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Magnetic Resonance Imaging of the Shoulder

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Magnetic resonance imaging (MRI) is proving to be an effective means for evaluating the shoulder. The use of a surface coil and high resolution scanning techniques have allowed detailed analysis of the normal anatomy of the shoulder. When evaluating for shoulder pathology, the choice of imaging plane and pulse sequencing will be determined by the suspected pathology. In patients with impingement syndrome, subacromial bursitis, supraspinatus tendinitis, and supraspinatus tendon tear can be differentiated, and the offending component of the subacromial arc traumatizing these soft tissues can be identified. MRI is also useful in determining the extent of retraction of the supraspinatus musculotendinous junction and the amount of muscle atrophy in cases of massive, chronic tears. Labral tear or attenuation due to glenohumeral instability can be imaged without the injection of contrast material, and MRI can identify those patients with multidirectional instability. Because of the ability to directly depict bone marrow, MRI is the imaging method of choice for the evaluation of early ischemic necrosis of the humeral head.

The current widespread interest in physical activity has brought disorders of the shoulder joint to the attention of both the medical and lay communities. Rotator cuff disease is no longer considered a condition afflicting only the elderly or the rheumatoid patient, and disorders such as shoulder impingement syndrome and shoulder instability are now under intensive investigation regarding their mechanism, pathology, and management.

Plain roentgenography and computed tomography (CT), although the most appropriate means for depicting soft-tissue calcification, lack the inherent soft-tissue contrast afforded by magnetic resonance imaging (MRI). Conventional arthrography is invasive and is of no assistance in the diagnosis of impingement syndrome unless a rotator cuff tear is present. CT arthrography has a high diagnostic yield for suspected labral pathology,[6,10] but this procedure is also invasive. Bursography has been advocated for the early detection of shoulder impingement syndrome[15,28] but has not gained wide acceptance. Shoulder ultrasonography (US) has been shown to be a useful screening modality for suspected rotator cuff tears.[4,16] However, US is difficult to perform and is highly operator-dependent.

The normal anatomy of the shoulder as depicted on MR images has been described in detail,[7,11,17,27] and MRI now provides the first noninvasive means of evaluating several common shoulder disorders. The tendinous rotator cuff is well displayed, the cuff muscles can be evaluated for atrophy, and the location of the musculotendinous junction can be visualized in order to determine the extent of muscular retraction in cases of massive rotator cuff tears. Tears of the glenoid labra are easily identified, and the exquisite depiction of marrow afforded by MRI allows the early detection of ischemic necrosis, primary and metastatic tumor, and osteomyelitis.

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TECHNICAL CONSIDERATIONS

There are several technical difficulties in shoulder MRI. Because the shoulder lies in the periphery of the magnetic field, significant lateral shift is needed for scan centering. Therefore, image acquisition is in a region of the magnet where the signal-to-noise ratio is inherently low. Also, the majority of shoulder disorders require imaging relatively small soft-tissue structures. High-resolution scanning techniques and the use of a surface coil can overcome these problems.

The optimal plane for shoulder MR imaging is dictated by the type of clinical problem under investigation. Imaging in the axial plane allows evaluation of the anterior and posterior glenoid labra, and the subscapularis and infraspinatus musculotendinous units. The frontal–oblique plane (along the course of the supraspinatus muscle) depicts the superior and inferior labra and displays the signal characteristics of the supraspinatus muscle and tendon. This plane also shows the relationship of the supraspinatus tendon and the subacromial bursa to the coracoacromial arc. The earliest changes of ischemic necrosis are identified in the sagittal plane.

The choice of appropriate pulsing sequences is also determined by the clinical problem. T1-weighted images are most useful for display of anatomic details and the evaluation of bone marrow. T2-weighted images identify fluid, for example within the glenohumeral joint or rotator cuff tendons. Often, imaging with both T1- and T2-weighting is required to characterize various tissues by their changes in signal characteristics.

MR scanning should be delayed after arthrography or corticosteroid injection. MRI is extremely sensitive to changes in the soft tissues, and these invasive procedures may alter their signal characteristics, leading to false-positive diagnoses.

Since MRI is insensitive to small foci of soft-tissue calcification, it is essential that plain roentgenograms be available at the time of scan interpretation.

The images shown in this article were acquired with a 0.3-tesla magnet, using a surface coil and spin-echo pulse sequences. A 16- to 19.2-cm field of view was used, with an imaging matrix of 256×256 that was interpolated to 512×512 for display. Slice thickness was 3–5 mm obtained at 5- to 7-mm intervals.

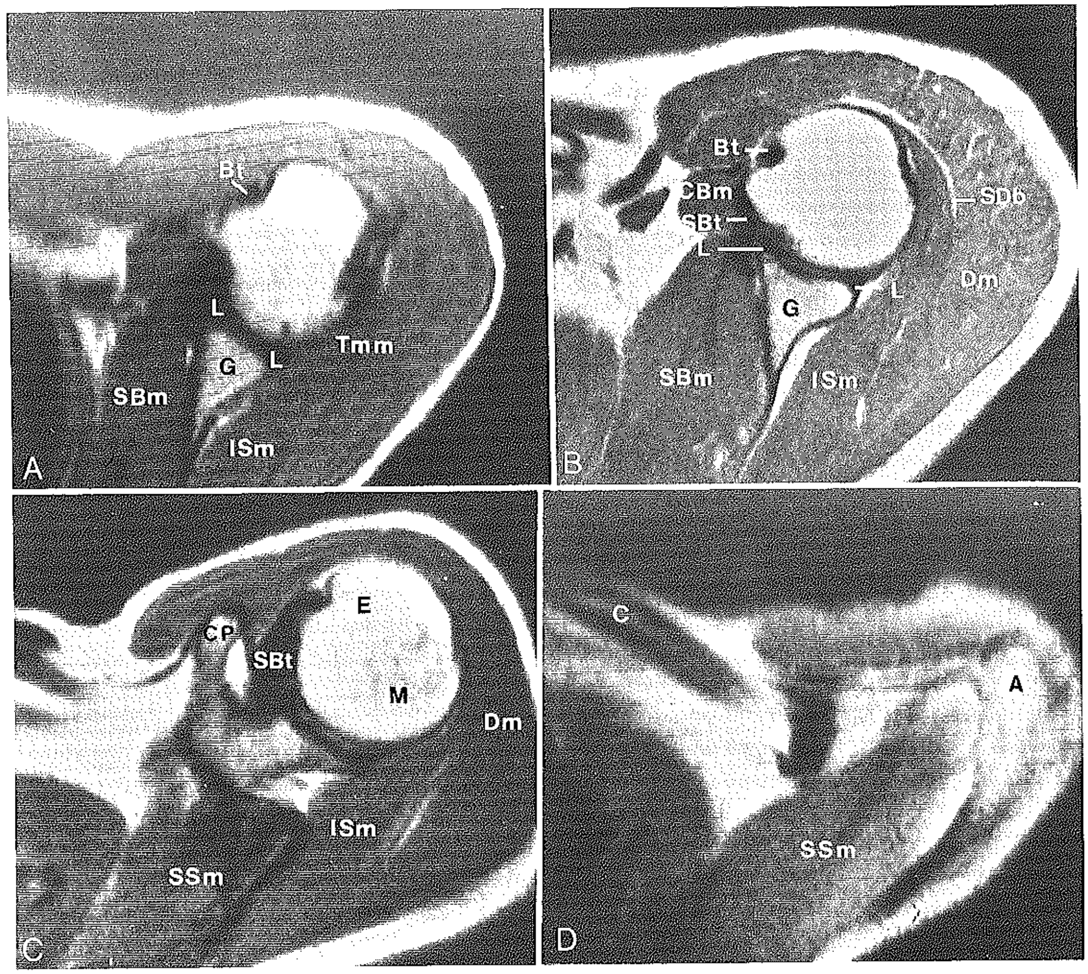
NORMAL ANATOMY

AXIAL PLANE

Axial imaging (Fig. 1) is optimal for evaluating the anteroposterior (AP) relationship of the glenohumeral joint, the portions of the rotator cuff that course transversely across the joint, and the anterior and posterior glenoid labra.

The inferior part of the humeral head is oblong, and its flattened posterior surface blends into an indentation posterolaterally. This area serves as the site of attachment for some fibers of the infraspinatus and teres minor tendons. More superiorly, the humeral head is rounded. Although the level of transition from oblong to round varies among individuals, the head is usually round at the level of the upper coracoid process. Because of partial volume averaging along the curved humeral head, the articular cartilage of the upper head is not well-delineated on high axial scans.

Through midadulthood, the bone marrow of the humeral head may appear inhomogeneous on axial images. This is due to the AP oblique orientation of the obliterated growth plate and the different signal intensities of the normal metaphysis and epiphysis. With the arm internally rotated, the brighter and more homogeneous signal intensity of the epiphysis is anterior, while the lower and more mottled signal intensity of the metaphysis is posterior.



FIGS. 1A–1D. An MR image (TR, 500 msec; TE, 30 msec) of normal anatomy in the axial plane. Anterior is at the top of the image. (A) Level of the lower humeral head. (B) Level of the midhumeral head. (C) Level of the coracoid process. (D) Level of the supraspinatus muscle. A = acromion; ACj = acromioclavicular joint; Bt = biceps tendon; C = clavicle; CAl = coracoacromial ligament; CBm = coracobrachialis muscle; CCl = coracoclavicular ligament; CP = coracoid process; Dm = deltoid muscle; E = humeral head epiphysis; G = bony glenoid; ISm = infraspinatus muscle; ISt = Infraspinatus tendon; L = glenoid labrum; M = humeral head metaphysis; P = physis (anatomic neck); SAb = subacromial bursa; SBm = subscapularis muscle; SBt = subscapularis tendon; SDb = subdeltoid bursa; SSm = supraspinatus muscle; SSt = supraspinatus tendon; Tm = trapezius muscle; Tmm = teres minor muscle.

The anterior and posterior glenoid labra are optimally imaged in the axial plane. These structures are believed to represent redundant folds of the fibrous joint capsule[18] and are thus imaged as a signal void. Since the labrum is quite pliable, its shape is determined by the position of the humeral head.[18] With the arm internally rotated, the larger anterior labrum becomes pointed, and the smaller posterior labrum is more rounded. A thin rim of intermediate- to high-intensity signal separating the labra from the surrounding cuff tendons and joint capsule may represent fat-laden folds of synovium that,

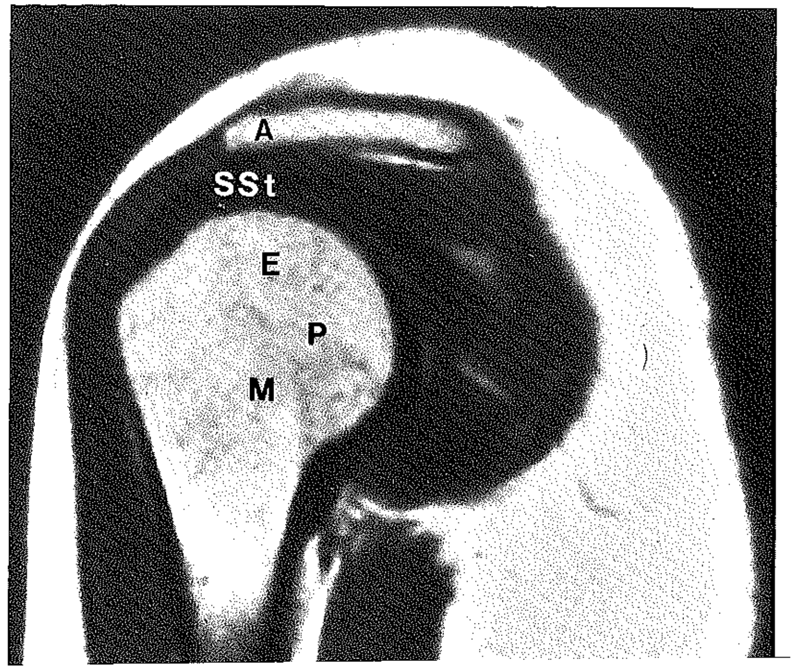


FIG. 2. An MR image (TR, 300 msec; TE, 30 msec) of normal anatomy in the sagittal plane at the level of the acromion. Anterior is to the left of the image. (For key, see Figure 1.)

by their redundancy, allow the shoulder its extreme mobility.[2,3,29]

Axial imaging is useful for evaluating the rotator cuff tendons anteriorly (subscapularis) and posteriorly (infraspinatus and teres minor). Although portions of the supraspinatus tendon can be seen superiorly on axial images, detailed evaluation is impossible due to the curve of the tendon over the humeral head.

The bicipital groove is well seen on axial scans. The tendon of the long head of the biceps muscle is seen as a signal void within the groove and, in individuals in whom the synovium of the joint extends into the groove, can be separated from the surrounding cortex and transverse humeral ligament by a thin rim of intermediate- to high-intensity signal.

SAGITTAL PLANE

The sagittal plane (Fig. 2) is useful for evaluating the course of the humeral head physis and avoids the confusion arising from the inhomogeneity seen within this region of the marrow on axial scans. This plane is also well suited for evaluating the acromion, both its general slope with respect to the supraspinatus tendon and its angle anteriorly in the case of an unfused os acromiale. Diagnostic information regarding these two conditions, however, is best acquired in the frontal–oblique plane, in which the longitudinal extent of the supraspinatus tendon can be evaluated in a single image.

FRONTAL–OBLIQUE PLANE

Alignment for frontal–oblique scanning is determined from a high axial image that shows the supraspinatus muscle (Fig. 3).[27] Cursors aligned along the long axis of this muscle yield images that are oblique along a coronal-to-sagittal plane (Fig. 4). This orientation provides visualization of the supraspinatus muscle and tendon in continuity. The tendon should be evaluated for signal intensity, anatomic course, and integrity.

The subacromial–subdeltoid bursa is

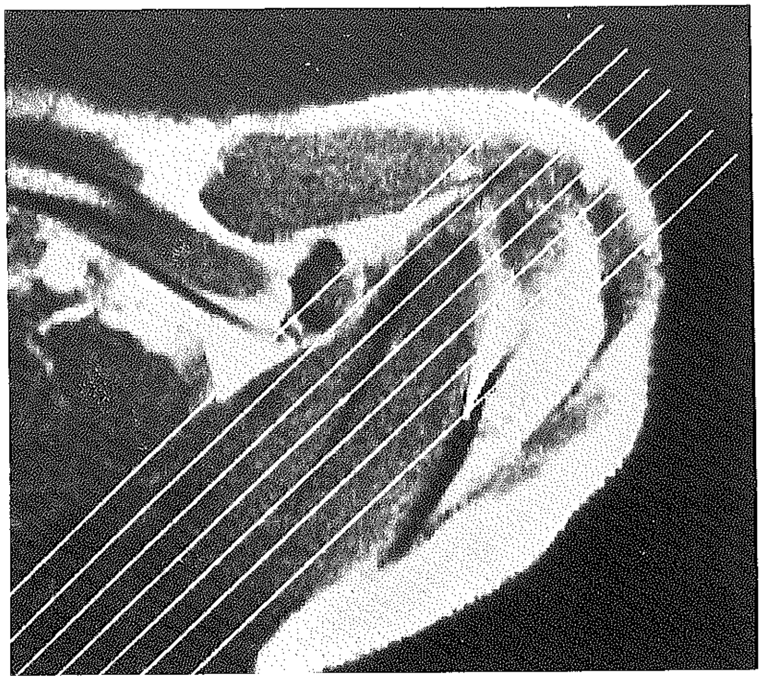


FIG. 3. A high axial MR image showing alignment of cursors for oblique imaging.

imaged as a thin band of high-signal intensity in both T1- and T2-weighted images. The high signal is felt to represent fat, corresponding to the abundant adipose and/or areolar tissue that is found both within and beneath synovium.[2,8,18,29]

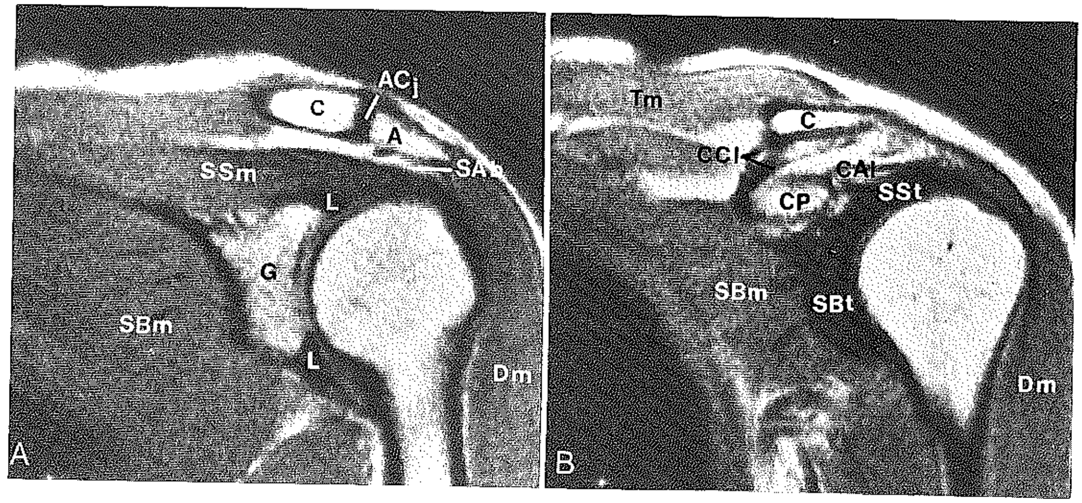
Because the angle of the scapula is similar to that of the supraspinatus apparatus,[29] the oblique plane is superior to the coronal plane for evaluation of the superior and inferior portions of the bony glenoid and the glenoid labra.

IMPINGEMENT SYNDROME/ ROTATOR CUFF TEAR

In its classic form, shoulder impingement syndrome refers to entrapment of the supraspinatus tendon and subacromial bursa between the humeral head below and the structures of the coracoacromial arc above.[9,19,20,22] The disorder is due most often to repetitive trauma caused by vigorous overhead occupational or athletic endeavors and/or degenerative exostoses.[5,19,20,22] Repeated mechanical trauma may result in inflammation, fibrosis, and eventual tendon rupture. A predisposition to impingement may be associated with the presence of spurs arising from the inferior aspect of the anterior acromion or acromioclavicular joint, hypertrophy of the acromioclavicular joint capsule, or a congenitally low-lying or large anterior acromion.[1,19,20] Neer believes that over 95% of rotator cuff tears are due to the impingement syndrome.[19]

MRI provides the first noninvasive means for evaluating all of the soft-tissue abnormalities associated with impingement syndrome.[13,14,26] By imaging in the frontal–oblique plane (along the long axis of the supraspinatus muscle and tendon), the relationship of the subacromial bursa and supraspinatus tendon to the osseous structures directly above is readily apparent.

MRI not only affords evaluation of the soft-tissue pathology associated with impingement syndrome but also provides information regarding the offending structures above the bursa and tendon. Small spurs off



FIGS. 4A AND 4B. MR images (TR, 500 msec; TE, 30 msec) of normal anatomy in the frontal–oblique plane at (A) the level of the midacromioclavicular joint and (B) the level of the anterior humeral head. (For key, see Figure 1.)

the anterior acromion or acromioclavicular joint are imaged as regions of signal void. Because larger spurs generally contain marrow, they are seen as extensions of the high-intensity signal from the parent bone surrounded by a cortical signal void. Hypertrophy of the acromioclavicular joint capsule appears as a rounded mass of medium-intensity signal surrounding the joint. In T2-weighted images, fluid within the acromioclavicular joint appears as a focus of high-intensity signal. Degenerative changes of the acromioclavicular joint lead to a loss of the sharp, smooth margins of the opposing cortical surfaces and replacement by irregular margins, with a resultant intervening irregular, inhomogeneous band of medium-signal intensity.

Subacromial bursitis (Fig. 5) is manifested as a widening of the high-intensity signal of the bursa medial to the region of depression and an abrupt cutoff at the site of impingement. The bursa generally shows high-signal intensity in both T1- and T2-weighted images, probably due to the high-fat content of its hypertrophied synovium. Uncommonly, excessive fluid may be present within the bursa. If present, bursal fluid displays low- to intermediate-signal intensity in T1-weighted images and high-signal intensity with T2-weighting.

In cases of supraspinatus tendinitis (Fig. 6), MRI reveals a medium-intensity signal within the substance of the tendon in T1-weighted images, which does not become bright with T2-weighting. The supraspinatus musculotendinous junction retains its normal position beneath the anterior acromion or acromioclavicular joint, and the bulk and signal intensity of the supraspinatus muscle remain normal.

In T1-weighted images, tendinitis cannot be differentiated from a small or partial tear of the supraspinatus tendon. A well-defined focus of high-intensity signal within the supraspinatus tendon in T2-weighted images that was not evident in T1-weighted images is diagnostic of a tear. By correlating the T1- and T2-weighted images, the amount of muscle retraction and evidence of muscle atrophy can be determined. If proton density or only T2-weighted imaging is used, foci of tendinous ossification may be confused with a small rotator cuff tear. Ossification will

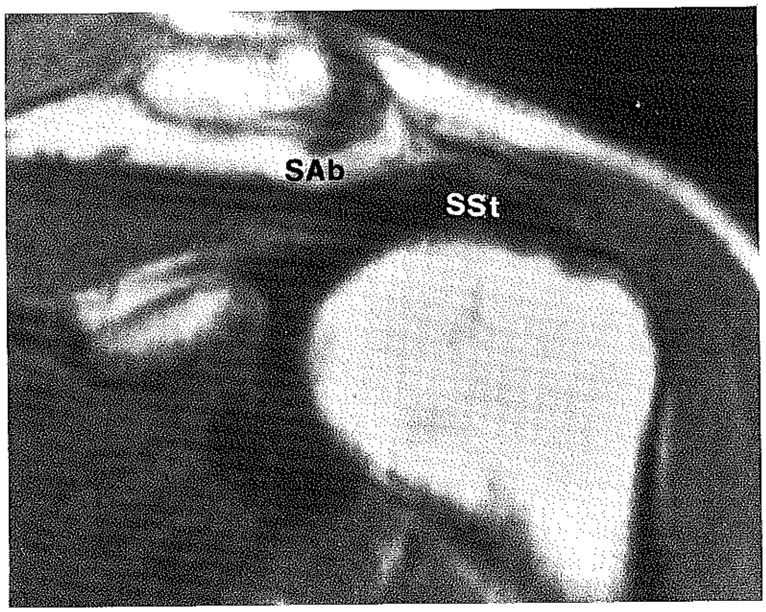


FIG. 5. An axial T1-weighted MR image (TR, 500 msec; TE, 28 msec) of subacromial bursitis in a 36-year-old man. The subacromial bursa (SAb) is thickened and is being impressed by a small spur off the inferior aspect of the distal clavicle. The signal intensity of the supraspinatus tendon (SSt) is normal.

show high-signal intensity in both true T1- and T2-weighted images because of the fat in the marrow. Fluid in a tear will be intermediate-signal intensity in T1-weighted images, and high signal intensity in T2-weighted images.

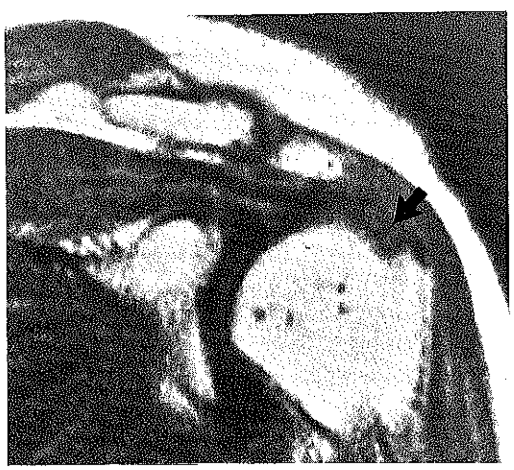


FIG. 6. Supraspinatus tendinitis in a 61-year-old man. The T1-weighted frontal–oblique MR image (TR, 500 msec; TE, 30 msec) shows intermediate-signal intensity within the supraspinatus tendon (arrow). There is no retraction of the supraspinatus musculotendinous junction. A small tear cannot be excluded with only T1-weighted imaging.

In cases of a small to moderate supraspinatus tear (Fig. 7), there is no retraction of the musculotendinous junction. These small tears are often within the distal portion of the tendon near its insertion on the greater tuberosity and are therefore best seen in extreme anterior images in the frontal–oblique plane. Larger tears can also be seen in more posterior images.

With a massive supraspinatus tear (Fig. 8), the muscle retracts medially. Atrophic changes of the muscle are seen in cases of extensive and long-standing rotator cuff disruption. Atrophy is imaged as bands of high-signal intensity within the supraspinatus muscle in T1-weighted images, indicating fatty replacement of muscle fibers. The mass of the muscle is also diminished in cases of atrophy, but this finding must be evaluated in light of the overall muscular development of each individual patient. With chronic tears of the rotator cuff, the subacromial bursa and supraspinatus tendon may be gradually replaced by fibrovascular granula-

FIG. 7. A frontal–oblique T2-weighted MR image (TR, 2000 msec; TE, 85 msec) of a supraspinatus tendon tear in a 65-year-old man. The focus of high-signal intensity within the supraspinatus tendon represents fluid (arrow) and is continuous between the glenohumeral joint and the subacromial bursal space.

tion tissue and are eventually obliterated by the superiorly migrating humeral head.

MRI has shown tears of the rotator cuff that were later surgically confirmed in patients with a negative arthrogram.[14] Theoretically, this situation could be found in cases in which either bursa or fibrotic tissue cover or fill the tear, thus keeping contrast from filling the tendon defect during arthrography.

The integrity of the infraspinatus musculotendinous unit is best evaluated in the axial plane. Pathology of the subscapularis portion of the rotator cuff is discussed in the following section on shoulder instability.

INSTABILITY

The glenohumeral joint is the most mobile joint in the body, largely because only a small portion of the humeral head is in contact with the bony glenoid at any given time.[23] The trade-off for the exceptional mobility of the glenohumeral joint is an inherent instability. Shoulder instability, either in

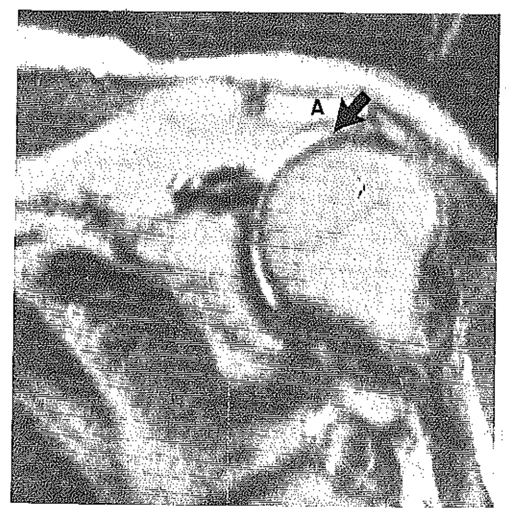


FIG. 8. A frontal–oblique T2-weighted MR image (TR, 2000 msec; TE, 85 msec) of a massive supraspinatus tendon tear in a 67-year-old man. The acromial–humeral distance is diminished, and high-signal intensity fluid is present in the expected region of the supraspinatus tendon (arrow). The supraspinatus muscle is not evident on this image. It was shown to be severely retracted and atrophic on a high axial image. A = acromion.

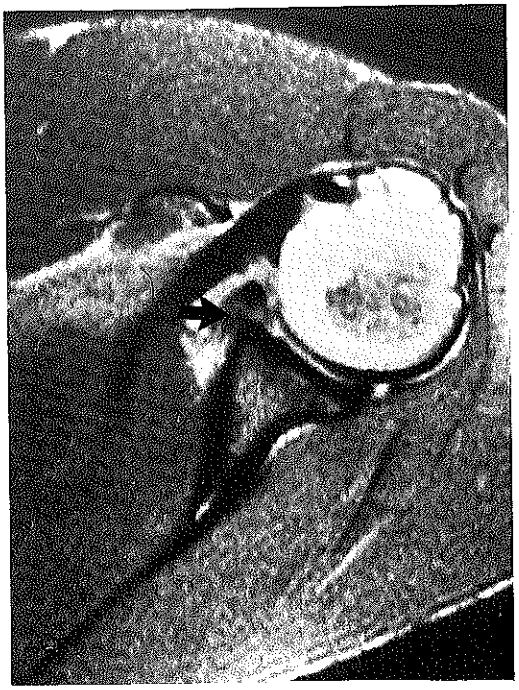


FIG. 9. An anterior labral tear in a 20-year-old man with chronic shoulder pain following a football injury. The axial MR image (TR, 800 msec; TE, 30 msec) with relative T1-weighting shows a band of intermediate-signal intensity (arrow) traversing the base of the anterior glenoid labrum. The posterior labrum is normal.

the form of recurrent subluxation or dislocation, is a common cause of chronic pain and disability.

Although glenohumeral instability often follows trauma, many patients with instability cannot recall a specific traumatic episode. In patients with subclinical instability, the initial complaint may be vague, including arm numbness, decreased range of motion, or nonspecific pain.[24] Diagnosis in this situation may be difficult. There is also a group of patients with multidirectional instability, in whom subluxation occurs in both the anterior and posterior directions.[21] If only the more common anterior lesion is repaired, these patients will experience persistent pain and disability due to what will have become a fixed, unidirectional posterior instability.

The cause of nontraumatic instability has long been debated but is believed to relate to a deficiency in the soft-tissue support of the joint.[18] The so-called capsular mechanism probably provides the majority of natural stability. This consists of the anterior and posterior rotator cuff muscles and tendons, the joint capsule and synovial membrane, the glenohumeral ligaments, and the fibrous glenoid labrum.

Regardless of the mechanism of instability, the resultant pathology is well-known. The glenoid labrum may become torn or detached from the bony glenoid. In cases of recurrent subluxation or dislocation, the labrum may become severely attenuated. Additional pathology may include separation of the joint capsule from the scapula, trauma to the rotator cuff muscles and/or tendons, and Hill–Sachs deformity of the humeral head.

Because of the inherent ability of MRI to depict the soft tissues without the injection of intra articular contrast material, it is well suited to the evaluation of pathology secondary to glenohumeral dislocation or subluxation.[12,25] Labral pathology is evident as increased signal intensity within the normal signal void of the fibrous labrum (Fig. 9). Tears show an intermediate-signal intensity in T1-weighted images and become bright in T2-weighted images. Labral abnormalities will be seen both anteriorly and posteriorly in images of patients with multidirectional instability (Fig. 10).

Hill–Sachs lesions are depicted on MR images as focal depressions in the contour of the humeral head (Fig. 11). When subtle, these depressed fractures are best seen in the axial plane. Large lesions may also be evident in the frontal–oblique plane. Care must be taken not to mistake the normal posterolateral flattening of the inferior humeral head for a Hill–Sachs deformity. As most humeral head dislocations are anteroinferior, Hill–Sachs defects are generally seen on the high posterolateral aspect of the head, at or above the level of the coracoid process in axial images.

Patients with significant trauma to the subscapularis tendon may show medial retraction of the subscapularis musculotendinous junction, indicating tendon rupture. Disproportionate atrophy of the subscapularis muscle in comparison to the adjacent muscles often indicates remote or chronic instability.

OSTEONECROSIS OF THE HUMERAL HEAD

The humeral head is a common site for osteonecrosis, and the detailed evaluation of bone marrow that is possible with MRI makes it an ideal means for the diagnosis of this disorder.

Because the signal intensity of the normal metaphysis may be mottled through mid-adulthood, axial images can be confusing in the evaluation of early osteonecrosis. In the coronal plane, small regions of abnormal signal intensity may be inapparent due to partial volume averaging. When the arm is internally rotated, sagittal imaging is opti-

FIG. 10. Multidirectional instability in a 52-year-old stunt man with a several-year history of multiple anterior and posterior dislocations. An axial MR image (TR, 800 msec; TE, 30 msec) shows posterior subluxation of the humeral head and complete obliteration of both the anterior and posterior glenoid labra. Intermediate-signal intensity within the joint represents fluid. Also note the retraction of the subscapularis musculotendinous junction (arrow), indicating tendon rupture.

FIG. 11. A Hill–Sachs defect in a 32-year-old man with a history of anterior dislocation. A high axial MR image (TR, 800 msec; TE, 30 msec) at the level of the coracoid process shows a depression of the posterolateral aspect of the humeral head (arrow). The head should be rounder at this level.

FIGS. 12A AND 12B. Avascular necrosis of the humeral head in a 28-year-old woman who had been on corticosteroid therapy for medulloblastoma. (A) A sagittal T1-weighted MR image (TR, 500 msec; TE, 28 msec) shows a bandlike focus of decreased signal intensity in the epiphysis posteriorly (arrow). (B) With T2-weighting (TR, 2000 msec; TE, 84 msec), the center of the lesion increases in signal intensity, but the band of low-signal intensity remains (arrow).

mal, as this plane shows the oblique course of the physis tangentially and depicts regions of abnormally diminished signal intensity in the epiphysis. The earliest changes are seen in the posterosuperior aspect of the humeral head (Fig. 12).

DISCUSSION

With the use of high-resolution scanning techniques and a surface coil, several shoulder abnormalities can now be thoroughly evaluated without radiation exposure or injection of intraarticular contrast material. MRI has been shown to be useful in both diagnosis and management planning of such common disorders as impingement syndrome, rotator cuff tear, glenohumeral instability, and osteonecrosis of the humeral head. This modality not only can assist in decision making for conservative *versus* surgical repair of these lesions but can guide in determining if arthroscopic or open repair is indicated. Surgical repair of massive rotator cuff tears that are doomed to failure in patients with marked muscle retraction and atrophy may also be avoided.

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