

# MR Imaging of Rotator Cuff Injury: What the Clinician Needs to Know<sup>1</sup>

## CME FEATURE

See accompanying test at [http://www.rsna.org/education/lrg\\_cme.html](http://www.rsna.org/education/lrg_cme.html)

## LEARNING OBJECTIVES FOR TEST 4

After reading this article and taking the test, the reader will be able to:

- Discuss the implications of the morphologic features and extent of rotator cuff tears for glenohumeral joint mechanics, treatment, and prognosis.
- Identify injuries to adjacent structures that may accompany rotator cuff tears and discuss their implications for treatment and prognosis.
- Describe the value of imaging and evaluating the rotator cuff muscles.

## TEACHING POINTS

See last page

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The rotator cuff muscles generate torque forces to move the humerus while acting in concord to produce balanced compressive forces to stabilize the glenohumeral joint. Thus, rotator cuff tears are often associated with loss of shoulder strength and stability, which are crucial for optimal shoulder function. The dimensions and extent of rotator cuff tears, the condition of the involved tendon, tear morphologic features, involvement of the subscapularis and infraspinatus tendons or of contiguous structures (eg, rotator interval, long head of the biceps brachii tendon, specific cuff tendons), and evidence of muscle atrophy may all have implications for rotator cuff treatment and prognosis. Magnetic resonance imaging can demonstrate the extent and configuration of rotator cuff abnormalities, suggest mechanical imbalance within the cuff, and document abnormalities of the cuff muscles and adjacent structures. A thorough understanding of the anatomy and function of the rotator cuff and of the consequences of rotator cuff disorders is essential for optimal treatment planning and prognostic accuracy. Identifying the disorder, understanding the potential clinical consequences, and reporting all relevant findings at rotator cuff imaging are also essential.

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## Introduction

The anatomic status of the rotator cuff tendons is one of a number of factors that must be taken into account when planning the treatment of rotator cuff injury. Diagnostic imaging of the rotator cuff provides valuable information with regard to the dimensions of full-thickness and partial-thickness tears, tendon retraction or thinning, tear shape, anatomic extent of tears and involvement of specific tendons or structures, pathologic changes involving the rotator cuff muscles, and morphologic features of the coracoacromial arch. This information is important because it may affect therapeutic decision making, surgical planning, and postsurgical prognosis.

In this article, we review the function and anatomy of the rotator cuff and the mechanism of cuff tears. In addition, we discuss and illustrate the treatment of rotator cuff tears and the role of diagnostic imaging—particularly magnetic resonance (MR) imaging—in the diagnosis and treatment of these tears.

## Rotator Cuff Function

The rotator cuff is important in shoulder movement; initiation of shoulder abduction relies on the function and integrity of the supraspinatus muscle and tendon and other rotator cuff tendons (1). Without supraspinatus function, a significant increase in the force exerted by the middle segment of the deltoid muscle is needed to initiate abduction. Large rotator cuff tears extending beyond the supraspinatus tendon are associated with loss of the ability to abduct the glenohumeral joint beyond 25°. The rotator cuff also has an important role in rotation of the shoulder. The infraspinatus muscle is the main external rotator in the shoulder, whereas the subscapularis muscle is an important internal rotator (2).

Glenohumeral joint stability is provided by a delicate balance between static stabilizers (eg, glenohumeral joint labroligamentous complex, joint capsule, osseous structures) and dynamic stabilizers, including the rotator cuff muscles (3). The rotator cuff provides substantial anterior dynamic stability to the glenohumeral joint in the end range as well as the midrange of motion (4). The infraspinatus, subscapularis, and latissimus dorsi muscles act as stabilizers during flexion, the

subscapularis muscle acts as a stabilizer during external rotation, and the subscapularis and supraspinatus muscles work together as stabilizers during extension (2). The subscapularis, infraspinatus, and teres minor muscles act in unison to firmly center the humeral head within the glenoid fossa (1). The infraspinatus muscle also has a role as a humeral head depressor (5). Clinicians suggest strengthening the rotator cuff muscles to compensate for laxity of the joint capsule and ligaments (4).

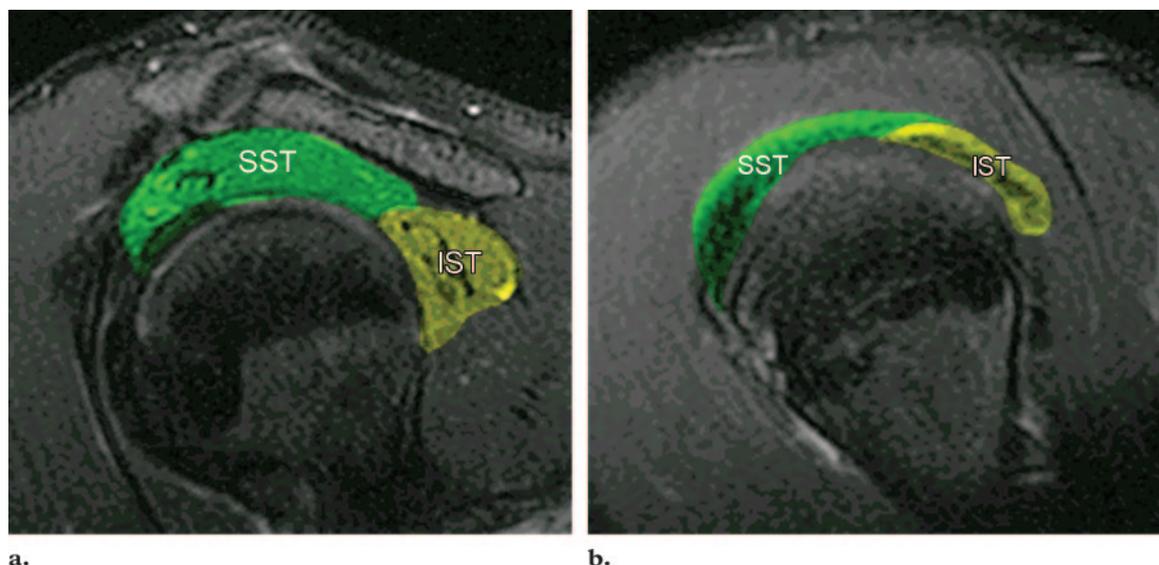
Proper shoulder function depends on a large range of motion without compromising stability, which entails precise balance between shoulder stabilizers and shoulder mobilizers. In a thrower, in whom extraordinary forces are applied to the shoulder complex, this need for precise balance is dubbed the “thrower’s paradox.” The thrower’s shoulder must be lax enough to allow external rotation but stable enough to prevent subluxation (6). Proper function of the rotator cuff muscles, which help both mobilize and stabilize the shoulder, is essential for optimal shoulder function.

## Rotator Cuff Anatomy

The rotator cuff consists of the supraspinatus, infraspinatus, subscapularis, and teres minor muscles and tendons. At the distal aspect of the rotator cuff, the supraspinatus and infraspinatus tendons splay out and interdigitate, forming a common continuous insertion on the middle facet of the humeral greater tuberosity (Fig 1) (7–9). To a lesser extent, the supraspinatus and subscapularis tendons demonstrate contiguity, with interwoven fibers from these two tendons enveloping the biceps tendon. With this arrangement of fibers, loads from the contraction of one muscle cuff are not isolated to that muscle insertion but are dispersed to adjacent tendons (10). Thus, the rotator cuff is a functional-anatomic unit rather than four unrelated tendons, and injury to one component may have an influence on other regions of the rotator cuff (11).

## Mechanism of Rotator Cuff Injury

The pathogenesis of rotator cuff injury is controversial. Neer (12) suggested an “extrinsic” theory: Hypertrophic changes of the acromion cause impingement of the subacromial-subdeltoid bursa and the rotator cuff. Association between rotator cuff tears and osteophytes from the acromioclav-



**Figure 1.** Overlap between the distal supraspinatus and infraspinatus tendons. Consecutive sagittal fat-saturated T2-weighted MR images (repetition time msec/echo time msec = 3000/60) (**a** obtained medial to **b**) show overlap between the distal supraspinatus tendon (SST) (green) and the distal infraspinatus tendon (IST) (yellow).

vicular joint and the type 3 (hooked) acromion lends additional support to the extrinsic impingement hypothesis (13,14).

According to the “intrinsic” (intratendinous) theory, the pathogenesis of rotator cuff tears is tendon degeneration. Degenerative partial-thickness tears of the rotator cuff tendons may allow superior migration of the humeral head. This migration will in turn cause abrasion of the rotator cuff tendons against the undersurface of the acromion, thereby leading to full-thickness tears (15,16).

Possible secondary causes of rotator cuff disease include overuse and fatigue of scapular stabilizers, adhesive capsulitis, and glenohumeral instability, which may lead to impingement (17). Intrinsic muscle contractile tension overload has also been cited as a potential cause of rotator cuff injury (18).

Rotator cuff tears have also been described following acute trauma. Anterior dislocation of the shoulder may be associated with rotator cuff tears, which, if undetected, may be the cause of recurrent anterior instability (19). Posttraumatic subscapularis tendon tears may be isolated or associated with injuries to the long head of the biceps brachii tendon (20). In older individuals, tendon rupture may occur after acute trauma to rotator cuff tendons with underlying chronic degenerative changes (21).

### Treatment of Rotator Cuff Tears

The goal in the treatment of rotator cuff injury is pain relief with return of shoulder strength and range of motion. Rotator cuff tears may initially be treated conservatively. Surgical treatment may be considered in symptomatic rotator cuff tears and in subacromial impingement that has not responded to nonsurgical treatment (22–24). Asymptomatic rotator cuff tears are relatively common, especially in older individuals, but whether surgical intervention is needed to avoid future complications in these cases is not clear (25–29). Thus, the anatomic status of the rotator cuff is only one of a number of factors that must be taken into account when considering surgical treatment. Other factors include the patient’s subjective symptoms, expectations, and functional requirements; shoulder function as objectively evaluated; and chronicity of the injury (23).

The potential benefits of repair of rotator cuff tears have been well established. The assumption that restoration of cuff integrity will restore function has been proved in cadaveric studies (30). Clinical studies have shown improved function and strength, decreased pain, and improved performance of daily activities after rotator cuff



**Figure 2.** Rotator cuff arthropathy. **(a)** Sagittal T1-weighted MR image (620/8) shows a massive rotator cuff tear with only subscapularis tendon (*SSC*) fibers remaining. *A* = acromion, *D* = deltoid muscle, *H* = humeral head. **(b)** Coronal oblique T1-weighted MR image (620/8) shows superior subluxation of the humeral head (*H*) abutting the acromion (*A*). *G* = glenoid fossa. **(c)** Radiograph obtained in a different patient also shows superior subluxation of the humeral head abutting the acromion (cf **b**). **(d)** Coronal oblique T1-weighted MR image (620/8) obtained in a third patient shows subchondral bone marrow edema caused by impaction of the humeral head (*H*) against the acromion (arrow), a condition that may progress to collapse.

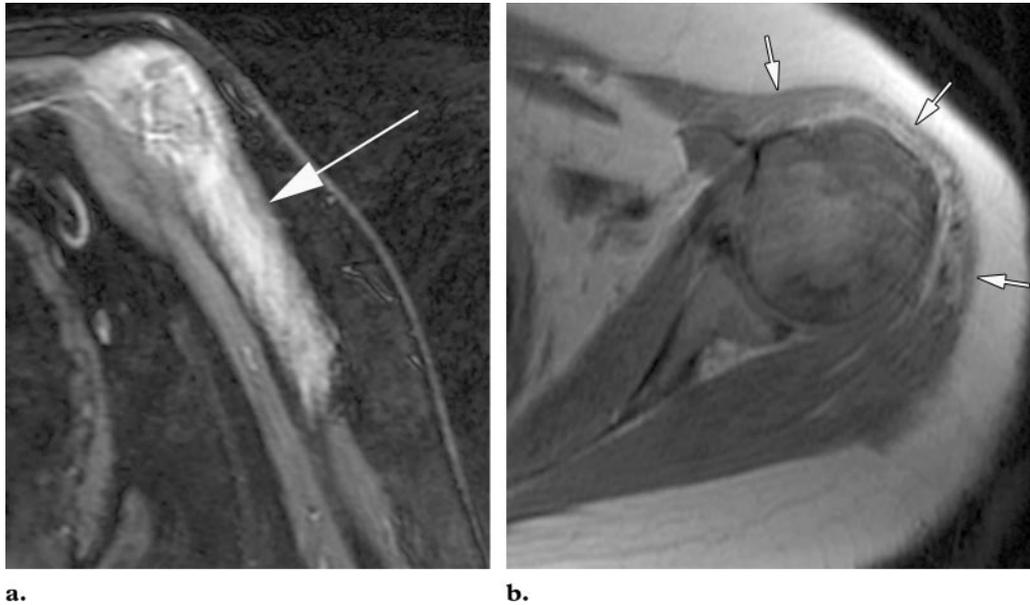
repair (31,32). Even patients with recurrent tear experienced improvement compared with their preoperative condition, although to a lesser extent than patients who had undergone successful repair (33).

Surgical repair of full-thickness rotator cuff tears has also been shown to be superior to subacromial decompression in terms of long-term (3–7-year) outcome and function (34,35).

Massive rotator cuff tears that are not treated may progress to rotator cuff arthropathy, which is characterized by progressive weakening of the

subchondral bone with impaction of the humeral head against the acromion and acromioclavicular joint, leading to bone erosions and, ultimately, humeral head collapse (Fig 2) (36,37).

The apparent advantages of surgical repair are offset somewhat by the fact that even successful surgery will only partially restore shoulder function, by the high risk of tear recurrence, and by a relatively lengthy rehabilitation process (31). Thus, when rotator cuff tears are diagnosed, the orthopedic surgeon must weigh the therapeutic options carefully before making a treatment recommendation. Imaging can supply important information that may assist in decision making and surgical planning.



**Figure 3.** Neurogenic injury to the deltoid muscle. Coronal oblique fat-saturated T2-weighted (3000/60) **(a)** and axial intermediate-weighted (2500/28) **(b)** MR images show the deltoid muscle (arrows) with abnormal high signal intensity and volume loss due to neurogenic injury.

### Role of Diagnostic Imaging

There are many causes of shoulder pain related to impingement, including rotator cuff disease, acromial spurs, subacromial-subdeltoid bursal inflammation, coracoacromial ligament thickening, and acromioclavicular joint encroachment. An experienced clinician can usually make the diagnosis of impingement but often cannot distinguish between the potential contributing factors, which may, however, be effectively demonstrated radiologically (23). In patients less than 40 years of age, shoulder instability and secondary rotator cuff impingement may coexist. In cases in which the diagnosis is not straightforward or conservative treatment is unsuccessful, findings of a normal rotator cuff at MR imaging or ultrasonography (US) may substantiate the diagnosis of instability. In older patients with chronic symptoms, the decision to image the rotator cuff is dependent on multiple factors, including the patient's expectations and the surgeon's therapeutic approach to chronic rotator cuff tears (23).

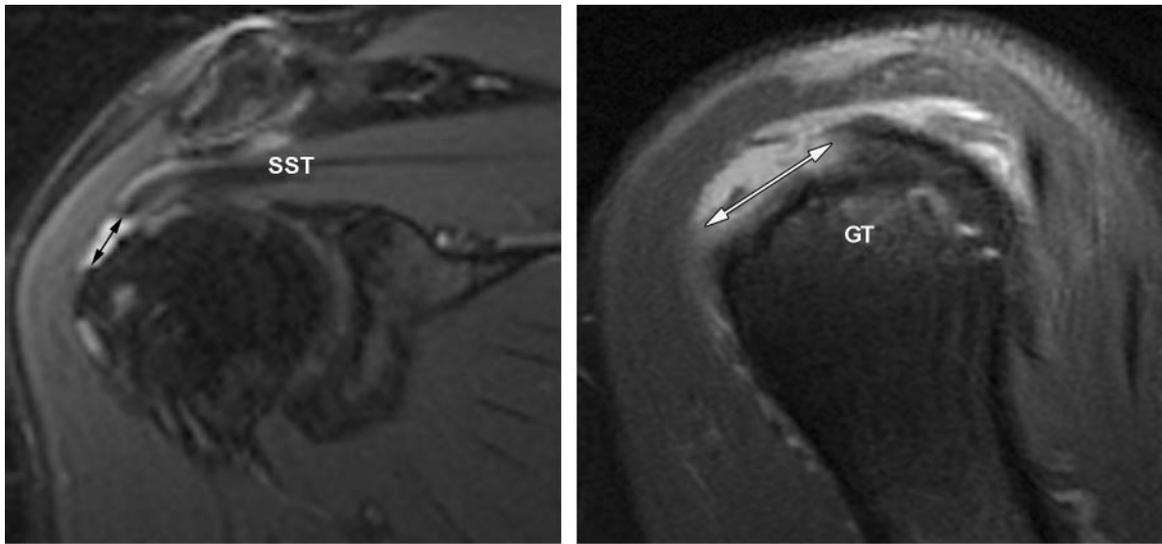
Findings at MR imaging may also help determine if surgery is contraindicated. Although they are not absolute contraindications, neurologic abnormalities involving the shoulder such as Parkinson disease or paraplegia have been associated with a higher failure rate for rotator cuff repair. In addition, deltoid muscle abnormalities may have an impact on the return of muscle strength. The radiologist should be aware of findings that suggest neurologic abnormalities of the shoulder or loss of deltoid muscle function (eg, atrophy), even though such findings are not the primary goal in

imaging of the rotator cuff (Fig 3). In some patients without these contraindications, surgery may be contemplated after taking into consideration the status of the rotator cuff muscles and tendons, since MR imaging findings of muscle atrophy, superior migration of the humeral head, or retraction of the tendon edge medial to the glenoid fossa are considered by some orthopedic surgeons to be signs of irreparability (38,39).

When imaging the rotator cuff, one should bear in mind possible clinical implications of the findings and strive to *(a)* identify and evaluate cuff lesions that may compromise glenohumeral joint function, taking into account functional anatomy; *(b)* recognize imaging findings that decrease the likelihood of favorable functional-anatomic outcome after cuff repair; and *(c)* identify and describe imaging findings that will assist in selecting a repair technique (38).

### MR Imaging of Rotator Cuff Tears

MR imaging can provide information about rotator cuff tears such as tear dimensions, tear depth or thickness, tendon retraction, and tear shape that can influence treatment selection and help determine the prognosis. In addition, tear extension to adjacent structures, muscle atrophy, size of muscle cross-sectional area, and fatty degeneration have implications for the physiologic and mechanical status of the rotator cuff. Lastly,



**a.**  
**Figure 4.** Focal full-thickness supraspinatus tendon tears. Coronal oblique (**a**) and sagittal (**b**) fat-saturated T2-weighted MR images (3000/60) obtained in two different patients show focal full-thickness tears of the supraspinatus tendon (*SST*). Double-headed arrow indicates the greatest dimension of the tears. *GT* = greater tuberosity.

information about the coracoacromial arch and impingement as it relates to rotator cuff tears can be obtained with MR imaging.

#### Dimensions of a Full-Thickness Tear

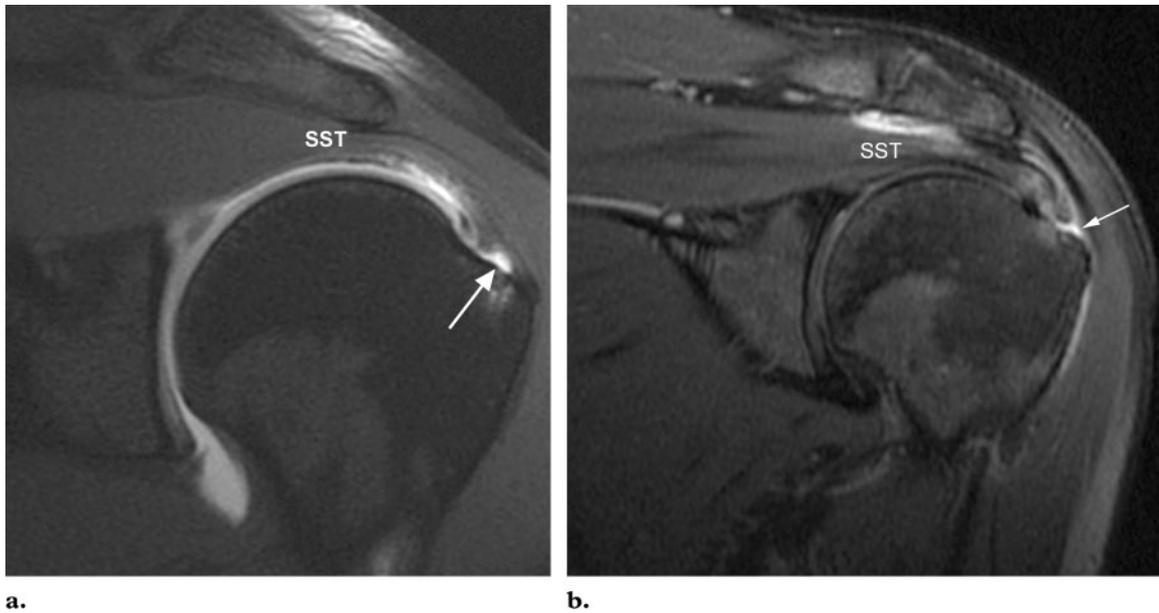
Rotator cuff tears can be classified according to size. DeOrio and Cofield (40) classified rotator cuff tears on the basis of greatest dimension as either small (<1 cm), medium (1–3 cm), large (3–5 cm), or massive (>5 cm) (Fig 4). **The dimensions of rotator cuff tears may have implications for selection of treatment and surgical approach, postoperative prognosis, and tear recurrence.** For example, with a different classification system, rotator cuff tears greater than 1 cm<sup>2</sup> are associated with an unfavorable outcome if treated conservatively and will, therefore, likely be treated surgically (41). In contrast, primary repair is often not possible when both the length and the width of the tear exceed 4 cm at preoperative MR imaging (42). The size of a tendon tear may also affect the choice of surgical approach (eg, open repair, arthroscopic repair, or a combination of the two), but there are no absolute criteria and there is an ongoing debate in this regard. Some studies have shown open repair to be advantageous in dealing with large or massive rotator cuff tears, whereas

other studies have indicated that arthroscopic repair yields results comparable to those of open surgery in cuff tears of any size (43–48).

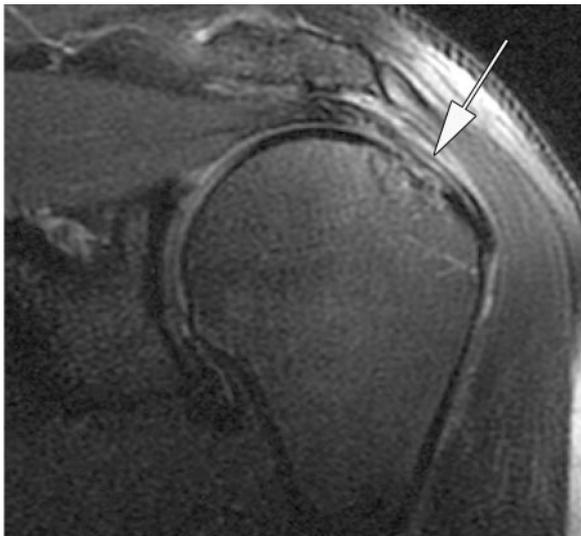
With regard to surgical outcome, controversy exists concerning the effect of tear size on postoperative function. Although some studies indicate that there is an association between tear size and surgical outcome, other studies indicate that tear size has no implications for the success of rotator cuff repair or arthroscopic debridement (48–56). Recovery of strength after large and massive rotator cuff tears is much slower and less consistent than with smaller tears (57). The size of the tear to be repaired has also been noted as one of the factors associated with postsurgical tear recurrence, with larger tears having a greater likelihood of recurrence (31,52,58).

#### Depth of a Partial-Thickness Tear

Articular-surface partial-thickness rotator cuff tears are common and occur more frequently than bursal-surface partial-thickness tears. Partial-thickness tears that are not repaired can lead to persistent pain and disability (Fig 5) (59,60). As the depth of a partial-thickness tear increases, there is increased strain in the remaining tendon and other rotator cuff tendons (61). Articular-surface partial-thickness tears may also propagate to a full-thickness tear (62). Both articular-surface and bursal-surface partial-thickness tears are



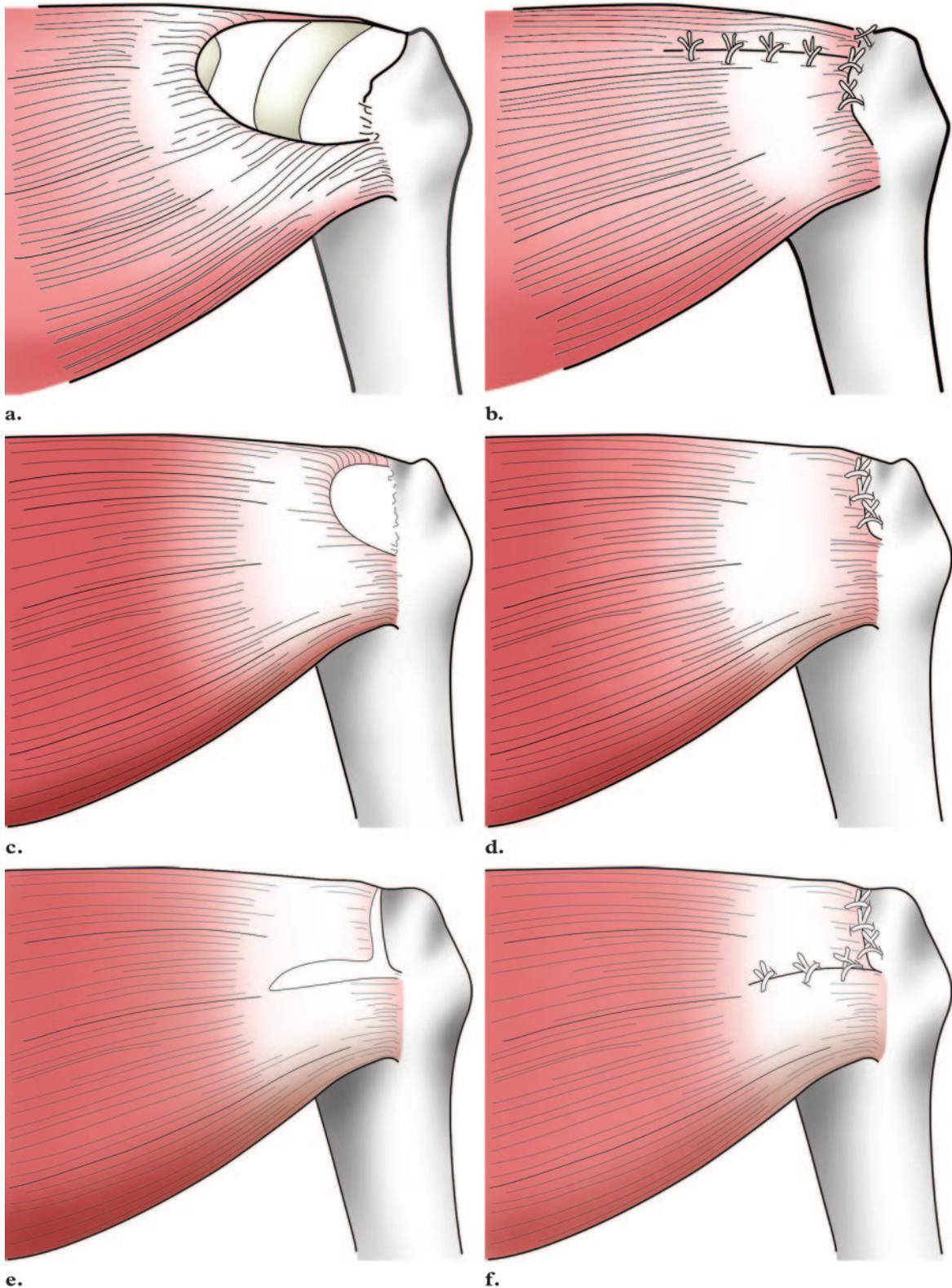
**Figure 5.** Partial-thickness tendon tears. **(a)** Coronal oblique fat-saturated T1-weighted MR image (570/11) shows an articular-surface partial-thickness tear (arrow) in the distal supraspinatus tendon (SST). **(b)** Coronal oblique fat-saturated T2-weighted MR image (3000/60) shows a bursal-surface partial-thickness tear (arrow) in the distal supraspinatus tendon (SST). These images can be used to estimate tear depth.



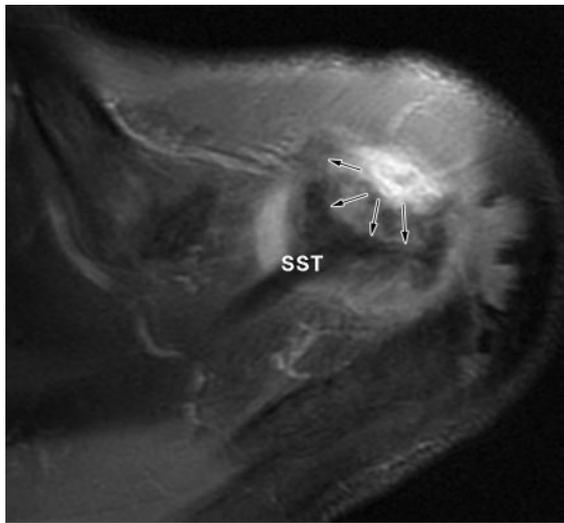
**Figure 6.** Thinning of the rotator cuff. Coronal oblique fat-saturated T2-weighted MR image (3000/60) shows thinning of the supraspinatus tendon (arrow).

graded according to their depth as either grade 1 (<3 mm), grade 2 (3–6 mm), or grade 3 (>6 mm) (63,64). The normal rotator cuff is 10–12 mm thick; thus, grade 3 tears are considered significant tears involving more than 50% of the cuff thickness (63).

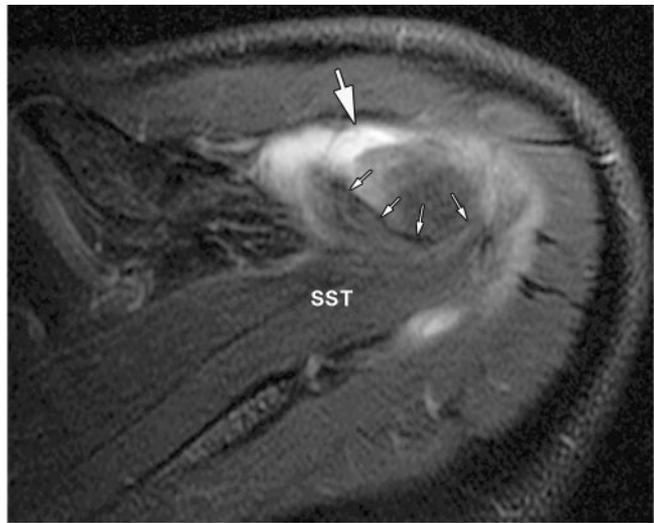
There is controversy regarding the appropriate treatment for partial-thickness rotator cuff tears. Initial treatment is typically nonsurgical, with rotator cuff strengthening and stretching; however, surgery may be considered when nonsurgical treatment is unsuccessful or when there are significant (grade 3) partial-thickness tears (65,66). Although acromioplasty and tendon debridement appear sufficient in cases of partial-thickness tears involving less than 50% of the tendon thickness (64,67,68), tears involving more than 50% are deemed significant and should be treated with surgical repair (60,66,69–71). Determining the depth of a partial-thickness tear with arthroscopic techniques may be difficult, with some investigators relying on indirect measurements such as the extent of uncovered greater tuberosity (60,72). MR imaging supplies the most complete information about tendon structure. This important information may influence therapeutic decision making and may include information about possible associated disease related to the labrum (73,74). In addition, tendon thinning as seen at MR imaging in the context of a partial-thickness tear may be an indication for surgical repair (Fig 6) (69).



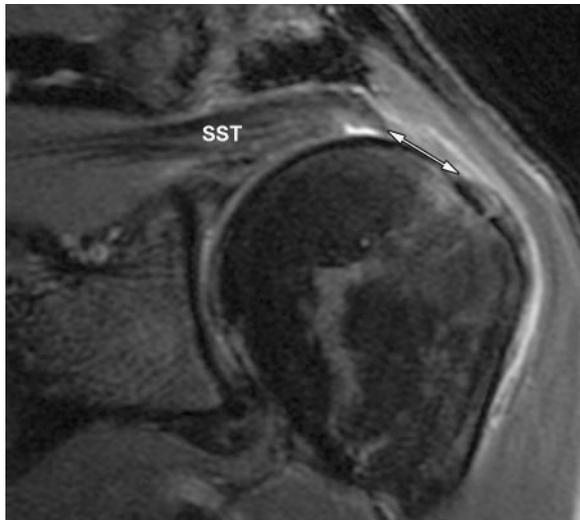
**Figure 7.** Tendon tears. Drawings illustrate a U-shaped tear before (a) and after (b) repair, a crescentic tear before (c) and after (d) repair, and an L-shaped tear before (e) and after (f) repair.



a.



b.



c.

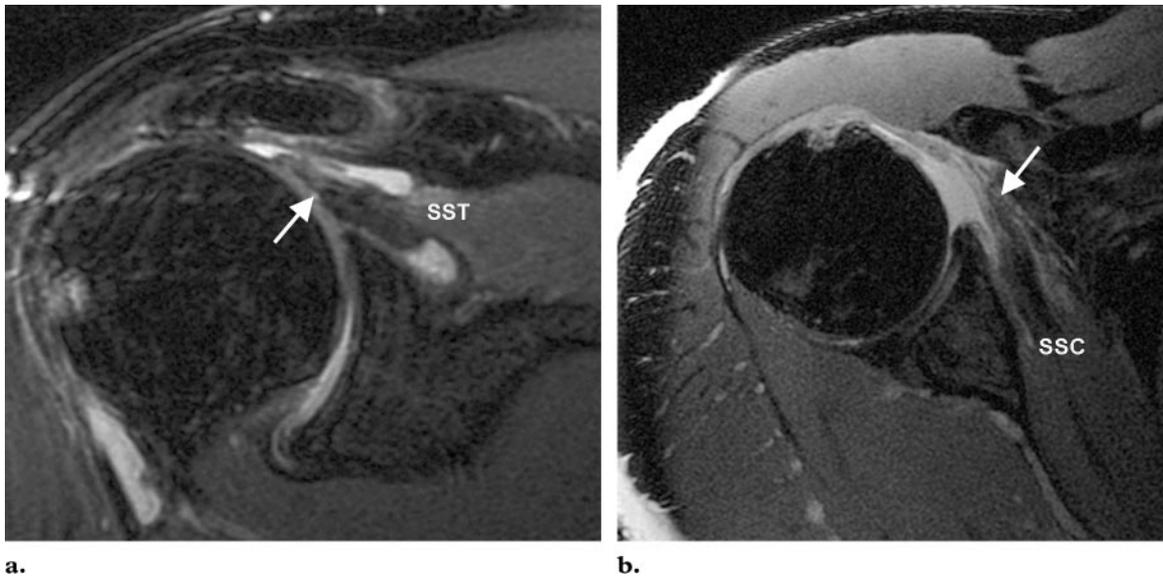
**Figure 8.** Tendon tears. (a) Axial fat-saturated T2-weighted MR image (3000/60) shows a tear (arrows) of the distal supraspinatus tendon (SST). The tear has mildly pulled away from bone, a finding that suggests a crescentic tear. (b, c) Axial (b) and coronal oblique (c) fat-saturated T2-weighted MR images (3000/60) depict a more medially displaced tear (small arrows in b) of the distal supraspinatus tendon (SST), a finding that suggests a U-shaped tear. This tear appears to extend into the rotator interval (large arrow in b). Double-headed arrow in c indicates the greatest longitudinal dimension of the tear.

### Tear Shape

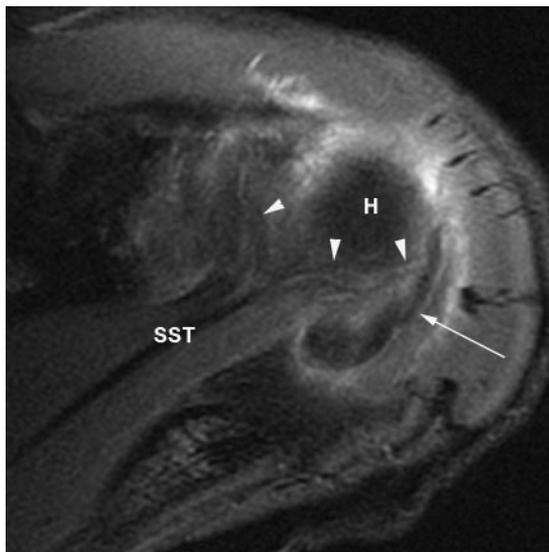
The shape of a rotator cuff tear is important in the selection of a surgical technique. Tears can be classified arthroscopically into three basic shapes according to the tear geometry as viewed from the tendon surface: crescentic, U shaped, and L shaped (48,75). In crescentic tears, the tendon pulls away from the greater tuberosity but typically does not retract far medially and therefore can be reattached to bone with minimal tension. U-shaped tears are massive rotator cuff tears that may extend medially to the level of the glenoid fossa. L-shaped tears are massive tears with a longitudinal component along the orientation of the rotator cuff fibers and a transverse component

along the cuff insertion. The geometry of a tear is a consequence of tear orientation and physiologic load from muscle pulling at the tear margin, with various surgical techniques being used depending on the degree of tear mobility. For example, U-shaped tears are treated with side-to-side (marginal convergence) suturing of the anterior and posterior leaves and reattachment of the transverse free margin to bone (Figs 7, 8) (48,75).

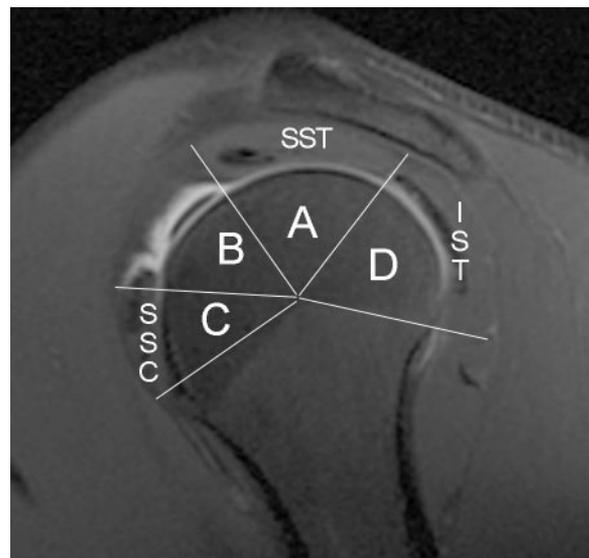
The ability to identify the tear geometry at arthroscopy diminishes as tear size increases (39). Massive contracted rotator cuff tears have been classified at MR imaging into two categories: massive crescentic tears (wide anteroposterior dimension) and massive longitudinal tears (spared anterior cuff tissue at the rotator interval) (75). Persistence of the coracohumeral ligament and intact anterior supraspinatus tendon fibers visualized at preoperative MR imaging in the context of massive rotator cuff tears can affect surgical planning.



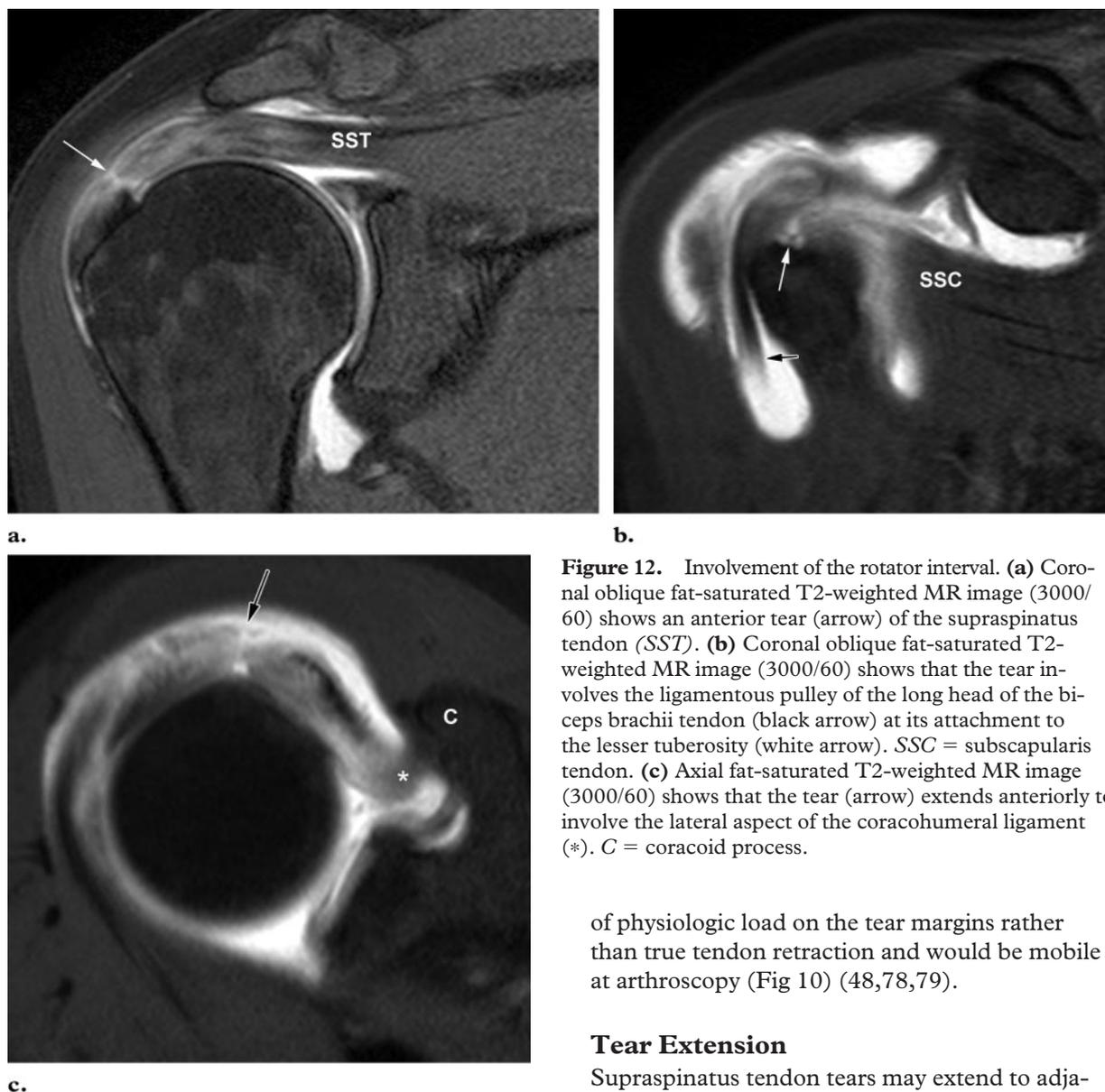
**Figure 9.** Medial tendon retraction. Coronal oblique (a) and axial (b) fat-saturated T2-weighted MR images (3000/60) show medial retraction (arrow) of the stumps of the supraspinatus tendon (SST) and subscapularis tendon (SSC) almost to the glenoid fossa. As with medially retracted supraspinatus tendon tears, primary repair of medially retracted subscapularis tendon tears may not be feasible, and pectoralis major tendon transfer may be indicated.



**Figure 10.** Factors affecting the medial extent of a tendon tear. On an axial fat-saturated T2-weighted MR image (3000/60), intact infraspinatus muscle and tendon fibers (arrow) are shown exerting a physiologic load on the posterior leaf of a U-shaped tear (arrowheads) of the distal supraspinatus tendon (SST), thereby increasing the distance between the tendon stump and the greater tuberosity. *H* = humeral head.



**Figure 11.** Sagittal extent of rotator cuff tears as described by Thomazeau et al (52). Chart superimposed on a sagittal fat-saturated T2-weighted MR image (3000/60) shows the division of the rotator cuff into four segments (A–D). Supraspinatus tendon (SST) tears that extend to involve the rotator interval (B) could worsen the prognosis. *IST* = infraspinatus tendon, *SSC* = subscapularis tendon.



**Figure 12.** Involvement of the rotator interval. **(a)** Coronal oblique fat-saturated T2-weighted MR image (3000/60) shows an anterior tear (arrow) of the supraspinatus tendon (SST). **(b)** Coronal oblique fat-saturated T2-weighted MR image (3000/60) shows that the tear involves the ligamentous pulley of the long head of the biceps brachii tendon (black arrow) at its attachment to the lesser tuberosity (white arrow). SSC = subscapularis tendon. **(c)** Axial fat-saturated T2-weighted MR image (3000/60) shows that the tear (arrow) extends anteriorly to involve the lateral aspect of the coracohumeral ligament (\*). C = coracoid process.

of physiologic load on the tear margins rather than true tendon retraction and would be mobile at arthroscopy (Fig 10) (48,78,79).

### Tear Extension

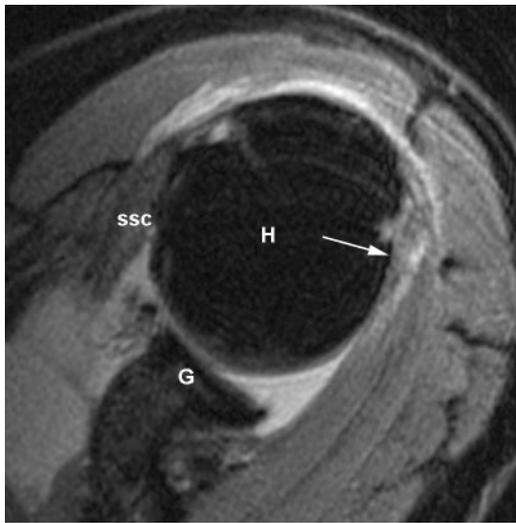
Supraspinatus tendon tears may extend to adjacent structures, significantly affecting the mechanics of the glenohumeral joint and having important prognostic implications. **A supraspinatus tendon tear may extend anteriorly to involve the medial aspect of the coracohumeral ligament and superior subscapularis tendon fibers, a situation that is associated with more severe supraspinatus atrophy and poor prognosis (Fig 11) (52).** In fact, in a study by Gazielly et al (80), the rate of tear recurrence following rotator cuff repair increased from 7% to 25% when the initial supraspinatus tendon tear involved the adjacent rotator interval (Fig 12). Determining the extent of subscapularis

### Tendon Retraction

The degree of tendon retraction is important information obtained with MR imaging. Optimally, in primary repair, the tendon stump should be adjacent to the attachment site so that reattachment is free of tension (38,76,77). **It has been suggested that a tear is suspected to be irreparable if MR imaging depicts retraction of the tendon edge medial to the glenoid fossa (Fig 9) (52).** It is important to recognize that the medial extent of the tendon as demonstrated at MR imaging may not represent true retraction. For example, the medial extent of a U-shaped tear is a consequence

Teaching Point

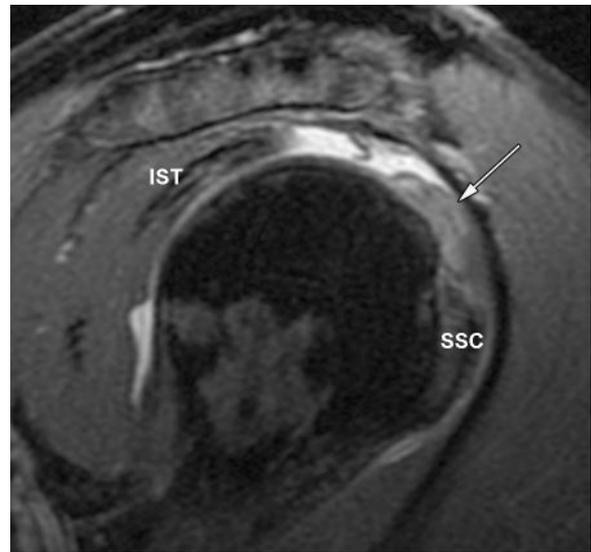
Teaching Point



**Figure 13.** Disruption of the transverse force couple. Axial fat-saturated T2-weighted MR image (3000/60) shows anterior subluxation of the humeral head (*H*) relative to the glenoid fossa (*G*), a finding that may be related to disruption of the coupled axial forces. Fluid is noted in the glenohumeral joint and subdeltoid bursa as part of an infraspinatus tendon tear (arrow) and a large tear (not seen) of the supraspinatus tendon (*SSC*).

tendon involvement at MR imaging is important because the subscapularis tendon is hard to visualize in the standard surgical approach to rotator cuff repair. Therefore, the extent of subscapularis tendon involvement in anterior cuff tears may go unrecognized during surgery, resulting in an unsuccessful outcome. In addition, subscapularis tendon repair requires a modified (deltopectoral) surgical approach (81,82). Supraspinatus tendon tears may also extend posteriorly to involve the infraspinatus tendon, the primary external rotator of the shoulder (8).

The key to optimal function of the glenohumeral joint is proper positioning of the humeral head relative to the glenoid fossa (“balanced shoulder” concept). The rotator cuff, both passively and actively, accomplishes this positioning. Stability in the axial plane is the result of a balance of forces between the anterior and posterior cuff muscles (“transverse force couple”) (1,83,84).

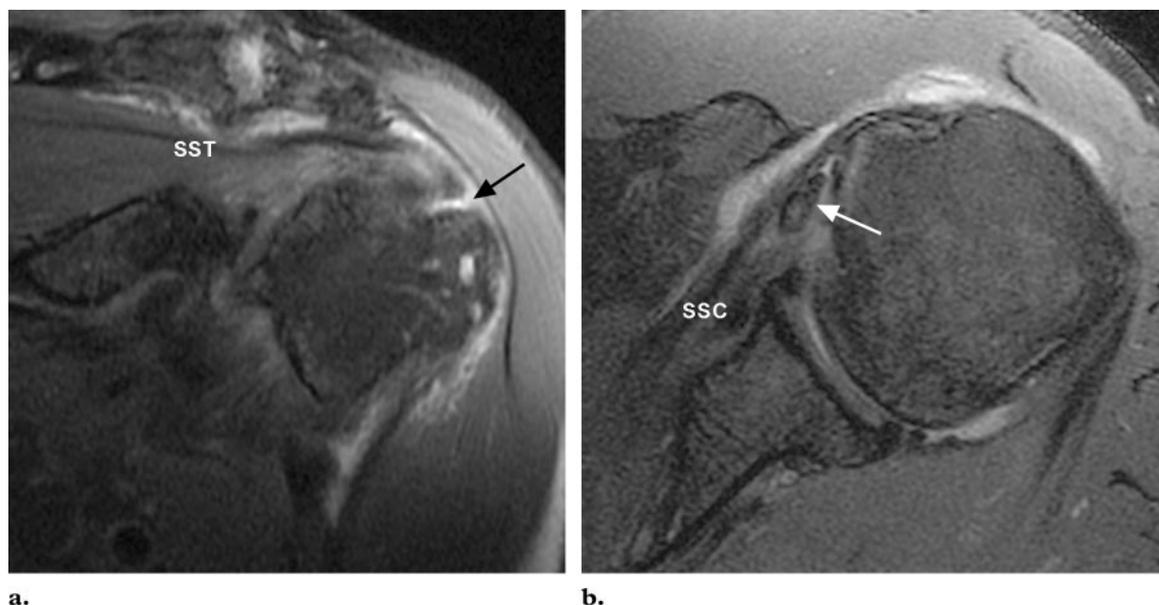


**Figure 14.** Injury to the long head of the biceps brachii tendon. Sagittal fat-saturated T2-weighted MR image (3000/60) shows an extensive full-thickness tear of the supraspinatus tendon. Note the abnormal thickening and intermediate signal intensity of the long head of the biceps brachii tendon (arrow) within the rotator interval superior to the subscapularis tendon (*SSC*). These findings are consistent with injury to the long head of the biceps brachii tendon. *IST* = infraspinatus tendon.

Supraspinatus tendon tear extension to involve the subscapularis and infraspinatus tendons is associated with significant detrimental effects on glenohumeral joint stability and function (Fig 13) (1,38).

The importance of the transverse force couple and of the infraspinatus and subscapularis tendons in shoulder motion may explain why some patients with full-thickness rotator cuff tears have acceptable shoulder function and why some surgeons suggest taking a conservative approach in selected cases of documented symptomatic, isolated full-thickness tears of the supraspinatus tendon (38,83).

Involvement of the long head of the biceps brachii tendon in the context of anterior cuff tears also has important clinical implications. In association with rotator cuff tear, abnormality of the biceps brachii tendon is one of several factors associated with poor surgical outcome (Fig 14) (50,54,85,86). Biceps brachii tendon abnormality in association with rotator cuff tear is not uncommon, with the abnormality consisting of injury or disruption in up to 77% of cases and subluxation



**Figure 15.** Dislocation of the long head of the biceps brachii tendon. **(a)** Coronal oblique fat-saturated T2-weighted MR image (3000/60) shows an anterior tear (arrow) of the distal supraspinatus tendon (SST). **(b)** Axial fat-saturated T2-weighted MR image (3000/60) shows the long head of the biceps brachii tendon (arrow) dislocated medially from the bicipital groove deep to the superficial subscapularis tendon (SSC) fibers.

or dislocation in 44% (85). Subluxation or dislocation of the long head of the biceps brachii tendon may be difficult to appreciate at the time of surgery and may be a cause of persistent postoperative discomfort. Careful inspection of the appearance and position of the long head of the biceps brachii tendon should be routine at imaging of the rotator cuff (Fig 15). MR imaging evaluation for subluxation of the long head of the biceps brachii tendon is static. However, US examination can and should include dynamic evaluation for intermittent subluxation, especially in the presence of anterior supraspinatus or superior subscapularis tendon tears (87).

### Muscle Atrophy, Cross-Sectional Area, and Fatty Degeneration

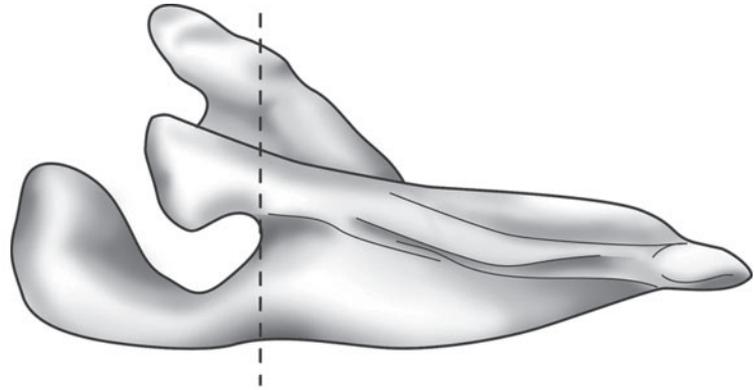
Repair of a rotator cuff tear will not result in optimal functional outcome if the ability of the muscle to contract is irreversibly lost, primarily due to muscle atrophy (88). Determination of tear dimensions is only one aspect of the evaluation of rotator cuff tears and does not take into account muscle atrophy (52). Measuring muscle cross-sectional area may provide important infor-

mation, since this measurement correlates with muscle strength (89).

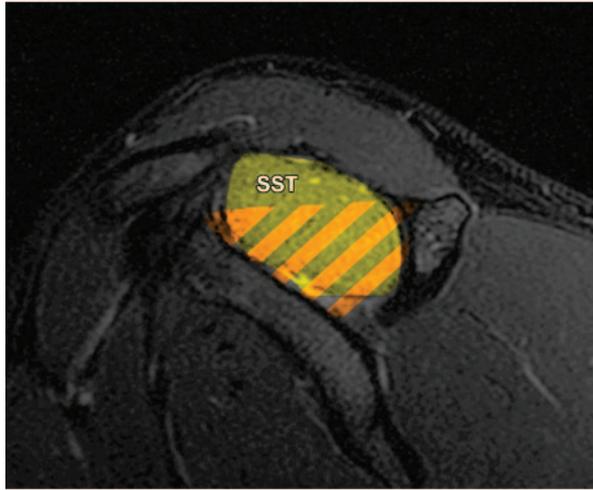
The cross-sectional area of the supraspinatus muscle can be measured with MR imaging. Direct volume estimation has been described as accurate but impractical (90,91). Two additional methods, the scapular ratio and the “tangent sign,” have been used to assess for supraspinatus muscle atrophy.

The scapular ratio is calculated in the sagittal oblique plane at the level of the medial coracoid process, where the supraspinatus fossa is largely encompassed by osseous boundaries (Fig 16) (92). **If the ratio of the cross-sectional area of the supraspinatus muscle to the area of the supraspinatus fossa (occupation ratio) is less than 50% in the sagittal oblique plane, supraspinatus muscle atrophy is indicated (Figs 17, 18). In a study by Thomazeau et al (92), supraspinatus muscle atrophy as determined with this method correlated with extent of tendon tear and was associated with tear recurrence after surgical repair.**

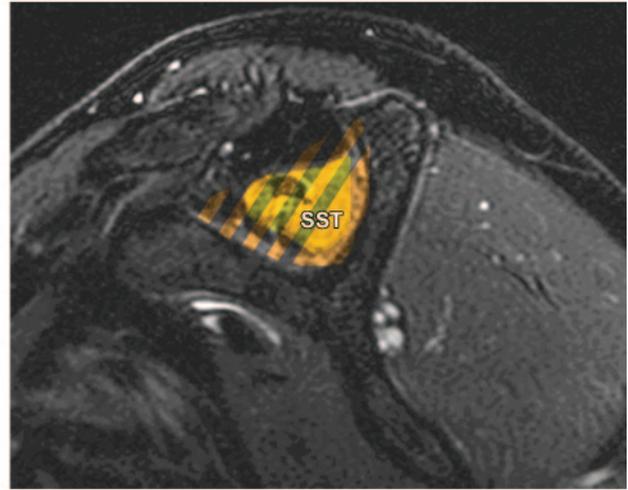
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16.

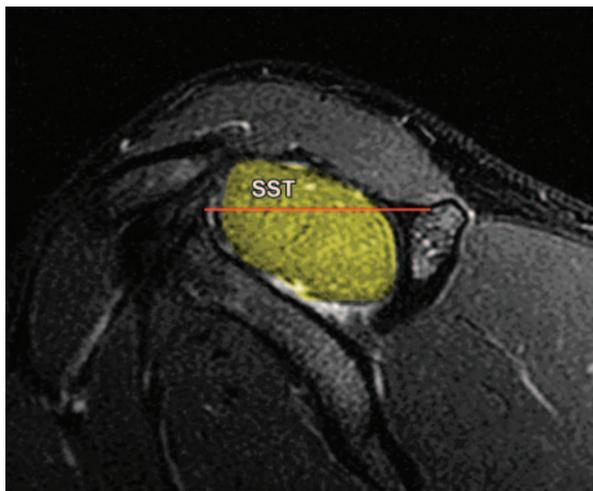


17.

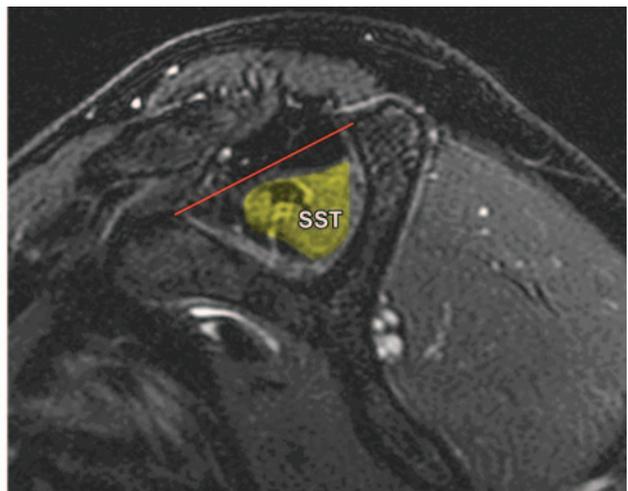


18.

**Figures 16–18.** (16) Drawing illustrates use of the sagittal plane (dashed line) relative to the coracoid base and acromial spine for estimating volume loss in the supraspinatus muscle. (17) Sagittal fat-saturated T2-weighted MR image (3000/60) shows a normal occupation ratio, representing the ratio between the cross-sectional area (green) of the belly of the supraspinatus muscle (*SST*) and that of the scapular fossa (orange). (18) Abnormal occupation ratio. Sagittal fat-saturated T2-weighted MR image (3000/60) shows volume loss in the supraspinatus muscle (*SST*), whose cross-sectional area (green) is now much smaller than that of the scapular fossa (orange).

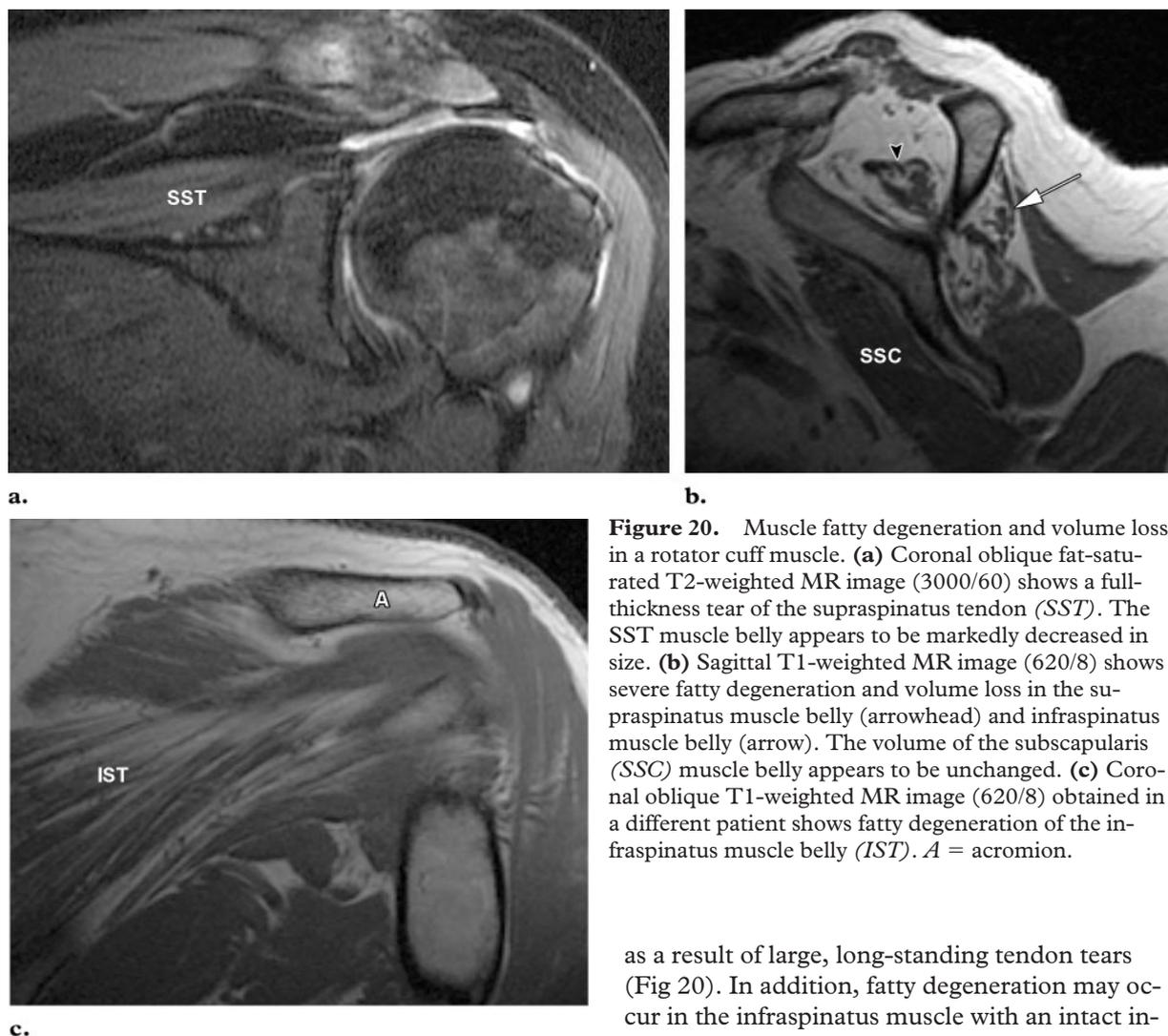


a.



b.

**Figure 19.** Tangent sign. (a) Sagittal fat-saturated T2-weighted MR image (3000/60) shows the belly (green) of a normal supraspinatus muscle (*SST*) crossing a tangent (red line) drawn between the superior borders of the scapular spine and the superior margin of the coracoid process. (b) Sagittal fat-saturated T2-weighted MR image (3000/60) shows atrophy of the belly (green) of the supraspinatus muscle (*SST*), which now lies entirely below the tangent (red line).



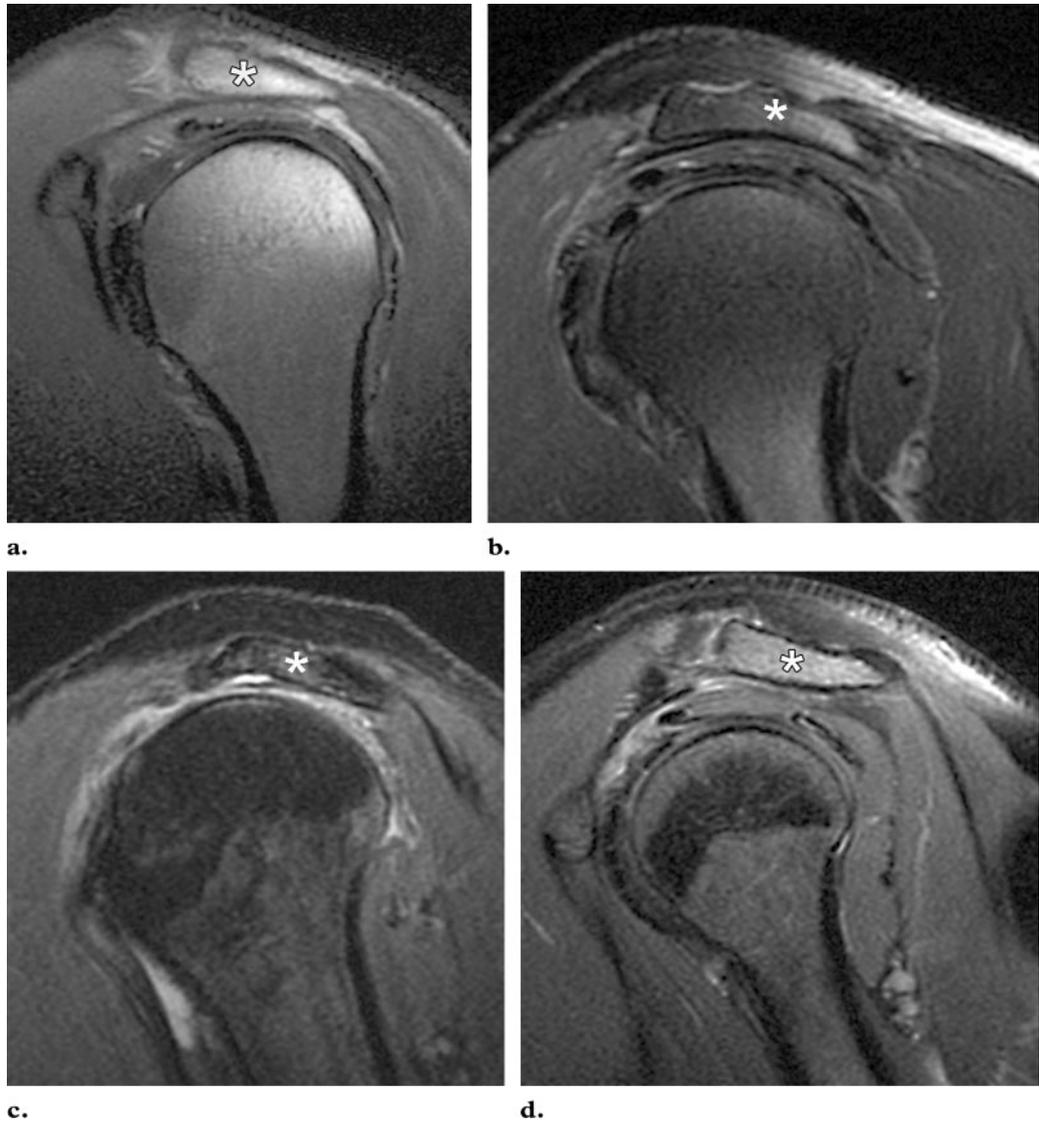
**Figure 20.** Muscle fatty degeneration and volume loss in a rotator cuff muscle. **(a)** Coronal oblique fat-saturated T2-weighted MR image (3000/60) shows a full-thickness tear of the supraspinatus tendon (SST). The SST muscle belly appears to be markedly decreased in size. **(b)** Sagittal T1-weighted MR image (620/8) shows severe fatty degeneration and volume loss in the supraspinatus muscle belly (arrowhead) and infraspinatus muscle belly (arrow). The volume of the subscapularis (SSC) muscle belly appears to be unchanged. **(c)** Coronal oblique T1-weighted MR image (620/8) obtained in a different patient shows fatty degeneration of the infraspinatus muscle belly (IST). A = acromion.

Another method of identifying supraspinatus muscle atrophy is the tangent sign (93). With use of an MR imaging plane and bone landmarks similar to those used in the scapular ratio method, a normal supraspinatus muscle should cross superior to a line drawn through the superior borders of the scapular spine and the superior margin of the coracoid process. This finding is not present with atrophy (Fig 19) (93). There is a significant correlation between occupation ratio, tangent sign, and improved strength and mobility (94). Cross-sectional areas of the infraspinatus, teres minor, and subscapularis muscles have also been compared with the chronicity of rotator cuff tears, with subscapularis muscle atrophy being associated with poorer surgical outcome (81,93).

Fatty degeneration of rotator cuff muscles may occur in connection with neurologic impairment, glenohumeral osteoarthritis, and rotator cuff tear and is not related to aging. In the context of rotator cuff tear, fatty degeneration occurs in muscles

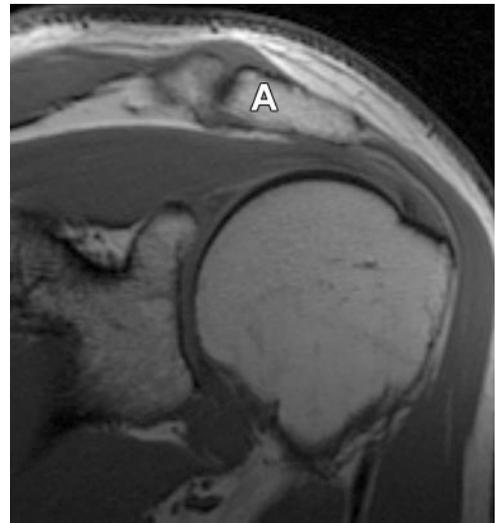
as a result of large, long-standing tendon tears (Fig 20). In addition, fatty degeneration may occur in the infraspinatus muscle with an intact infraspinatus tendon in the presence of large anterosuperior rotator cuff tears (95). The subscapularis muscle belly may also undergo fatty degeneration in the setting of a cuff tear not involving the subscapularis tendon (95–97). Fatty degeneration usually occurs around tendon fibers and blood vessels, and the true pathologic process may, in fact, be fatty infiltration rather than fatty degeneration (98,99). There is an association between worsening fatty degeneration and alteration in muscle function. **Fatty degeneration is an important predictive factor for surgical outcome (38,95–97,100).** A correlation was noted between the severity of fatty degeneration of the supraspinatus muscle, the extent of the supraspinatus tendon tear, a more medially located tendon stump, and an increase in the number of torn tendons. The risk of tear recurrence was found to be associated with the severity of muscle fatty degeneration. Infraspinatus and subscapularis muscle fatty degeneration was associated with a higher

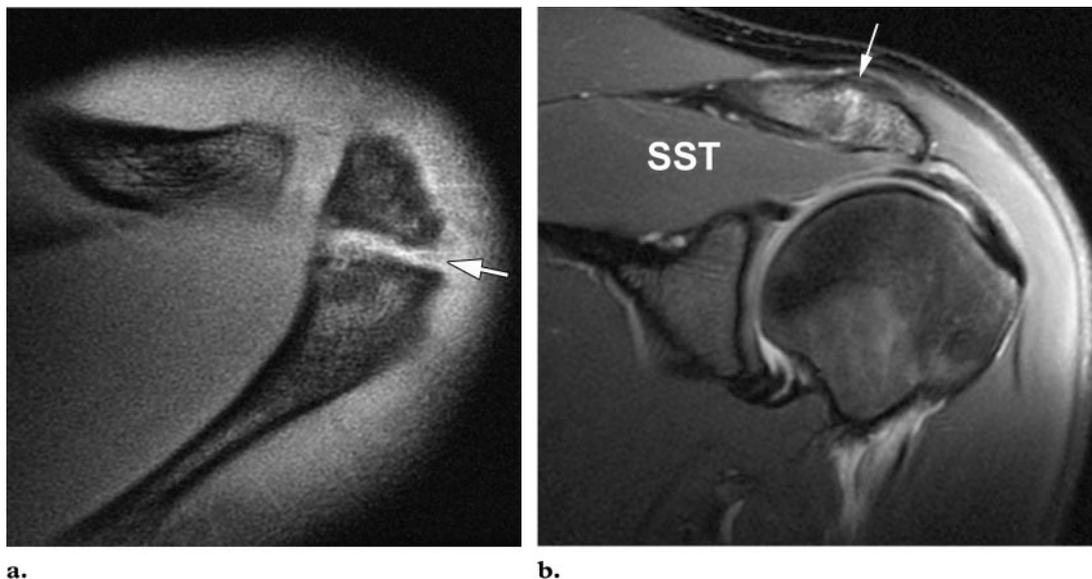
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**Figure 21.** Types of acromia. Sagittal fat-saturated T2-weighted MR images (3000/60) show type 1 (**a**), type 2 (**b**), type 3 (**c**), and type 4 (**d**) acromia (\*).

**Figure 22.** Lateral acromial angle. Coronal oblique T1-weighted MR image (620/8) shows a downsloping acromion (*A*).





**a.** **b.**  
**Figure 23.** Os acromiale. Axial (**a**) and coronal oblique (**b**) fat-saturated T2-weighted MR images (3000/60) show an os acromiale (arrow). SST = subscapularis tendon.

rate of tear recurrence in the supraspinatus tendon—possibly because of diminished depressor capability, resulting in supraspinatus tendon impingement (96). Both conventional MR imaging techniques and more advanced techniques such as MR spectroscopy (101,102) have been used to evaluate fatty degeneration of rotator cuff muscles.

Optimally, surgical repair of rotator cuff tears should be performed before there is evidence of muscle atrophy such as volume loss and fatty degeneration. Surgical decision making and technique (primary tendon repair, flap augmentation, palliative repair) are influenced by the status of the muscles (52,96).

### Coracoacromial Arch and Impingement

The coracoacromial arch consists of the anterior third of the acromion, the coracoacromial ligament, and the coracoid process. The supraspinatus glides under the coracoacromial arch, with the intervening subacromial-subdeltoid bursa allowing relatively frictionless movement. The space between the coracoacromial arch and the superior aspect of the humeral head is called the impingement interval (103). This space is normally narrow, and it narrows even more upon abduction. Anything that further narrows this space can cause impingement (10,103).

The acromial process of the scapula has been classified into four types: type 1 (flat), type 2 (curved downward), type 3 (hooked downward anteriorly), and type 4 (curved upward). A higher prevalence of rotator cuff tears—especially bursal-surface tears—is found in type 3 and possibly in type 2 acromia, likely in association with traction-type enthesophyte spurs from the coracoacromial ligament (Fig 21) (16,104–107). A significant association has been noted between the lateral acromial angle depicted with coronal oblique sequences and rotator cuff disease as seen at MR imaging (Fig 22) (108). Acromioclavicular osteophytes from the inferior surface of the joint have also been associated with supraspinatus tendon tears (13). Thickening of the coracoacromial ligament, as well as the presence of an os acromiale (unfused acromial apophysis) (Fig 23), have been associated with rotator cuff impingement (109). MR imaging, with its multiplanar capability, provides important information regarding the coracoacromial arch, including acromion type, presence of acromioclavicular osteophytes, narrowing of the impingement interval, and presence of an os acromiale (110).

## Subcoracoid Space and Coracohumeral Impingement

Morphometric studies of the coracoid process have raised the possibility that certain types of coracoid processes may be associated with coracoglenoid narrowing and thus may predispose to coracohumeral impingement (111).

A review of 100 shoulder MR images and correlation of computed tomographic (CT) measurements of the subcoracoid space with the presence of isolated subscapularis tendon lesions showed no significant correlation between the CT measurements and the presence of rotator cuff tears (112,113). The role of coracoid morphologic features and the imaging criteria associated with subcoracoid impingement have yet to be defined.

### Conclusions

The dimensions and extent of rotator cuff tears, the condition of the involved tendon, tear morphologic features, involvement of the subscapularis and infraspinatus tendons or of contiguous structures (eg, rotator interval, long head of the biceps brachii tendon), and evidence of muscle atrophy may all have implications for rotator cuff treatment and prognosis. The orthopedic surgeon must take multiple factors into consideration when deciding on treatment. Identifying the disorder, understanding the potential clinical consequences, and reporting all relevant findings at rotator cuff imaging are essential for ensuring that the most appropriate course of action is taken. A thorough understanding of the anatomy and function of the rotator cuff and of the consequences of rotator cuff disorders is also essential.

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## MR Imaging of Rotator Cuff Injury: What the Clinician Needs to Know

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### Page 1050

The dimensions of rotator cuff tears may have implications for selection of treatment and surgical approach, postoperative prognosis, and tear recurrence.

### Page 1055

It has been suggested that a tear is suspected to be irreparable if MR imaging depicts retraction of the tendon edge medial to the glenoid fossa (Fig 9) (52).

### Page 1055

A supraspinatus tendon tear may extend anteriorly to involve the medial aspect of the coracohumeral ligament and superior subscapularis tendon fibers, a situation that is associated with more severe supraspinatus atrophy and poor prognosis (Fig 11) (52).

### Page 1057

If the ratio of the cross-sectional area of the supraspinatus muscle to the area of the supraspinatus fossa (occupation ratio) is less than 50% in the sagittal oblique plane, supraspinatus muscle atrophy is indicated (Figs 17, 18). In a study by Thomazeau et al (92), supraspinatus muscle atrophy as determined with this method correlated with extent of tendon tear and was associated with tear recurrence after surgical repair.

### Page 1059

Fatty degeneration is an important predictive factor for surgical outcome (38,95–97,100).