A linear 12–15 Hz transducer ensures high spatial resolution without sacrificing depth penetration, although lower frequency transducers may be required for larger patients.⁵ On US, the normal rotator cuff tendons are hyperechoic with fibrillar architecture. The tendons should be evaluated in both the transverse and longitudinal imaging planes. Dynamic assessment can also be performed with abduction of the shoulder to assess for subacromial impingement of the supraspinatus tendon.

Magnetic resonance imaging (MRI) and US have similar sensitivities and specificities for detecting rotator cuff disease in the native rotator cuff⁴ (►Fig. 1). US accuracy depends on technique, but in the hands of an experienced operator, it approaches 100% for detection of a full-thickness tear and 91% for a partial-thickness tear.⁵

There are several scanning pitfalls to be aware of when performing and interpreting shoulder US. Anisotropy occurs when the normal hyperechoic tendon appears artifactually hypoechoic when the tendon is not perpendicular to the sound beam,⁵ most common at the supraspinatus footprint. Alternating hypoechoic bands can also occur at the supraspinatus-infraspinatus junction or in the subscapularis tendon in the short axis due to anisotropy.⁵ Care should be taken to evaluate the full anteroposterior width of the greater tuberosity to

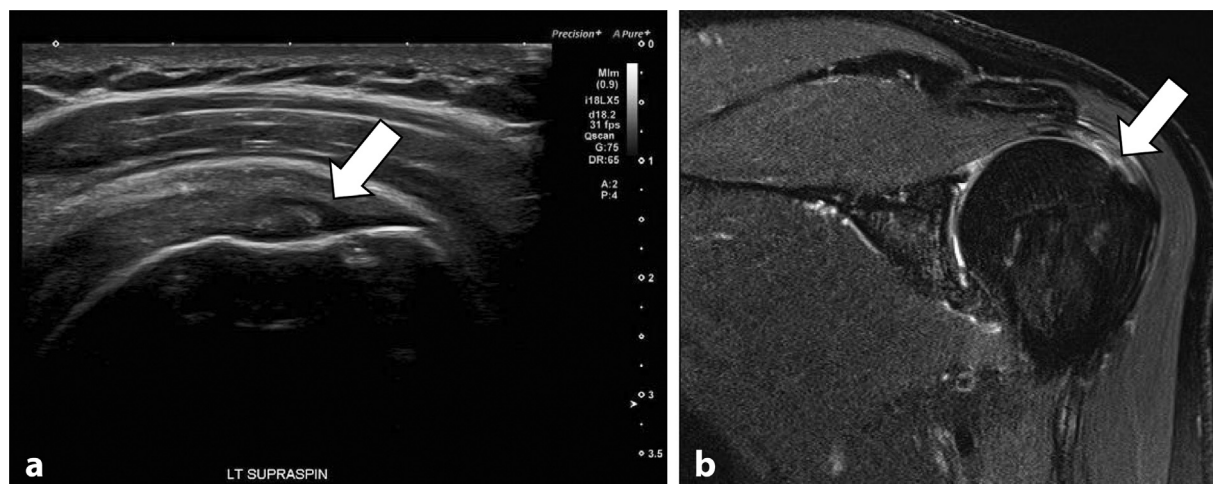


Fig. 1 (a) Longitudinal ultrasonographic image of the left shoulder reveals an intermediate-grade partial articular-sided tear at the supraspinatus footprint (arrow). (b) Corresponding coronal T2 fat-sat sequence confirms these findings.

avoid missing small anterior supraspinatus tears near the rotator interval.⁴

Magnetic Resonance Imaging

MRI has higher interobserver reliability in determining tear size and degree of retraction compared with US.⁶ A meta-analysis in 2020 suggested that 1.5- or 3-T magnetic resonance arthrography (MRA) has the highest diagnostic value to detect partial articular-sided and full-thickness rotator cuff tears, followed by conventional non-MRA 3-T imaging; however, the marginal increase in sensitivity with MRA may be offset by the added cost and resources required.^{6,8}

The tendons of the rotator cuff should appear low signal on short and long TE sequences with smooth margins and no areas of intervening high signal. Similar appearances are expected on direct MRA studies. The supraspinatus and infraspinatus tendons are best visualized on coronal and sagittal oblique images, and the subscapularis and teres minor tendons on axial and sagittal oblique images.³

Tears are normally fluid signal intensity on T2-weighted images, although 10% of tears can be low signal due to scarring or fibrosis. In these cases, ancillary signs, like tendon retraction or muscle atrophy, can point toward the presence of a tear; these types of tears are better seen on MRA.

Care should be taken not to mistake artifacts such as magic angle or volume averaging for tendinopathy. Magic angle occurs on short TE sequences (proton-density [PD], T1-weighted imaging) when the tendon is oriented 54.74 degrees from the main magnetic field, causing intermediate to hyperintense signal in the tendon. Long TE sequences (T2-weighted imaging) can help differentiate between true tendinopathy versus artifact, with the tendon showing normal low signal in the setting of a magic angle artifact.

Computed Tomography Arthrography

Computed tomography (CT) arthrography is a reasonable alternative test in patients who have a contraindication to MRI or when US is not available. Two studies showed no statistical difference in the detection of rotator cuff lesions by CT arthrography or MRA when compared against arthroscopy as the gold standard.^{9,10} Full-thickness tears are easily identified as full-thickness gaps in the tendon substance with extension of contrast into the subacromial-subdeltoid bursa. The articular cartilage and osteoarthritic changes are also well delineated on CT. One of the drawbacks of CT arthrography is the poor delineation of bursal and interstitial tears,⁶ as well as slightly reduced sensitivity in the detection of infraspinatus and subscapularis tears.

Tendinopathy

Tendinopathy, or tendinosis, refers to degeneration of the rotator cuff tendons and is frequently a precursor to rotator cuff tears. On US, the tendon appears hypochoic and thickened in the setting of tendinopathy, often visually graded as mild, moderate, or severe. On MRI, tendons are thickened and show intermediate signal on both short (T1, PD-weighted imaging) and long (T2-weighted imaging) TE sequences.

Calcific tendinopathy results from deposition of hydroxyapatite crystals in the rotator cuff tendons and is one of the most frequent causes of shoulder pain, with an estimated prevalence of 2.7 to 10.3%.^{3,11} Patients may present with shoulder pain and reduced range of motion in the chronic setting; however, acute calcific tendinopathy can cause acute shoulder pain and may be mistaken for infection due to the overlapping clinical presentation. Asymptomatic calcific deposits are common, occurring in up to 8% of cases in one study^{3,12}; middle-aged women 30 to 60 years old and those with calcifications measuring > 1.5 cm are more likely to be symptomatic.¹² The distal supraspinatus tendon is most frequently involved in calcific tendinitis, although the other tendons can also be affected.³ Hydroxyapatite crystals can migrate into the bursa (calcific bursitis), musculature, and bones.³

Typical US features of calcific tendinopathy include punctate or coarse echogenic foci within the substance of the tendon with variable posterior acoustic shadowing.⁶ On MRI, these calcifications appear as globular hypointense foci within the tendon or surrounding structures. In the acute phase, there may be markedly increased signal or edema around the calcification on fluid-sensitive sequences, reflecting inflammation.

Patterns of Injury

The prevalence of rotator cuff tears in the general population is ~20% and increases with age.^{6,13} Chronic rotator cuff tears are most common and result from intrinsic degeneration of the rotator cuff tendons from long-standing overuse, with or without impingement. The typical pattern of progression is tendinopathy, followed by partial-thickness tears and eventual full-thickness tears if left untreated.

Acute tears of the rotator cuff are less frequent, with a reported incidence of up to 8%. They are often the result of a high-energy mechanism and tend to be large full-thickness tears. Acute tears of the subscapularis are most common in the setting of anterior shoulder dislocation, although any combination of tendons can be involved, depending on the mechanism of injury.¹⁴ Avulsion of the rotator cuff tendons from the greater tuberosity has also been reported in the acute setting.

Supraspinatus tendon tears frequently occur at the anterior margin.³ These tears can propagate posteriorly to the infraspinatus tendon or anteroinferiorly through the rotator interval to involve the coracohumeral ligament and superior subscapularis tendon.³

Infraspinatus tears often result from posterior extension of supraspinatus tendon tears, although isolated tears can be seen in the setting of posterosuperior (internal) impingement in overhead throwing athletes.^{3,15} In posterosuperior impingement, the rotator cuff becomes entrapped between the greater tuberosity and posterosuperior glenoid and labrum during abduction and external rotation. Over time, this can lead to partial-thickness articular-sided tears of the posterior supraspinatus and anterior infraspinatus tendons.¹⁵ Teres minor tendon tears are rare and usually associated with infraspinatus tears.³

Although subscapularis tears were previously thought to be uncommon, the reported incidence has increased with advanced arthroscopic techniques.¹⁶ Subscapularis tears may result from anterior propagation of a supraspinatus tear, or they may occur in isolation in the setting of subcoracoid impingement or anterior shoulder dislocation.¹⁷

Rotator Cuff Tears: What to Include in Your Report

Important imaging features to describe in the radiology report for rotator cuff tears include location, size, and thickness (partial or full thickness), tendon retraction, tendon quality (delamination), and degree of muscle atrophy and fatty infiltration. ▶Table S1 outlines a standardized approach to reporting cases of rotator cuff tear.

Full-thickness rotator cuff tears involve the entire tendon thickness, manifesting as high T2/PD signal extending from the articular to bursal surface (▶Fig. 2c, d). Conversely, partial-thickness rotator cuff tears only involve a portion of the tendon, occurring at the articular side, bursal side, or within the tendon substance (referred to as intrasubstance or interstitial tears) (▶Figs. 1 and 2a, b). Several acronyms describe the subtypes of partial-thickness rotator cuff tears, many of which originated in the arthroscopic literature (summarized in ▶Table S2, with accompanying examples in ▶Fig. S1 and ▶Fig. S2). To prevent confusion, we encourage a standard description of tears (e.g., partial-thickness articular-sided tear with intrasubstance delamination), rather than the use of acronyms.

Grading of partial-thickness tears is based on the thickness of the tendon involved: low grade (< 25%), intermediate grade (25–50%), and high grade (> 50%). Partial tears at the supraspinatus or infraspinatus footprint and intrasubstance tears are important to identify because these are often occult at arthroscopy (▶Fig. S1).⁶ Care should be taken not to mistake the rotator cable, a normal thickened hypointense band of signal frequently seen on the undersurface of the supraspinatus, as a partial-thickness articular-sided tear.¹⁸

Tear size should be measured in both the anteroposterior and mediolateral dimensions. Full-thickness tears can be more

broadly classified as small (< 1 cm), medium (1–3 cm), large (3–5 cm), or massive (> 5 cm) based on the AP dimension, as per the DeOrto and Cofield classification.^{3,19} The degree of medial retraction of the tendon stump can be measured (e.g., retracted 2 cm relative to the greater tuberosity) or described relative to surrounding structures (e.g., at the superior humeral head, at the glenoid margin) (▶Fig. 2d).

Delamination refers to separation of the tendon layers in the setting of an intrasubstance partial- or full-thickness tear. Delamination may result in differential retraction of the articular- and bursal-sided fibers, with the articular-sided fibers often demonstrating greater retraction (▶Fig. 2b). Delaminating tears should be noted in the report because studies suggest these patients are more likely to fail conservative management.²⁰ The presence of delamination is also a negative prognostic factor for surgical repair. Fluid dissecting into the tendon substance may undergo synovialization that reduces tendon quality and healing potential.^{20,21}

Delaminating tears can also propagate along the myotendinous unit and form small cysts within the muscle belly, referred to as sentinel cysts³ (▶Fig. 3). Studies evaluating the clinical significance of sentinel cysts have found an association with both partial- and full-thickness tears, suggesting this is a helpful ancillary feature for identification of small occult tears that may otherwise be missed.²²

Muscle atrophy, an important predictive factor for anatomical and functional outcome after surgical repair, is associated with increased retear rates.²³ The degree of muscle atrophy can be quantified with the occupational ratio using the method of Thomazeau et al²⁴ (▶Fig. 4). The cross-sectional area of the supraspinatus fossa is calculated on the T1-weighted sagittal oblique Y view where the scapular spine and body intersect, with the undersurface of the trapezius and distal clavicle delineating the superior margin of the supraspinatus fossa.²³ This is compared with the cross-sectional area of the supraspinatus muscle, calculated with the best fit line drawn around the outer margin of the muscle. The occupational ratio (R) may be graded as follows: grade I, $R \geq 0.6$ (normal or slightly atrophied); grade II, $R \geq 0.6$ to 0.4 (moderate atrophy); and grade III, ≤ 0.4 (severe atrophy), with a smaller R indicating more advanced atrophic changes.²³ The tangent sign, also

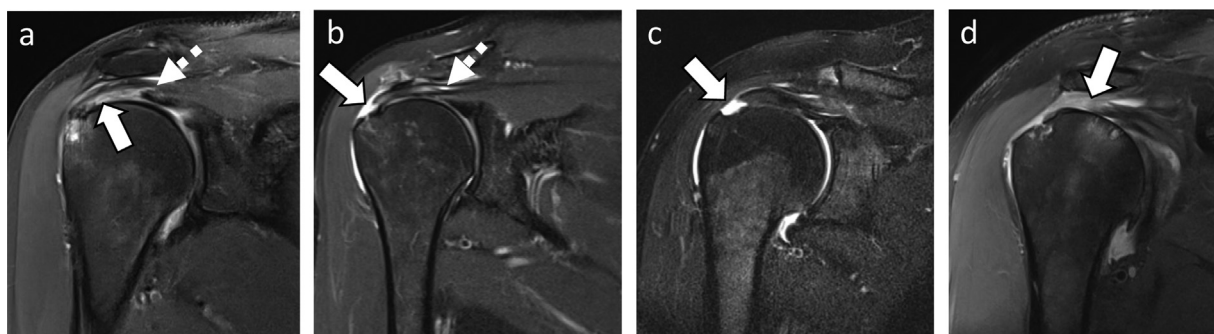


Fig. 2 (a) Coronal T2 fat-sat sequences of the right shoulder showing intermediate-grade partial articular-sided tear, (b) high-grade partial bursal-sided tear, (c) full-thickness tear *without* retraction, and (d) full-thickness tear *with* retraction of the supraspinatus tendon (solid arrows). There is intrasubstance delamination of the partial tears shown in (a) and (b) (hashed arrows), with differential retraction of the articular-sided fibers in (a). In the high-grade partial bursal-sided tear (b), there are a few intact articular-sided fibers compared with the full-thickness tears (c, d) where there are no intact articular-sided fibers. The tendon is medially retracted to the superior glenoid in (d).

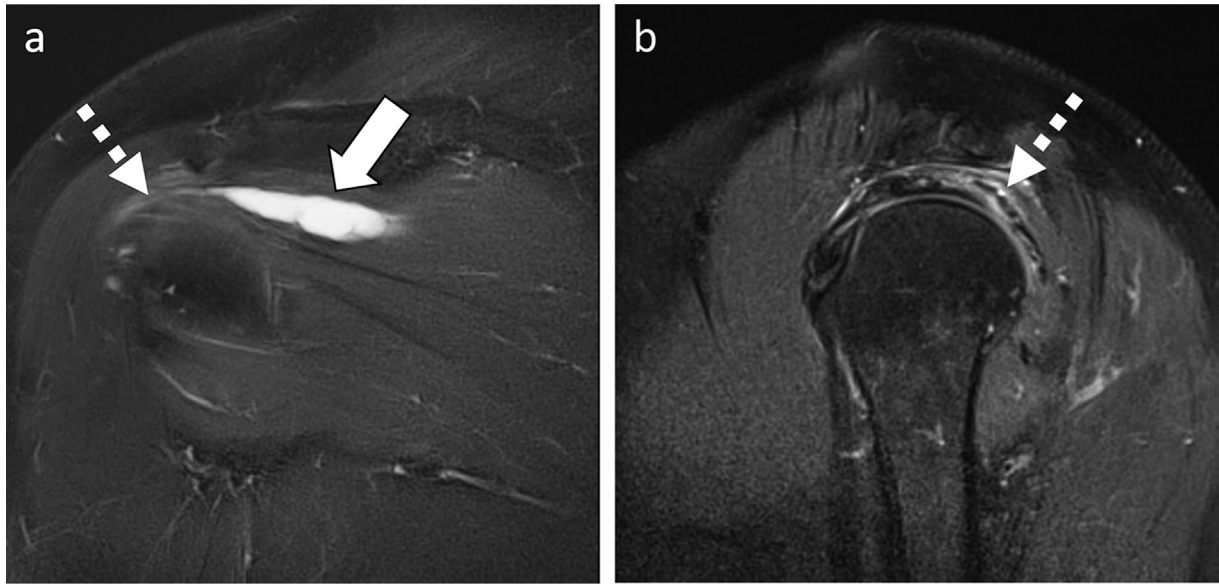


Fig. 3 (a) Coronal T2 fat-sat and (b) sagittal T2 fat-sat sequences of the right shoulder show a lobulated so-called sentinel cyst at the infraspinatus myotendinous junction (a, solid arrow). This was tracking from a pinhole low-grade partial articular-sided tear of the anterior infraspinatus (a, b, hashed arrows).

measured on the Y view, is another method to evaluate for the presence or absence of atrophy. It is considered positive (atrophy present) when the superior border of the supraspinatus lies inferior to a tangential line drawn between the coracoid process and scapular spine.²⁵ Fatty infiltration is graded using the Goutallier classification system, where 0 is normal, 1 is mild fatty infiltration with a few fatty streaks, 2 is increased fatty infiltration involving < 50% of the muscle, 3 is 50% fatty infiltration (equal fat and muscle), and 4 is > 50% fatty infiltration.²⁶

The “comma sign” is an arthroscopic finding seen with combined superior subscapularis and anterior supraspinatus tears. Comma-shaped tissue composed of the superior glenohumeral and coracohumeral ligaments can be followed to identify the retracted superolateral edge of the torn subscapularis tendon.^{16,27} Recent studies showed that the comma sign can be prospectively identified on preoperative imaging, best appreciated in the coronal plane where torn subscapularis fibers are displaced superiorly through the rotator interval, contiguous with a comma-shaped fibrous structure lateral to the coracoid process²⁷ (→Fig. 5). The presence of the comma sign should be noted because it may alter the arthroscopic approach and repair technique.^{16,27}

The position of the long head of the biceps should also be assessed in the setting of a subscapularis tear. The biceps tendon can be subluxed into the substance of the partially torn subscapularis tendon or may medially dislocate into the anterior glenohumeral joint in the setting of an articular-sided or full-thickness tear.

The report should address findings that may predispose to subacromial impingement, such as AC osteoarthritis, acromial enthesopathy, and abnormal acromial morphology (in particular, lateral downsloping or anterior hooked configuration).

The presence of chondrosis and osteophytes at the glenohumeral joint should be noted because it may have implications for surgical management. Patients presenting with end-stage osteoarthritis may not be candidates for primary rotator cuff repair, instead requiring reverse total shoulder arthroplasty. Superior migration of the humeral head and resultant narrowing of the acromiohumeral interval often represents the first stage of rotator cuff arthropathy.

Postoperative Imaging of the Rotator Cuff

Indications for primary rotator cuff repair include failure to respond to conservative measures, ongoing pain, and functional deficits.²⁸ Small partial-thickness tears are typically treated with debridement, whereas high-grade partial- or full-thickness tears often require reattachment at the greater tuberosity with the single- or double-row repair technique.⁴ Double-row repair involves anchor fixation of the tendon to the medial articular margin with a second set of suture anchors at the lateral footprint, with lower reported rates of retear compared with other techniques.²⁹

Imaging of the postoperative rotator cuff is challenging due to distorted anatomy, postsurgical soft tissue changes, and metal-related artifact, although this is decreased with titanium or plastic hardware. When available, preoperative imaging and operative reports should be reviewed to avoid misinterpreting normal postsurgical findings as pathology. Occasionally, portions of the torn tendon may be left unrepaired by the surgeon due to poor tendon quality, reduced tendon volume, or an inability to mobilize the retracted tendon stump.⁴ It is also important to consider the time interval between surgery and imaging. The appearance of the repaired cuff varies, depending on the time elapsed since surgery.

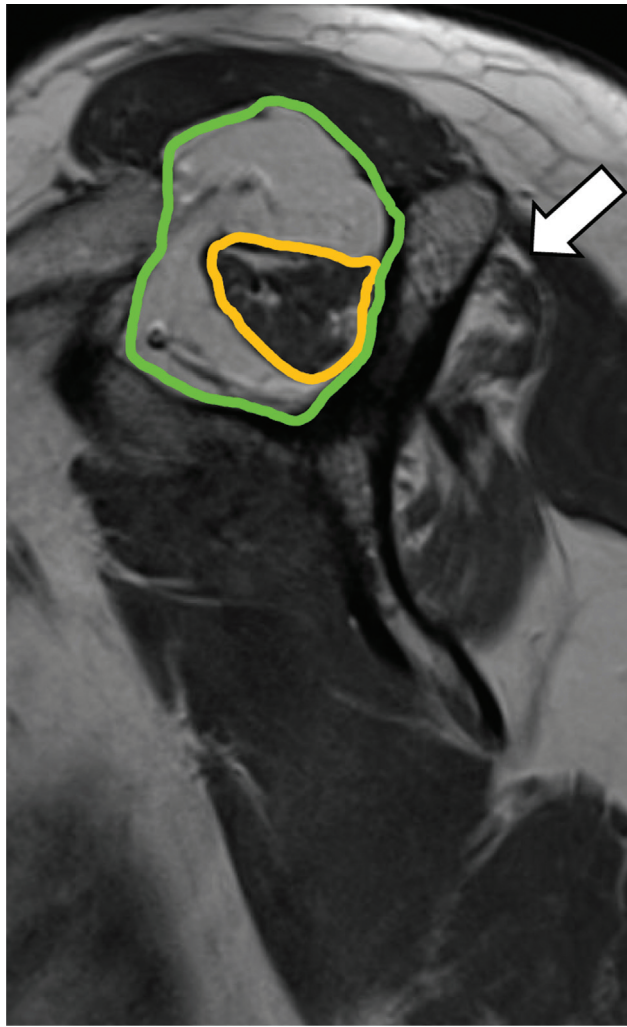


Fig. 4 T1-weighted sagittal oblique Y view demonstrating measurement of the *occupation ratio*, at the intersection of the scapular spine and body. The yellow circle denotes the cross-sectional area of the supraspinatus muscle; the green circle denotes the area of the supraspinatus fossa. The yellow area is divided by the green area to determine the occupation ratio ($R < 0.4$, severe supraspinatus atrophy). Note mild fatty infiltration of the supraspinatus (Goutallier grade 1). The infraspinatus (arrow) is also atrophic with more pronounced fatty infiltration (Goutallier grade 3).

High-resolution non-MRA at 1.5 or 3 T is usually sufficient for most cases of suspected retear.⁴ Although MRA has the highest sensitivity of all imaging modalities for detecting retears, this examination is more time and resource intensive, and it may overestimate cuff repair failure due to small areas of irregularity and fraying that are misinterpreted as tears.⁴ CT arthrography avoids the challenges of metal-associated artifact seen with MRI and is highly sensitive for the detection of partial articular-sided tears postoperatively.³⁰

In the early postoperative period, the repaired tendon may appear hypoechoic on US, hyperintense on MRI, and variable in thickness (→**Fig. 6a**)^{4,28}; this may be due to edema, inflammatory change, or early granulation tissue. The intermediate to increased intratendinous signal on MRI can persist for months to years.⁴ CT and MR arthrography must be interpreted with caution when evaluating the

postoperative rotator cuff because repairs are not watertight, allowing for seepage of gadolinium into the subacromial space, even in an intact repair.^{4,28}

Reported rates of rotator cuff retear range from 11% to 68%.⁴ Larger rotator cuff tears, increased tendon retraction, and more severe tendon degeneration are associated with worse clinical outcomes 1 year following repair.³¹ One study found that the degree of tendon retraction and narrowing of the acromiohumeral interval on preoperative MRI were independent predictive factors for retear following cuff repair.³² Additional risk factors for retear cited in the literature include advanced age, diabetes, smoking, atrophy, delamination, longer time to repair, surgical technique, and inadequate postoperative rehabilitation.^{4,32,33}

Key features of recurrent tears are partial or complete gaps in the tendon, either at the greater tuberosity or more proximally along the repaired tendon. Recurrent tears on MRI are depicted by fluid signal extending into the tendon substance or completely through the tendon with an associated gap (→**Fig. 6b**). MRA may be useful in distinguishing between granulation tissue that shows intermediate to high T2 signal intensity and true recurrent tears, the former not filling with contrast material.³⁰ Other ancillary findings suggestive of retear include new or worsening tendon retraction or hardware loosening.²⁸

US may offer advantages over MRI for assessing rotator cuff integrity in the early postoperative period, such as increased availability and accessibility and the opportunity for dynamic assessment.⁴ The postoperative tendon can appear heterogeneously hypoechoic, thickened, and irregular, findings that can persist for many years postsurgery.⁴ Presence of a fluid-filled defect or nonvisualization of the tendon at the greater tuberosity attachment is suggestive of tendon retear.⁴ Occasionally focal scarring and fibrosis may produce hypoechoic clefts in the tendon substance mimicking a tear; however, unlike a true tear, these areas should show progressive healing on follow-up US.⁴ Limitations of US in evaluating the postoperative cuff include the operator-dependent nature of this modality and artifact from post-surgical hardware and suture anchors.⁴

Other postoperative complications that can occur include broken sutures, displaced anchors (→**Fig. 7**), progressive muscle atrophy or fatty infiltration, recurrent subacromial spurs, capsular thickening and edema, nerve injury, chondrolysis, osteoarthritis, and infection.²⁸ The open surgical approach for rotator cuff repair requires detachment of the deltoid from the acromion to access the cuff tendons, with reattachment of the deltoid at the end of surgery; stripping or dehiscence of the deltoid from the site of reattachment can occur as a complication of an open approach. The risk of deltoid dehiscence is reduced with a mini-open approach where a vertical split is made in the deltoid to gain access to the rotator cuff. a postoperative hematoma or fluid collection can occasionally be seen at the site of the vertical deltoid split.

Subacromial decompression may be performed as part of rotator cuff surgery, with any combination of the following: acromioplasty for hooked acromion or enthesopathy, subacromial-subdeltoid bursectomy, resection of the os acromiale and

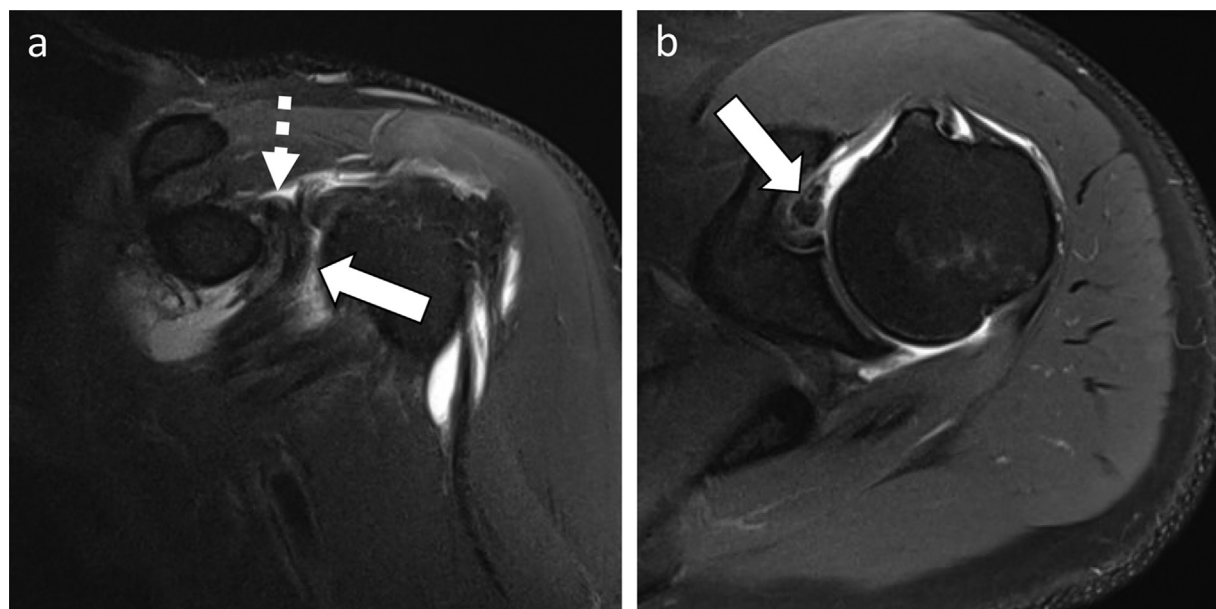


Fig. 5 “Comma sign.” (a) Coronal T2 fat-sat and (b) axial T2 fat-sat sequences of the left shoulder demonstrate a tear of the superior subscapularis (solid arrows). The torn fibers are displaced superiorly through the rotator interval, contiguous with a comma-shaped fibrous structure lateral to the coracoid process (hashed arrow).

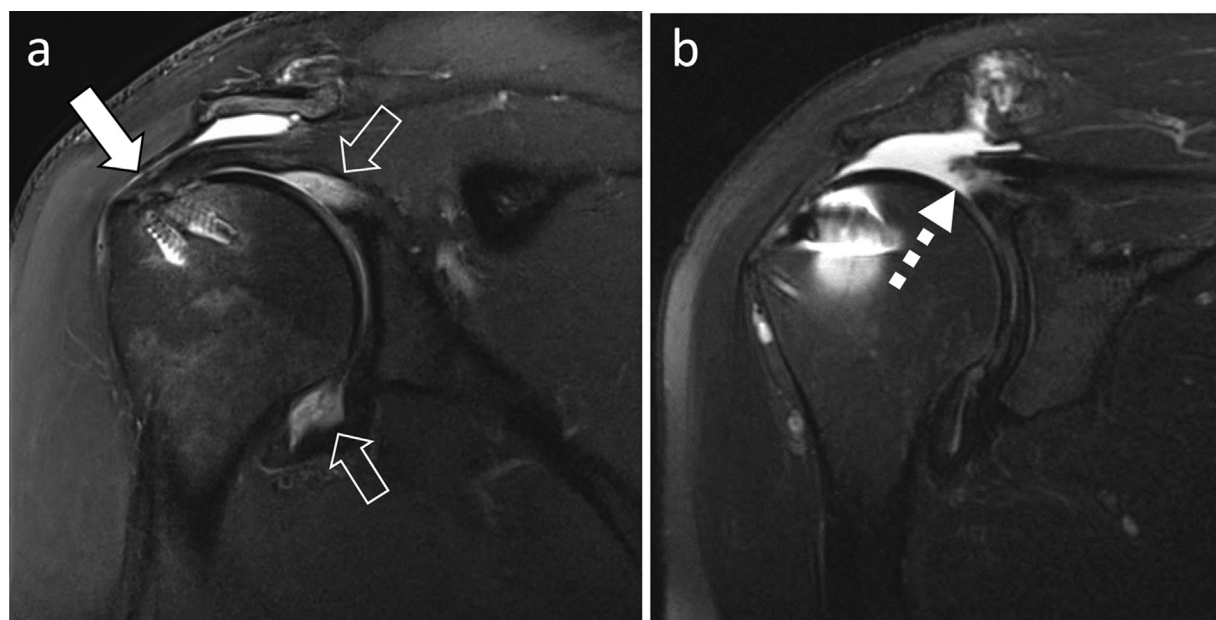


Fig. 6 (a) Coronal T2 fat-sat sequence of the right shoulder shows intact postoperative rotator cuff repair of the supraspinatus (arrow). Note the medial anchor at the edge of the articular surface and more lateral anchor at the greater tuberosity, in keeping with the double-row repair technique. Mild increased signal in the repaired tendon is an expected postoperative finding. Because the graft is not watertight, fluid can travel from the glenohumeral joint into the subacromial-subdeltoid bursa, as seen in this case. Synovitis was noted at the axillary recess and near the biceps-labral anchor (open arrows), likely reactive in the postoperative setting. (b) Coronal T2 fat-sat sequences of the right shoulder shows re-tearing of the previously repaired supraspinatus, with retracted tendon stump adjacent to the superior labrum (hashed arrow). Remodeling of the acromial undersurface is related to previous subacromial decompression with a deficient inferior acromioclavicular (AC) joint, allowing fluid to traverse from the subacromial-subdeltoid bursa into the AC joint.

resection of the distal clavicle (Mumford procedure).²⁸ Suggestive findings on postoperative imaging include susceptibility artifact at the AC joint, surgical defect along the acromial undersurface, subacromial scarring, debrided distal clavicle, and pseudo-widening of the AC joint.²⁸ Fluid in the subacromial-subdeltoid space may persist for years after surgery.

Massive Rotator Cuff Tears and Repair

The reported prevalence of massive tears is 10 to 40%,³⁴ defined as a tear measuring > 5 cm in either the anteroposterior dimension or complete tears involving at least two adjacent tendons.³⁵

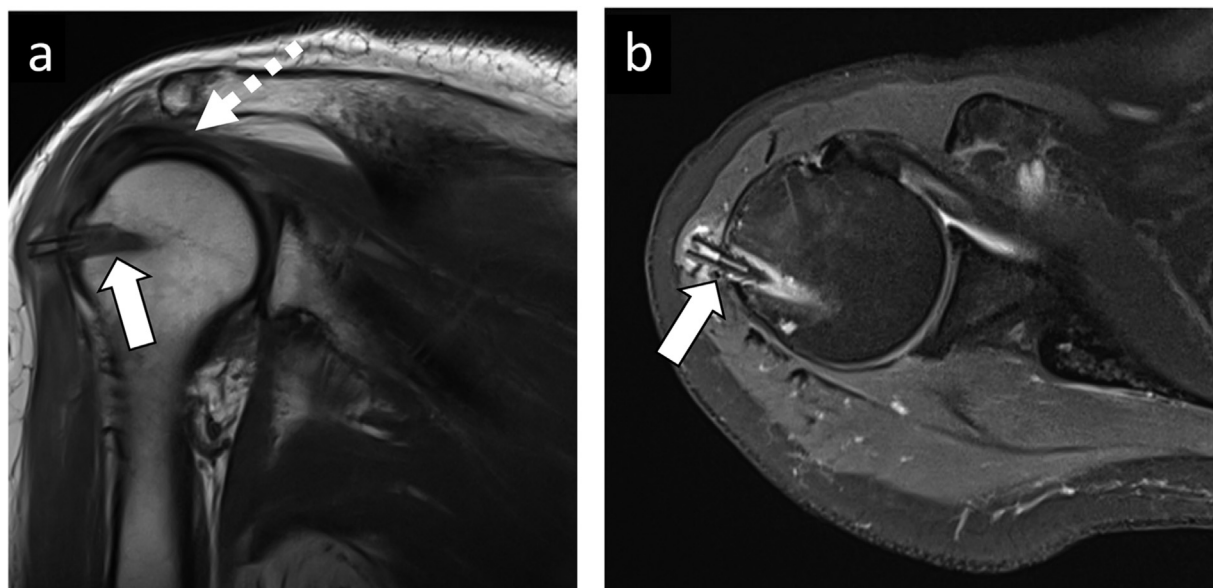


Fig. 7 (a) Coronal proton-density and (b) axial T2 fat-sat sequences of the right shoulder show anchor loosening and pullout at the site of previous rotator cuff repair (arrows). The repaired tendon is intact (a, hashed arrow); mild thickening and altered in signal of the tendon is within normal limits postoperatively. There is edema in the deltoid musculature surrounding the retracted screw.

Massive rotator cuff tears are difficult to repair surgically due to retraction, scarring and fibrosis of the tendon, and associated muscle atrophy and fatty infiltration.^{34,36} Although arthroscopic repair of chronic massive rotator cuff tears was shown to improve pain, range of motion, and functional outcome, the retear rate is high, up to 79% in one systemic review.³⁷

The management of massive rotator cuff tears varies, depending on patient age, tendon quality, muscle atrophy, and the presence of secondary glenohumeral degenerative changes.³⁶ Older patients with decreased functional demands may undergo debridement of the tear with or without biceps tenotomy or tenodesis, or they may require reverse total shoulder arthroplasty in the setting of rotator cuff arthropathy.³⁶ Reverse total shoulder arthroplasty is preferred in patients with a deficient rotator cuff because there is reduced superior migration of the humeral component and greater deltoid compensation compared with conventional total shoulder arthroplasty.¹

In patients with minimal osteoarthritis and high functional requirements, several surgical techniques can be used when primary repair is not possible: patch graft augmentation, patch graft bridging, muscle-tendon transfer, and superior capsular reconstruction.³⁶ **Table 1** summarizes these techniques.

Grafts are used to augment the repair at the footprint when the native cuff cannot provide full coverage, when the tendon is poor quality, or in the setting of severe retraction with inability to mobilize the tendon.²⁹ Patch graft *augmentation* is often used for small irreparable defects; patch graft *bridging* is preferred for larger defects with scarring and inelasticity of the native tendon.

Superior capsular reconstruction aims to restore glenohumeral instability and function by reconstructing the superior joint capsule, and it has lower failure rates than

conventional patch grafting.³⁸ The original graft used for this procedure was tensor fascia lata autograft; more recently, dermal allograft has been used to reduce complications at the donor graft site and improve surgical time.³⁶

Muscle-tendon transfer is an option for younger patients with irreparable symptomatic massive rotator cuff tears without glenohumeral osteoarthritis, most commonly utilizing the latissimus dorsi or pectoralis major tendons.³⁹ When the latissimus dorsi is transferred to the greater tuberosity, it can simulate posterolateral rotator cuff function (external rotation and humeral head depression^{39,40}) that helps improve the biomechanics of the glenohumeral motion.³⁶ Pectoralis major transfers are more frequently performed to restore anterosuperior cuff deficiencies.³⁹

The interpreting radiologist should be aware of the postoperative appearance of each of these techniques and the typical locations for graft failure. Normal intact grafts are low to intermediate in signal with minor heterogeneity.³⁶ Grafts may fail at three major sites: (1) at the proximal or distal attachments, (2) midsubstance, or (3) at the side-to-side anastomosis with the native tendon.⁴¹ The presence of a fluid cleft or defect in any of these locations is in keeping with a graft tear. **Table 1** summarizes the expected postsurgical findings for the different surgical techniques, with further discussion on latissimus dorsi tendon transfer and superior capsular reconstruction here (which are the preferred treatments for massive rotator cuff tears at our institution).

With latissimus dorsi tendon transfer, the tendon is removed from its humeral attachment at the base of the intertubercular groove and passed through a soft tissue plane fashioned deep to the deltoid and posterior to the teres minor muscle.³⁴ The tendon graft is sutured to the lateral aspect of the greater tuberosity to assist with external rotation.³⁴ On MR imaging, the normal tendon transfer is low to intermediate in signal with suture anchors at the greater tuberosity

Table 1 Surgical techniques for massive rotator cuff repair, expected postoperative findings, and signs of graft failure

	Patient selection	Tissue reconstruction	Normal magnetic resonance appearance	Common sites of failure
Patch graft <i>augmentation</i>	Irreparable defect (< 1 cm)	Autograft (fascia lata), allograft (acellular human dermal graft), xenografts (porcine dermis), synthetic	Low to intermediate heterogeneous signal at site of previous tear Medially attached to stump of torn tendon; laterally attached to greater tuberosity	Lateral attachment at greater tuberosity footprint Medial row suture failure (if double-row repair technique used)
Patch graft <i>bridging</i>	Defects > 1 cm; inadequate excursion of native tendon due to scar	Same as above	Same as above	Medial tendon attachment; lateral less common
Muscle-tendon transfer	Younger patients; no arthrosis	Latissimus dorsi (posterosuperior tear), pectoralis major (anterosuperior tear)	Low to intermediate, heterogeneous signal of transferred tendon	Lateral attachment at greater tuberosity
Superior capsular reconstruction	Younger patients; no arthrosis	Dermal allograft, less commonly fascia lata allograft	Low-signal taut graft, uniform thickness (3 mm) with intact attachments to superior glenoid tubercle medially and greater tuberosity laterally Small suture holes or fenestrations are expected postoperative finding	Lateral attachment at greater tuberosity Less frequently at medial glenoid attachment or intrasubstance

attachment³⁶ (► **Fig. 8**). Complications can occur in up to 9.5% of latissimus dorsi transfer procedures and include infection, hematoma, injury to the latissimus muscle neurovascular pedicle, and tears of the tendon graft.⁴² The latissimus dorsi muscle should be evaluated for denervation edema and fatty infiltration that could result from nerve damage during surgery.³⁶

In superior capsular reconstruction, suture anchors are typically placed at the 10 and 2 o'clock position of the glenoid with additional anchors at the articular margin of the greater tuberosity and lateral footprint³⁶ (► **Fig. 9**). The distance between these anchors is measured to determine the appropriate graft size for adequate humeral head coverage. The

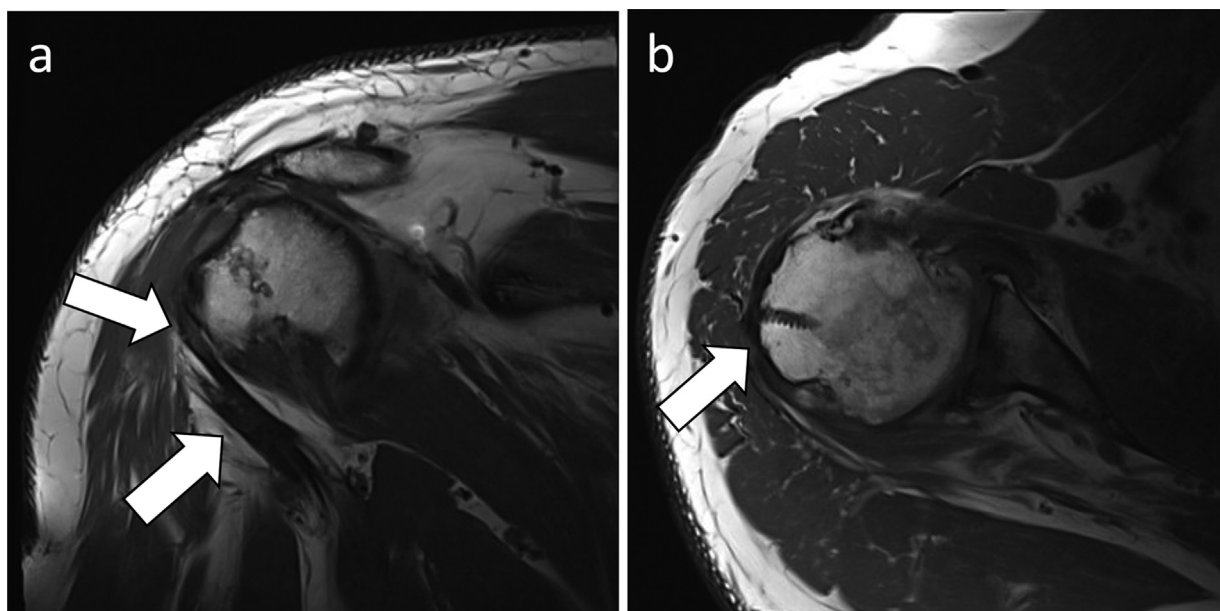


Fig. 8 (a) Coronal proton-density (PD) and (b) axial PD-weighted sequences showing the normal postoperative appearance of a latissimus dorsi tendon transfer. The latissimus dorsi tendon (arrows) is detached from its humeral attachment and passed through a soft tissue plane between the deltoid and teres minor, then sutured to the lateral aspect of the greater tuberosity.

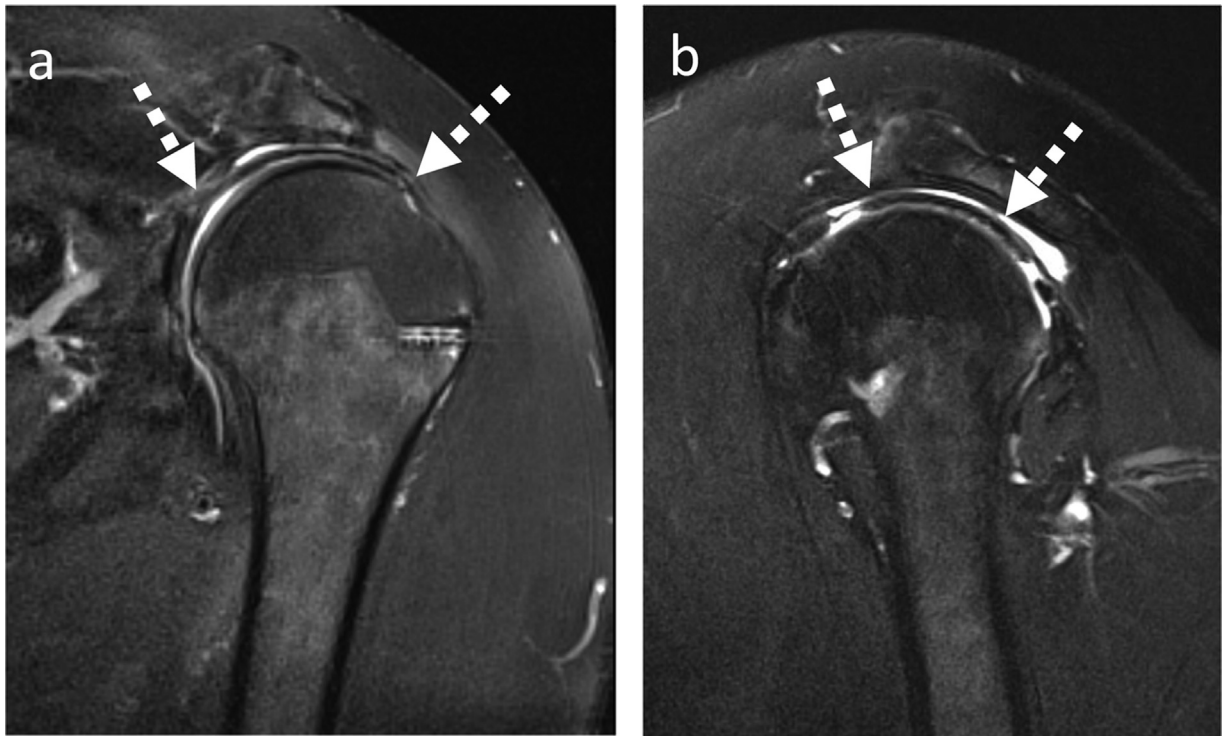


Fig. 9 (a) Coronal T2 fat-sat and (b) axial T2 fat-sat sequences of the left shoulder showing the normal postoperative appearance of a superior capsular reconstruction. The graft (hashed arrows) is homogeneously low in signal and uniform thickness, with the medial margin secured at the superior glenoid tubercle and the lateral margin attached to the greater tuberosity.

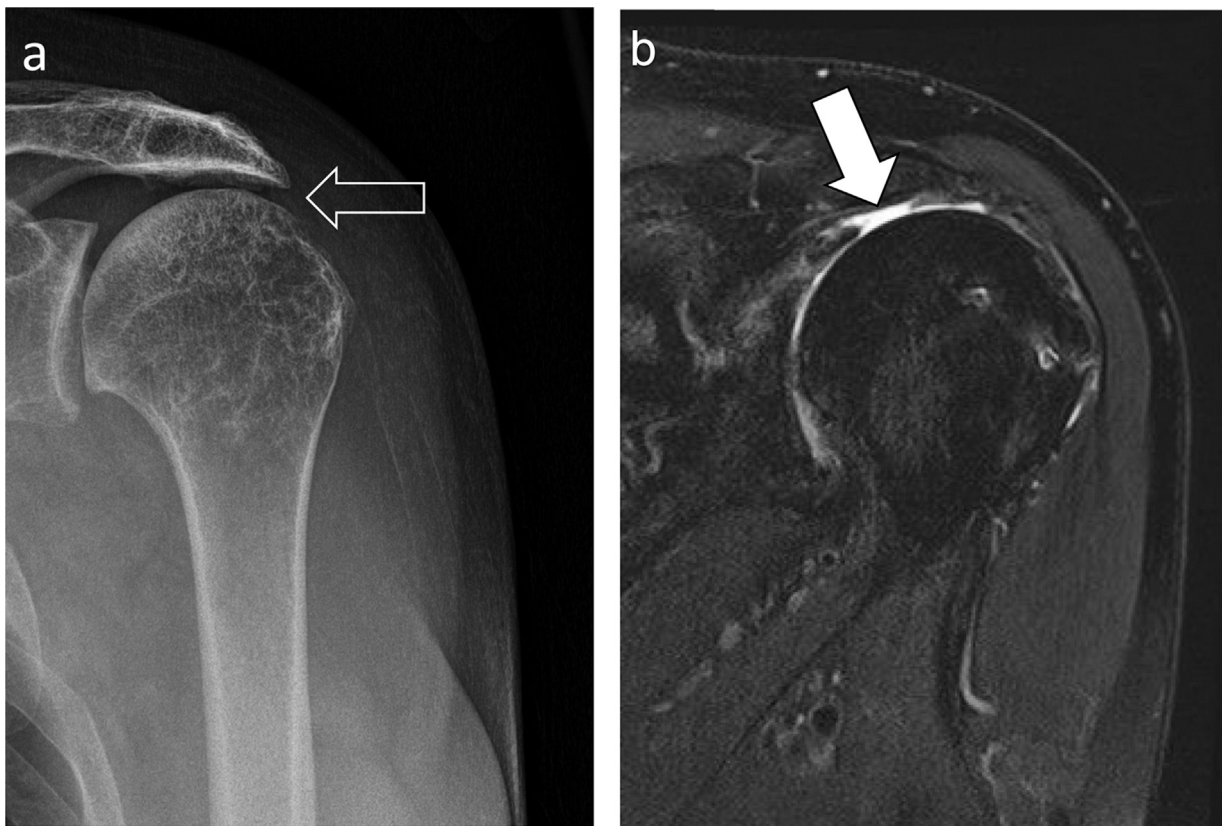


Fig. 10 (a) Anteroposterior radiograph and (b) coronal T2 fat-sat sequence of the left shoulder demonstrating failed superior capsular reconstruction. The acromiohumeral interval (a, open arrow) showed progressive narrowing postoperatively, a finding that may suggest graft failure. The magnetic resonance image in (b) shows a focal defect (arrow) in the midsubstance of the graft with fluid traversing through this defect.

graft is advanced into the subacromial space and fastened to the suture anchor. Additional side-to-side anastomoses with the residual native cuff anteriorly and posteriorly may be performed in some cases.³⁶ The graft can tear at the glenoid or humeral anchors or in the midsubstance (►Fig. 10). Care should be taken not to interpret small suture holes in the graft as tears; these are an expected postsurgical finding. The acromiohumeral interval is also a useful predictor for graft integrity following superior capsular reconstruction, with progressive narrowing of the interval and eccentric humeral head positioning suggestive of graft failure.⁴¹

Other modes of failure in rotator cuff repair include anchor loosening and suture cutout from the tendon.²⁹ When a double-row suture repair technique is used, failure may occur at the medial anchors, exposing the articular margin while the anchors at the lateral footprint remain intact. Progressive fatty infiltration of the rotator cuff musculature may be another helpful ancillary feature, suggesting graft failure when direct signs of re-tear are absent.²⁹

Conclusion

Rotator cuff tears are one of the most commonly encountered pathologies in musculoskeletal radiology. First-line investigations include radiography, followed by MRI or US that show similar sensitivities for detecting pathology in the native rotator cuff. MRA should be reserved for postoperative cases to delineate granulation tissue and fibrosis from re-tear. Several features should be described in the report that will help guide management, most notably tear size, delamination and tendon quality, retraction, and degree of fatty atrophy and infiltration. Radiologists should be aware of the various surgical techniques used for partial- and full-thickness and massive rotator cuff tears and the expected postoperative imaging appearances, to improve diagnostic accuracy for the detection of recurrent tears.

Conflict of Interest

None declared.

References

- Eajazi A, Kussman S, LeBedis C, et al. Rotator cuff tear arthropathy: pathophysiology, imaging characteristics, and treatment options. *AJR Am J Roentgenol* 2015;205(05):W502–W511
- Morag Y, Jacobson JA, Miller B, De Maeseneer M, Girish G, Jamadar D. MR imaging of rotator cuff injury: what the clinician needs to know. *Radiographics* 2006;26(04):1045–1065
- Abreu MR, Recht M. MR imaging of the rotator cuff and rotator interval. In: Hodler J, Kubik-Huch RA, von Schulthess GK, eds. *Musculoskeletal Diseases 2017–2020: Diagnostic Imaging*. Berlin, Germany: Springer International; 2017:203–214
- Kalia V, Freehill MT, Miller BS, Jacobson JA. Multimodality imaging review of normal appearance and complications of the postoperative rotator cuff. *AJR Am J Roentgenol* 2018;211(03):538–547
- Jacobson JA. Shoulder US: anatomy, technique, and scanning pitfalls. *Radiology* 2011;260(01):6–16
- Zoga AC, Kamel SI, Hynes JP, Kavanagh EC, O'Connor PJ, Forster BB. The evolving roles of MRI and ultrasound in first-line imaging of rotator cuff injuries. *AJR Am J Roentgenol* 2021;217(06):1390–1400
- Moosikasuwon JB, Miller TT, Burke BJ. Rotator cuff tears: clinical, radiographic, and US findings. *Radiographics* 2005;25(06):1591–1607
- Liu F, Cheng X, Dong J, Zhou D, Han S, Yang Y. Comparison of MRI and MRA for the diagnosis of rotator cuff tears: a meta-analysis. *Medicine (Baltimore)* 2020;99(12):e19579
- Omoumi P, Bafort AC, Dubuc JE, Malghem J, Vande Berg BC, Lecouvet FE. Evaluation of rotator cuff tendon tears: comparison of multidetector CT arthrography and 1.5-T MR arthrography. *Radiology* 2012;264(03):812–822
- Charoussat C, Bellaïche L, Duranthon LD, Grimberg J. Accuracy of CT arthrography in the assessment of tears of the rotator cuff. *J Bone Joint Surg Br* 2005;87(06):824–828
- Sansone V, Consonni O, Maiorano E, Meroni R, Goddi A. Calcific tendinopathy of the rotator cuff: the correlation between pain and imaging features in symptomatic and asymptomatic female shoulders. *Skeletal Radiol* 2016;45(01):49–55
- Louwerens JK, Siersevelt IN, van Hove RP, van den Bekerom MP, van Noort A. Prevalence of calcific deposits within the rotator cuff tendons in adults with and without subacromial pain syndrome: clinical and radiologic analysis of 1219 patients. *J Shoulder Elbow Surg* 2015;24(10):1588–1593
- Yamamoto A, Takagishi K, Osawa T, et al. Prevalence and risk factors of a rotator cuff tear in the general population. *J Shoulder Elbow Surg* 2010;19(01):116–120
- Abdelwahab A, Ahuja N, Iyengar KP, Jain VK, Bakti N, Singh B. Traumatic rotator cuff tears—current concepts in diagnosis and management. *J Clin Orthop Trauma* 2021;18:51–55
- Lin DJ, Wong TT, Kazam JK. Shoulder injuries in the overhead-throwing athlete: epidemiology, mechanisms of injury, and imaging findings. *Radiology* 2018;286(02):370–387
- Atinga A, Dwyer T, Theodoropoulos JS, Dekirmendjian K, Naraghi AM, White LM. Preoperative magnetic resonance imaging accurately detects the arthroscopic comma sign in subscapularis tears. *Arthroscopy* 2021;37(10):3062–3069
- Morag Y, Jamadar DA, Miller B, Dong Q, Jacobson JA. The subscapularis: anatomy, injury, and imaging. *Skeletal Radiol* 2011;40(03):255–269
- Gyftopoulos S, Bencardino J, Nevsky G, et al. Rotator cable: MRI study of its appearance in the intact rotator cuff with anatomic and histologic correlation. *AJR Am J Roentgenol* 2013;200(05):1101–1105
- DeOrio JK, Cofield RH. Results of a second attempt at surgical repair of a failed initial rotator-cuff repair. *J Bone Joint Surg Am* 1984;66(04):563–567
- Bierry G, Palmer WE. Patterns of tendon retraction in full-thickness rotator cuff tear: comparison of delaminated and non-delaminated tendons. *Skeletal Radiol* 2019;48(01):109–117
- Choo HJ, Lee SJ, Kim JH, et al. Delaminated tears of the rotator cuff: prevalence, characteristics, and diagnostic accuracy using indirect MR arthrography. *AJR Am J Roentgenol* 2015;204(02):360–366
- Manvar AM, Kamireddi A, Bhalani SM, Major NM. Clinical significance of intramuscular cysts in the rotator cuff and their relationship to full- and partial-thickness rotator cuff tears. *AJR Am J Roentgenol* 2009;192(03):719–724
- Jeong JY, Chung PK, Lee SM, Yoo JC. Supraspinatus muscle occupation ratio predicts rotator cuff reparability. *J Shoulder Elbow Surg* 2017;26(06):960–966
- Thomazeau H, Rolland Y, Lucas C, Duval JM, Langlais F. Atrophy of the supraspinatus belly. Assessment by MRI in 55 patients with rotator cuff pathology. *Acta Orthop Scand* 1996;67(03):264–268
- Mellado JM, Calmet J, Olona M, et al. Surgically repaired massive rotator cuff tears: MRI of tendon integrity, muscle fatty degeneration, and muscle atrophy correlated with intraoperative and clinical findings. *AJR Am J Roentgenol* 2005;184(05):1456–1463

- 26 Somerson JS, Hsu JE, Gorbaty JD, Gee AO. Classifications in brief: Goutallier classification of fatty infiltration of the rotator cuff musculature. *Clin Orthop Relat Res* 2016;474(05):1328–1332
- 27 Zappia M, Ascione F, Romano AM, et al. Comma sign of subscapularis tear: diagnostic performance and magnetic resonance imaging appearance. *J Shoulder Elbow Surg* 2021;30(05):1107–1116
- 28 Beltran LS, Bencardino JT, Steinbach LS. Postoperative MRI of the shoulder. *J Magn Reson Imaging* 2014;40(06):1280–1297
- 29 Duchman KR, Mickelson DT, Little BA, et al. Graft use in the treatment of large and massive rotator cuff tears: an overview of techniques and modes of failure with MRI correlation. *Skeletal Radiol* 2019;48(01):47–55
- 30 Pierce JL, Nacey NC, Jones S, et al. Postoperative shoulder imaging: rotator cuff, labrum, and biceps tendon. *Radiographics* 2016;36(06):1648–1671
- 31 Kijowski R, Thurlow P, Blankenbaker D, et al. Preoperative MRI shoulder findings associated with clinical outcome 1 year after rotator cuff repair. *Radiology* 2019;291(03):722–729
- 32 Shin YK, Ryu KN, Park JS, Jin W, Park SY, Yoon YC. Predictive factors of retear in patients with repaired rotator cuff tear on shoulder MRI. *AJR Am J Roentgenol* 2018;210(01):134–141
- 33 Kim YK, Jung KH, Kim JW, Kim US, Hwang DH. Factors affecting rotator cuff integrity after arthroscopic repair for medium-sized or larger cuff tears: a retrospective cohort study. *J Shoulder Elbow Surg* 2018;27(06):1012–1020
- 34 Bedi A, Dines J, Warren RF, Dines DM. Massive tears of the rotator cuff. *J Bone Joint Surg Am* 2010;92(09):1894–1908
- 35 Greenspoon JA, Petri M, Warth RJ, Millett PJ. Massive rotator cuff tears: pathomechanics, current treatment options, and clinical outcomes. *J Shoulder Elbow Surg* 2015;24(09):1493–1505
- 36 Samim M, Walsh P, Gyftopoulos S, Meislin R, Beltran LS. Postoperative MRI of massive rotator cuff tears. *AJR Am J Roentgenol* 2018;211(01):146–154
- 37 Henry P, Wasserstein D, Park S, et al. Arthroscopic repair for chronic massive rotator cuff tears: a systematic review. *Arthroscopy* 2015;31(12):2472–2480
- 38 Mihata T, Lee TQ, Watanabe C, et al. Clinical results of arthroscopic superior capsule reconstruction for irreparable rotator cuff tears. *Arthroscopy* 2013;29(03):459–470
- 39 Greenspoon JA, Millett PJ, Moulton SG, Petri M. Irreparable rotator cuff tears: restoring joint kinematics by tendon transfers. *Open Orthop J* 2016;10:266–276
- 40 Henseler JF, Nagels J, Nelissen RG, de Groot JH. Does the latissimus dorsi tendon transfer for massive rotator cuff tears remain active postoperatively and restore active external rotation? *J Shoulder Elbow Surg* 2014;23(04):553–560
- 41 Al-Ani Z, Monga P, Walton M, Funk L, Basu S. An orthoradiological review of superior capsular reconstruction in the shoulder. *Skeletal Radiol* 2021;50(02):267–280
- 42 Namdari S, Voleti P, Baldwin K, Glaser D, Huffman GR. Latissimus dorsi tendon transfer for irreparable rotator cuff tears: a systematic review. *J Bone Joint Surg Am* 2012;94(10):891–898