This chapter provides a concise overview of the capacity of MRI to assist in distinguishing pathology and anatomic disruptions adjacent to shoulder articulations and is a crucial tool in evaluating the symptomatic shoulder. The differentiation of traumatic and degenerative etiologies is important for patient management. A review of common adult degenerative and posttraumatic conditions can help familiarize general orthopaedic surgeons and sports medicine care providers to the perspective of shoulder specialists and musculoskeletal radiologists.

Abstract
MRI can be used to assist in distinguishing pathology and anatomic disruptions adjacent to shoulder articulations and is a crucial tool in evaluating the symptomatic shoulder. The differentiation of traumatic and degenerative etiologies is important for patient management. A review of common adult degenerative and posttraumatic conditions can help familiarize general orthopaedic surgeons and sports medicine care providers to the perspective of shoulder specialists and musculoskeletal radiologists.

Equipment and Technique
The first MRI of a live human, performed in 1977, required many hours to acquire a single image. Since then, MRI has evolved into a rapid and commonly used evaluation tool; however, its quality is affected by several factors. Higher magnet strength (field strength), denoted by Tesla (T), increases the signal-to-noise ratio; in general, a 3.0-T magnet has a higher signal-to-noise ratio than does a 1.5-T magnet. The “closed magnet,” narrow MRI machine generally produces the highest quality images, whereas the “open magnet” MRI machine allows more room for the patient at the expense of reduced strength (usually 1.0 T or less) and decreased image quality. The receiver coil (the apparatus placed around the tissue of interest) contains readout channels that collect the signal; in general, the greater the number of channels, the better the image quality.

Higher-strength magnets have increased metallic artifact susceptibility. Metals cause poor fat suppression on T2-weighted (or fluid-weighted) sequences, decreasing the visibility of fluid; thus, a short tau inversion recovery T1 sequence (a fluid-sensitive sequence with more uniform fat suppression) may be more useful. Similarly, when metallic implants are a consideration, image quality may benefit from a lower strength magnet.

Routine shoulder MRI protocols typically consist of axial, sagittal oblique, and coronal oblique sequences. The sagittal and coronal sequences are oriented along the long axis of the scapula to better profile the rotator cuff. Most protocols employ a combination of fluid-weighted sequences (T2- or proton density–weighted) and T1-weighted sequences. In the former, fluid and edema are bright (hyperintense); fat is...
natively bright, although fat suppression is often used to turn fat and bone marrow dark (hypointense) to increase lesion visibility. On T1-weighted images, fat and bone marrow are bright, unless fat suppression is used. If arthrographic or intravenous gadolinium contrast is administered, T1-weighted sequences are used, whereas gadolinium is bright.

Normal and AbnormalAppearances of Soft Tissues

Normal ligaments, tendons, capsules, and labrum should be hypointense on all sequences (Figure 1). As a result of edema and fluid, traumatic soft-tissue injuries manifest as increased signal on T2-weighted sequences. Sprained tissues show intrasubstance, intermediate-to-hyperintense signal, and ill-defined fibers but not fiber discontinuity. Tear defects demonstrate bright fluid. Chronic, atraumatic mucoid (myxoid) degeneration may confound a sprain diagnosis but should be amorphous, nonlinear, and intermediate in signal intensity. Such degeneration is often seen in the rotator cuff tendons and the labrum.

Acromion andAcromioclavicular Joint

Degenerative joint disease is common in the adult acromioclavicular (AC) joint and is often reported. However, one study found up to 82% of asymptomatic patients had MRI abnormalities in the AC joint.\(^2\,3\) Distinguishing incidental degenerative joint disease from relevant disease requires clinical correlation. The joint should be smoothly margined (Figure 1, A). Abnormal findings include osteophytes, bone marrow signal changes, and (rarely) intra-articular abnormalities. Capsular distention is suggested as an important factor associated with symptomatic AC joints.\(^4\) Degenerative osteophytes at either the distal clavicle or the articulating acromion can result in roof impingement on the supraspinatus or infraspinatus tendons, leading to tendinopathy and tearing. Static impingement is identified on sagittal and coronal images as inferiorly projecting spurs indenting the superior tendon surface (Figures 2 and 3).
the subscapularis tendon is best seen on axial images. Normal cuff musculature is evaluated on sagittal oblique sequences, with uniform intermediate signal throughout; sagittal oblique T1-weighted images best reveal atrophy and more advanced fatty degeneration. The spectrum of rotator cuff pathology ranges from intrinsic tendinopathy to partial- and full-thickness tears that can all appear as areas of intermediate- or fluid-intense signal within the tendon on fluid-weighted sequences. Distinguishing these entities requires further evaluation.

Tendinopathy, which is most apparent on fluid-weighted sequences, can represent acute tendinitis, a contusion, or degenerative mucoid tendinosis. It appears as ill-defined, focal or diffuse intermediate signal intensity in the tendon (Figure 3). However, the articular and bursal tendon surfaces should remain smooth and intact.

Conventional MRI is relatively accurate for diagnosing rotator cuff tears, with 80% sensitivity and 95% specificity for partial-thickness tears and 91% sensitivity and 97% specificity for full-thickness tears. Tendon tears may involve the articular surface or the bursal surface (a partial-thickness tear), both surfaces (a full-thickness tear) or be confined to the interstitium (a mid-substance tear; Figures 5 and 6). A tear is diagnosed as a discrete, fluid-intense abnormality across all or part of a tendon; it is usually best appreciated on fat-suppressed, T2-weighted sequences. Tears are frequent within 1 cm of the insertion (critical zone) or at the humeral head insertion. Associated adjacent tendinopathy is common. Partial-thickness tears represent approximately 20% to 25% of cases, with most occurring along the articular supraspinatus footprint. Articular-sided footprint tears may be referred to as partial articular-sided supraspinatus tendon avulsions (PASTA), which commonly occur in those younger than 40 years.

In the setting of a suspected tear, close inspection at the far-anterior margin (high stress zone) of the tendon is essential; anterior supraspinatus tendon fibers should extend to the tuberosity at the posterior biceps interval. Distinguishing small partial-thickness tears from surrounding tendinopathy can be difficult. Full-thickness tears may demonstrate only pinpoint extension to one surface and, if oblique in nature, may be mistaken for partial-thickness tears. Larger, full-thickness tears may demonstrate retraction, which is seen as medial and posterior displacement of the tendon and myotendinous junction; the normal junction is located slightly lateral to the AC joint.

Interstitial tears most commonly occur adjacent to the humeral insertion footprint. A focal, fluid-intense signal within the tendon, with the articular and bursal surfaces intact, suggests an interstitial-type, partial-thickness tear. The differentiation of acute traumatic injuries from chronic degeneration and attrition is important for both clinical and surgical management. A degenerated rotator cuff will demonstrate thinning of one or more tendons and may be accompanied by muscle atrophy and fatty degeneration. In contrast, in a traumatic rotator cuff injury, abnormal signal will be localized to a discrete portion of the rotator cuff tendon(s), but the rotator cuff will maintain its normal bulk, and the tendon may even be thickened.

Depending on severity, atrophy and fatty degeneration of the rotator cuff muscles suggest long-standing disease.

Figure 3  Coronal fat-suppressed T2-weighted image of supraspinatus tendinopathy, acromioclavicular (AC) degenerative joint disease, and superior labral degeneration. The supraspinatus tendon is abnormally thickened and diffusely increased in signal (arrowheads), but no focal, fluid-intense defect is present. Degenerative osteophytes of the AC joint indent the myotendinous junction (arrow). The posterior-superior labrum (curved arrow) demonstrates diffuse intermediate signal compatible with degeneration, without a focal, fluid-intense tear.

Four types of acromial shapes have been described and variably associated with rotator cuff pathology. Type 2, which is the most common, includes a smooth lateral undersurface that parallels the humeral head (Figure 1, B). Type 3 (hooked) describes downward lateralmost sagittal acromial images is nearly as reliable.
and influence clinical management.\textsuperscript{14,15} Grading is best accomplished on sagittal T1-weighted images. Supraspinatus muscle bulk is assessed by using the tangent sign: the muscle should extend above a line drawn tangentially between the coracoid process and scapular spine (Figure 1, C). Fatty...
degeneration of the muscles is evaluated on sagittal T1-weighted images with the Goutallier grading system, which has been adapted for MRI. Normal muscle has no fatty (bright) streaks through the muscle, whereas fatty degeneration will show streaks of fat (Figure 1, D).

Assessing a repaired rotator cuff for a retear is challenging because shaver debris, anchor artifact, and progressive tissue remodeling may all obscure the certainty of diagnosis. Granulation tissue and fibrovascular scars have intermediate and/or bright signal on fluid-weighted sequences, which are often difficult to differentiate from a retear. Spielmann et al reported that only 10% of postoperative patients had normal (dark) signal intensity in the repaired rotator cuff, whereas 53% had mildly increased signal intensity, and 20% had foci of frank fluid intensity. Postoperative MRIs of the rotator cuff should therefore be interpreted with caution, and a retear diagnosis should be limited to a symptomatic patient with a discrete focus of fluid-intense signal. MRI arthrography may be useful in the setting of prior rotator cuff repair or periarticular hardware.

**Long Head of the Biceps Tendon**

The long head of the biceps tendon (LHBT) is normally homogeneously dark, and T2-weighted sequences provide the best visualizations. The biceps-labral anchor is most apparent on coronal sequences, whereas an intra-articular tendon is seen best with sagittal imaging (Figure 7). The extra-articular tendon and sheath are best assessed axially (Figure 8).

At the upper margin of the bicipital groove, the subscapularis tendon, the coracohumeral ligament, and the superior glenohumeral ligament border and secure the biceps in the groove. Tendon displacement suggests injury to one or all of these structures. LHBT position is assessed with axial imaging. The tendon should be located lateral to the lesser tuberosity within the bicipital groove. When it is superficial to the subscapularis tendon, the coracohumeral ligament and the superior glenohumeral ligament are torn; when it is in the glenohumeral joint, a full-thickness subscapularis tear is present (Figure 9).

A complete tendon avulsion from the labral anchor can be diagnosed on coronal imaging via nonvisualization of the tendon at the superior labrum. Often, the tendon will retract into the upper arm and also may be absent from the bicipital groove.

Tendinopathy typically shows tendon thickening and intermediate signal intensity, often accompanied by an increased amount of fluid in the tendon sheath, commonly near the biceps interval where adjacent rotator cuff tendon tears and associated bicipital groove instability may irritate the tendon (Figure 10).

**Labrum**

The labrum should be homogeneously dark on all sequences (Figure 4, A and C and Figure 8). It is normally triangular in shape, although a slightly blunted free edge can be a normal finding. The labrum should blend imperceptibly into adjacent hypointense cortical bone and intermediate-intensity hyaline cartilage. The joint capsule and the inferior glenohumeral ligament may attach directly to the labrum, the superficial labral base, or the paralabral glenoid.

The labrum has several variants that can be mistaken for disease or injury. The anterosuperior labrum may be diminutive in size to absent (with a thickened middle glenohumeral ligament known as the Buford complex; Figure 11) but should reconstitute at
the midanterior glenoid. It is either attached to the underlying hyaline cartilage or separated by a sublabral foramen; however, the anterior labrum should be firmly attached below the 3-o’clock position. Superiorly, the labrum may attach to the underlying glenoid or hyaline cartilage (cartilage undercutting) or be separated from both by a thin, fluid-filled sulcus that parallels the glenoid contour (known as the sublabral sulcus; Figure 4, A). Distinguishing a normal sulcus from chondrolabral separation can be difficult, but a sulcus is usually thin (< 2 to 3 mm wide) and parallels the glenoid.23–25

The pathology of the superior labrum usually falls into two categories: traumatic superior labrum anterior to posterior (SLAP) tears and degeneration. Traumatic tears appear as hyperintense signal on fluid-weighted sequences; are morphologically linear; and extend to the labral surface, coursing away from the glenoid. Labral degeneration is amorphous and intermediate in signal intensity (Figure 3).

Given labral variability, it is recommended to initiate a search for superior labral tears at the biceps-labral anchor and the posterior-superior labrum on coronal images; axial images complement this search. With tear suspicion, the morphology should be determined to differentiate a stable lesion from an unstable lesion.

Currently, 10 types of SLAP tears have been described.26 Type I is characterized by irregularity and fraying at the biceps-labral complex and is often an incidental finding or related to degeneration (Figure 12, A). Type II tears are most common and demonstrate linear hyperintense signal at the biceps-labral anchor extending into the posterior-superior labrum (Figure 12, B). Type III tears are bucket-handle tears of the superior labrum in which the central portion of the labrum can displace into the joint, but the biceps tendon is spared. These tears are most apparent on coronal images as linear hyperintensities coursing across the labrum from one portion of the articular surface to another. Type IV injuries extend through the anchor into the biceps tendon and are seen on coronal and sagittal images (Figure 12, C). The remaining types are uncommon,
unstable variants of type II injuries extending into adjacent contiguous structures (for example, the adjacent labrum or the middle glenohumeral ligament).

Lesions of the anterior-inferior labrum are usually divided into bony Bankart (osteochondral) fractures, Bankart lesions, and Bankart-like lesions. Axial MRIs are most helpful for visualizing linear, fluid-intense signal abnormalities coursing into the labrum itself or through the chondrolabral junction. Bankart fractures (Figure 13, A) almost universally include an articular component and should therefore be considered osteochondral fractures; axial T1-weighted images optimize cortex-medullary bone differentiation and help demonstrate the osseous component, whereas fluid-weighted images help reveal cartilage involvement. A Bankart lesion is diagnosed if a labral tear extends anteromedially beyond the margin of the scapula through the scapular periosteum, whereas a Bankart variant-type tear spares the periosteum, which is normally an uninterrupted, thin, linear, hypointense structure extending from the anterior scapular margin to the labral base.

A Hill-Sachs impaction fracture of the humeral head may be a helpful secondary sign of dislocation, raising sensitivity for detecting a Bankart injury. In an anterior dislocation, it is found on axial images through the superior margin of the humeral head as a postero lateral articular surface concavity (Figure 13, B). Engaging lesions are associated with a more horizontally oriented defect that may require multiple sequences to appreciate.27,28 Posterior dislocation may
produce a similar morphology (reverse Hill-Sachs lesion) along the anterior surface of the humeral head.

Diagnosis of an anterior-inferior labral tear may be assisted by the ABER (abduction-external rotation) sequence (Figure 14). To obtain the ABER sequence, the ipsilateral palm is placed onto the occiput, forward flexing the humerus and placing stress on the anteroinferior labroligamentous junction. The shoulder is then imaged in an oblique plane. Although the plane of orientation can be confusing, one locates the anterior aspect of the joint (referring the coracoid process) where the capsule appears most taut; this is the anteroinferior labroligamentous junction29 (Figure 15).

Magnetic Resonance Arthrography

Magnetic resonance arthrography (MRA) can be accomplished in two ways. Direct MRA (dMRA) is the traditional and common technique, where diluted gadolinium contrast material is injected directly into the glenohumeral joint. Bright gadolinium signal outlines the labrum, the capsule, and the articular surface of the rotator cuff, revealing any tears. Indirect MRA (iMRA) is a newer technique, where gadolinium is injected intravenously. After about 15 minutes, there is evidence of gadolinium passively diffusing into the joint, providing arthrographic contrast; passive or active exercise for 10 to 15 minutes may improve diagnostic accuracy.30,31 The former technique (dMRA) is dependable, minimally invasive, and well-studied, and it has a minimal risk of postprocedure synovitis. The latter technique (iMRA) is well tolerated but shows enhancing vascularity in the labrum and the rotator cuff, which can be mistaken for a tear.32 Of note, although commonly used in practice and generally accepted as routine, the FDA has not approved gadolinium contrast material for MRA, so its use must be considered off-label for such applications.

For assessing rotator cuff pathology in patients with no history of rotator cuff surgery, conventional MRI is the usual test of choice. Although dMRA is more sensitive and slightly more specific for detecting partial-thickness tears (86% sensitive and 96% specific compared with 64% and 92% for conventional MRI), it has little advantage over conventional MRI for diagnosing all rotator cuff tears.33 In postoperative patients, dMRA is up to 87% accurate for all rotator cuff tears and may be beneficial in diagnosing full-thickness tears, but it is only moderately diagnostic for partial-thickness tears.34,35 Contrast extravasation into the subacromial/subdeltoid bursa may suggest a full-thickness cuff but also can result from an incidental capsular defect or an injection error.

MRA is most commonly used to evaluate labral tears. Contrast material will extend into most tears, being visualized as a bright linear signal in the labrum. However, 3.0-T conventional MRI is up to 86% to 90% sensitive and 100% specific for labral tears, similar to dMRA.36–38 Thus, in patients with no history of labral surgery, conventional MRI may suffice for diagnosis. For patients with prior labral surgery, dMRA may still be beneficial. The repaired labrum tends to be heterogeneous in signal as a result of proton density– and T2-hypointense granularity and fibrovascular tissue, potentially being confused with a tear, and anchor and suture artifacts may obscure small tears. dMRA has shown up to 92% accuracy for diagnosing tears compared with 83% for conventional MRI.35,39
Periarticular Cysts
Cysts around the glenohumeral joint are common and may be incidental or secondary signs of pathology. Differentiating between the two may assist in finding additional pathology and/or associated injury.

Subcortical cysts are frequently seen in the humeral head. Cysts in the posterior half of the greater tuberosity show no statistical correlation with rotator cuff disease. However, cysts of the anterolateral humeral head (deep to the supraspinatus insertion) are highly specific for rotator cuff tears. Cysts within and immediately superior to the lesser tuberosity are highly correlated with supraspinatus and subscapularis tendon tears.

Cysts deep to the glenoid and humeral head articular cartilage are important to recognize. These are almost invariably secondary to degenerative joint disease, presumably reflecting a ball-valve phenomenon related to intra-articular fluid, and assist the viewer in recognizing and characterizing other degenerative findings.

Cysts around the labrum are useful clues for diagnosing labral tears. A nearly 100% incidence of adjacent labral tears in the setting of a paralabral cyst has been reported (Figure 16, A). Paralabral cysts vary in size but can be large enough to cause mass effect on adjacent structures and remodeling of adjacent bone. When located in the spinoglenoid notch, they can impinge the traversing suprascapular nerve and produce infraspinatus muscle denervation edema and/or atrophy.

Capsule, Synovium, and Bursa
Multidirectional instability in the shoulder can be associated with a patulous capsule. Several studies have investigated MRI diagnosis, with limited success. Most use complex, time-consuming measurements that lack practical application. MRA is usually needed to demonstrate the potential degree of joint distention. However, it should be emphasized that the concept of a patulous capsule is neither specific nor diagnostic.

Traumatic injuries to the capsule may include a tear or an avulsion of the inferior glenohumeral ligament (Figure 16, B). The normal inferior glenohumeral ligament is seen in all three imaging planes as a hypointense, U-shaped band connecting the inferior labrum or the paralabral glenoid to the humerus; the anterior and posterior...
bands of the ligament lie at the anterior and posterior margins of the axillary capsule. A humeral avulsion of the glenohumeral ligament, known as a HAGL lesion (Figure 16, C), is diagnosed when the anterior band of the inferior glenohumeral ligament fails to insert on the humeral head, forming the appearance of the letter J instead of a U (the J sign), which is best visualized on coronal sequences. Acutely, it will be surrounded by soft-tissue edema. A variant of this injury includes bony humeral avulsion of the glenohumeral ligament, which will demonstrate an osseous avulsion from the humerus. A posterior humeral avulsion of the glenohumeral ligament, known as a PHAGL lesion, is a bony humeral avulsion of the glenohumeral ligament lesion of the posterior band of the inferior glenohumeral ligament.

The glenohumeral synovium is normally thin and imperceptible on MRI. When inflamed, the thickened synovium may be visualized. Synovitis (Figure 16, D) is relatively hyperintense on fluid-weighted sequences and may be difficult to distinguish from a joint effusion but tends to be more heterogeneous in signal. Intravenous contrast may help in the diagnosis because the thickened synovium will enhance. The subacromial/subdeltoid bursa is normally decompressed, but when distended by fluid or synovitis, it will appear as a curvilinear, fluid-intense structure interposed between the rotator cuff, the acromion, and the deltoid muscle. Trace physiologic fluid may be present but usually lies lateral to the AC joint and is less than 2 mm in thickness. Bursal fluid is often seen in rotator cuff tears (Figure 6, B) but can be seen in other processes, such as tendinitis, rheumatoid arthritis, gout, and infection.

Bursitis can be difficult to differentiate from bursal fluid because both are hyperintense on fluid-weighted sequences; however, bursitis typically appears slightly more heterogeneous and less bright than fluid. If intravenous gadolinium contrast is given, the walls of an inflamed bursa will show thicker wall enhancement (usually greater than 1 mm), whereas a noninflamed bursa will show only very thin uniform wall enhancement.

**Cartilage and Degenerative Joint Disease**

Visualization of glenohumeral articular cartilage disease is challenging because of the relatively thin cartilage depth, the limited spatial resolution of routine MRI sequences, and blurring between the cartilage base and the subchondral bone plate. Fat-suppressed T2-weighted sequences are usually used for evaluation (Figure 17). The normally intermediate-intense cartilage signal is contrasted superficially with the hyperintense joint fluid; fissures, delaminating tears, and ulcerations fill with fluid and appear as bright defects. Studies of conventional MRI show variable diagnostic accuracy ranging from 65% to 96%. One study found MRA to have only a slightly increased diagnostic accuracy over conventional MRI (86% versus 84%).

MRI evaluation of cartilage has made tremendous progress in the past decade, but glenohumeral cartilage MRI research is still in its early stages. The use of specialized fluid-weighted, three-dimensional gradient-recalled echo sequences can increase spatial resolution and potentially raise the sensitivity for detecting partial-thickness lesions. However, the drawbacks include additional scan time and increased metallic susceptibility artifact.

Molecular imaging of hyaline cartilage is a rapidly evolving area of research focused on identifying early degeneration and characterizing disease progression. It seeks to reveal regional variations in the cartilage molecular matrix (such as glycosaminoglycans and water), which may be...
altered in degeneration. T2-mapping and delayed gadolinium-enhanced MRI of cartilage are two techniques that have been applied to the glenohumeral joint; although still in early investigations, normal index values are being elucidated to help differentiate normal cartilage from early degeneration. Other advanced imaging methods, such as sodium and T1-rho imaging, have not yet been extensively investigated in the shoulder.

Summary

MRI is a crucial tool in evaluating the symptomatic shoulder. Recent advances in MRI technology have enhanced diagnostic accuracy. Differentiation of traumatic and degenerative etiologies is important for patient management and a thorough understanding of optimal sequences and imaging planes for identifying individual shoulder pathologies is crucial to an accurate diagnosis. Although an off-label use of arthrography, the judicious use of gadolinium contrast can enhance visualization for selected pathologies.

References

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