Rotator Cuff Disease

MR imaging has revolutionized the evaluation of the glenohumeral joint and has emerged as an accurate, noninvasive means to assess disorders of the shoulder. Its multiplanar imaging capability and superior soft tissue contrast offer information not readily provided by other imaging techniques allowing both detection and characterization of pathology.

Shoulder pain is a common clinical presentation. Though the spectrum of disorders affecting the shoulder is quite diverse; emphasis is often placed on abnormalities of the rotator cuff and glenohumeral joint instability. The rotator cuff plays an important role in both the function and stability of the shoulder. Moreover, its pathology, with early and accurate diagnosis, is amenable to treatment, which can markedly affect patient outcome.

This unit will present an MR imaging protocol for evaluation of the glenohumeral joint. Though its specific emphasis is on the rotator cuff, it can certainly be used for a global assessment of the shoulder.

BASIC PROTOCOL

IMAGING OF THE ROTATOR CUFF

MR imaging scans of the glenohumeral joint can be attained at a variety of field strengths with a variety of magnet types. Suffice it to say that the primary limitation of low-field-strength MR imaging is a decreased signal-to-noise ratio which can be increased by using lower spatial resolution and longer acquisition times. The sequences described here are based on a 1.5 T magnet, and rely on fat saturation in many cases. In low- and mid-field strength scanners, these sequences can be replaced by inversion recovery or T_2-weighted sequences.

Sequence options for musculoskeletal applications include conventional spin-echo, fast spin-echo (FSE), gradient echo, short tau inversion recovery (STIR), and fast STIR. This imaging protocol will emphasize the use of fast spin-echo imaging techniques, also known as turbo spin-echo. This adaptation of the rapid acquisition with relaxation enhancement (RARE) technique (Hennig et al., 1986) revolutionized MR imaging, allowing shortened acquisition times, increased spatial resolution, or improved signal-to-noise ratio. Though contrast is similar between conventional-spin echo and fast-spin echo, there are important differences. One such difference is the bright fat signal seen with fast-spin echo imaging, which can obscure areas of pathology adjacent to fat on T_2-weighted sequences. For this reason, frequency-selective fat saturation is often used with fast-spin echo proton density and T_2-weighted sequences. Fat-saturated fast-spin echo T_2-weighted imaging for detection of rotator cuff pathology has proven quite successful (Quinn et al., 1995; Reinus et al., 1995; Singson et al., 1996) and will also form an important part of the imaging protocol presented in this unit.

Routine MR imaging of the shoulder is usually performed in three different planes. Though there is some degree of redundancy in the anatomic information provided, certain features are optimally evaluated in specific planes and it is often desirable to evaluate complex structures in more than one plane. The imaging protocol reflects this, keeping in mind that the hallmark of rotator cuff tears is abnormally high signal intensity in the tendon on T_2-weighted images, which should be constant between imaging planes. The sequences that comprise the protocol include: transverse fat-suppressed FSE proton density weighted, sagittal oblique FSE T_1-weighted, sagittal fat-suppressed FSE T_2-weighted, coronal oblique FSE T_1-weighted, coronal oblique fat-suppressed FSE proton density weighted MR images, and coronal oblique STIR MR images, which provide

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Table A22.1.1 Equipment Parameters for MRI of the Rotator Cuff

Coil type	Phased array shoulder or standard shoulder coil
Gradient coil strength	22 mT/m
Cardiac gating	No
Pheripheral gating	No
Respitatory gating	No
Oxygen	No
Motion cushions	Useful
Use of contrast agents	No

excellent fat-suppression and are extremely sensitive to free water protons. The entire protocol can be performed in 45 min.

Table A22.1.1 lists the hardware and parameters needed to perform the examination.

NOTE: Be sure that technologists and nurses have immediate access to any emergency equipment that may be relevant to a given study, or that may be needed for a particular patient, such as crash carts or oxygen.

Set up patient and equipment

1. Initial screening of the patient is achieved by completion of a standardized form designed to ensure that he or she has no internal ferromagnetic materials. In our screening process, specific reference is made to the following items, which can prove to be a health hazard to the patient or interfere with image acquisition.

    a. Cardiac pacemaker
    b. Retained metal fragments in eyes
    c. Heart valve replacement, venous umbrella
    d. Vascular clips
    e. Prosthetic devices in the eyes and joints
    f. Hearing aid, neurostimulator, insulin pump
    g. Intrauterine device (I.U.D.)
    h. Shunts/stents (ventricular, spinal, biliary), metal mesh/coil implant
    i. Orthopedic hardware

    Questions regarding safe scanning of implants can be researched in Shellock (1996).

2. In addition, the screening form includes general inquiries regarding health issues that are pertinent to the performance of the MR imaging study, the need for any emergency equipment (crash cart, oxygen) and its interpretation.

    a. Pregnancy status of patient
    b. Respiratory difficulties or nausea when lying in supine position
    c. Past medical history and current medications
    d. History of claustrophobia

3. In conjunction with the standardized screening form, ask the patient to complete a background information form. The questionnaire includes:

    a. Requesting physician and subspecialty
    b. Origin and progression of symptoms

c. Request for diagram of the symptomatic area

d. Activities that exacerbate symptoms

This proves to be an invaluable source of history and clinical information given the paucity of information often provided on the requisition forms. The information that the patient provides may help the technician to do a more specific study and the radiologist to render the most accurate interpretation of the exam.

4. Review data sheets and interview the patient to ensure he or she understands the nature of all questions and that the data sheets have been filled out as completely and accurately as possible.

5. Have the patient sign any necessary consent forms.

6. Instruct the patient to remove all jewelry or metal from their body, and change into a gown.

7. Explain what will happen during the course of the procedure and what the patient will experience while in the magnet, including the following.

   a. The patient will be given earphones to wear during the examination to protect from the loud knocking sound produced during the study. This knocking will occur when images are being acquired, take place 6 to 7 times, and last a few minutes each time. The technologist and patient may communicate at any time during the study by simply speaking out, though it is preferable to wait until the knocking sound has stopped.

   b. The patient is asked to remain quiet and avoid any movement during the time images are being acquired—i.e., when the knocking sound is occurring.

   c. The patient will be provided a safety squeeze-bulb. Demonstrate how it works and explain to the patient when to use the squeeze-bulb (i.e., if they need assistance during the exam).

8. Have the patient mount onto the table in a supine position. Place a wedge under the patient's knees to facilitate comfort and lessen the likelihood of motion. Cover the patient with a sheet to maintain personal privacy.

9. Fully extend the arm at the patient's side and in neutral position. This is achieved by having the thumb pointed toward the ceiling (see Fig. A22.1.1). When the thumb points away from the body, the humerus is in external rotation; when it points toward the body, internal rotation.

10. Place a dedicated shoulder coil over the region of the glenohumeral joint (see Fig. 22.1.1).

11. Use the centering light to assign a reference point of the patient's position (middle of humeral head) on the table relative to the bore of the magnet and localize the region of the shoulder to be imaged. Then place the patient into the bore of the magnet.

    In order to preserve a true frame of reference from one scan relative to another, the patient must not move after this point.

Sequence 1: Spoiled gradient-recalled (SPGR) coronal localizer

12. This large field of view localizer will result in an image of the upper extremity, axilla, and thorax. From this, plan the transverse images. Next, set the grid lines (graphic prescription) to begin in the soft tissues just above the AC joint and extend to a point below the inferior most aspect of the glenoid (see Fig. A22.1.2). Let the patient know that you are ready. Run sequence 1 (Pilot scan) following the parameters in Table A22.1.2.

Sequence 2: Transverse fat-suppressed fast spin echo (FSE) proton density

13. After the grid lines are set, changes in the sequence prescription can still be made. Check Table A22.1.3 to see that the parameters have been correctly entered.
14. Let the patient know that you will begin the scan. Run sequence 2.
15. After the images have been acquired, if they are satisfactory in appearance, plan both the sagittal and coronal oblique imaging planes from these transverse images.

Figure A22.1.1 The arm is extended at the patient's side and in neutral position, with the thumb pointed toward the ceiling. The coil is placed over the glenohumeral joint.

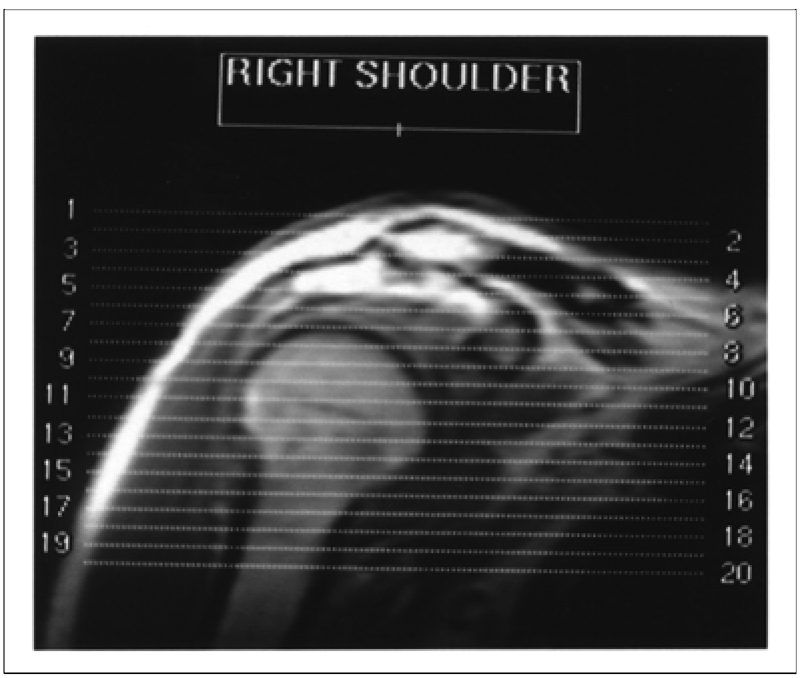

Figure A22.1.2 SPGR coronal localizer. The grid lines are set from above the acromioclavicular joint and extend to a point below the inferior aspect of the glenohumeral joint.

Sequence 3: Sagittal oblique fast spin echo (FSE) T_1-weighted

16. Review the transverse images and select an image at the level of the mid-scapula in which the scapular spine is visualized. Place the localizer line parallel to the articular surface of the glenoid and perpendicular to the spine of the scapula. The grid lines should begin 2 cm medial to the glenoid and extend beyond the lateral margin of the humeral head. (see Fig. A22.1.3).

Table A22.1.2 Primary Clinical Imaging Parameters for Sequence 1 (Pilot Scan): Spoiled Gradient-Recalled (SPGR) Coronal Localizer

Patient position	Supine
Scan type	2-D spoiled gradient-recalled, fast multiplanar
Imaging plane (orientation)	Coronal
Central slice or volume center	Center anatomy
Echo time (T_E)	4.2 msec
Repeat time (T_R)	175 msec
Flip angle (FA)	60°
Fields of view (FOV_x, FOV_y)	320 mm, 320 mm (off set to side)
Resolution (Δx, Δy)	1.25 mm, 2.5 mm
Number of data points collected (N_x, N_y)	256, 128
Display matrix (D_x, D_y)	512, 512
Slice thickness (Δz)	7 mm
Number of slices	15
Slice gap	2 mm
Number of acquisitions (N_{acq})	2
Swap read and phase encoding	No
Saturation pulses	None
Scan time	46 sec

Table A22.1.3 Primary Clinical Imaging Parameters for Sequence 2: Transverse Fat-Suppressed Fast Spin Echo (FSE) Proton Density

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Transaxial
Central slice or volume center	Superior AC joint to inferior glenoid
Echo time (T_E)	10 msec
Echo train length (ETL)	4–8
Repeat time (T_R)	2400 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	160 mm, 160 mm
Resolution (Δx, Δy)	0.63 mm, 0.63 mm
Number of data points collected (N_x, N_y)	256, 256
Display matrix (D_x, D_y)	512, 512
Slice thickness (Δz)	4 mm
Number of slices	22
Slice gap	1 mm
Number of acquisition (N_{acq})	3
Swap read and phase encoding	No
Saturation pulses	Inferior
Scan time	4 min, 46 sec

17. Let the patient know that you will begin to scan. Run sequence 3 following the parameters in Table A22.1.4.

Sequence 4: Sagittal oblique fat-suppressed fast spin echo (FSE) T_2-weighted

18. Use the same localizer for this sequence. Run this sequence according to the parameters in Table A22.1.5.

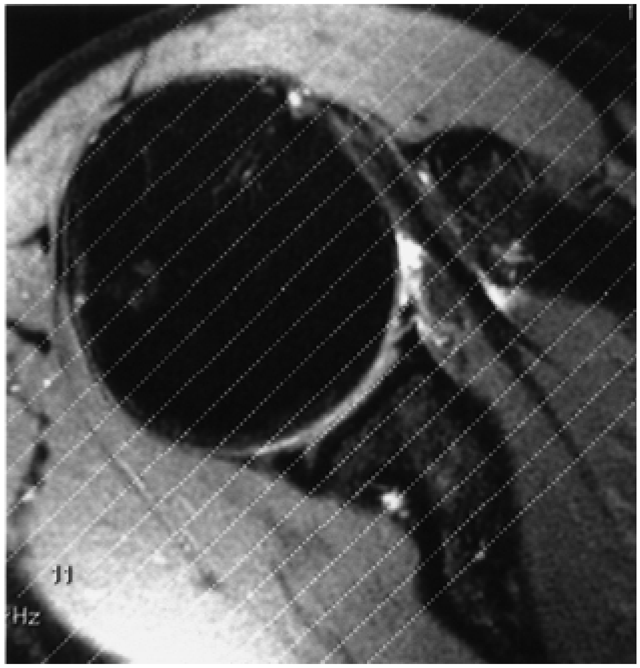

Figure A22.1.3 The grid lines are placed perpendicular to the spine of the scapula to perform the sagittal oblique images.

Table A22.1.4 Primary Clinical Imaging Parameters for Sequence 3: Sagittal Oblique Fast Spin Echo (FSE) T_1-Weighted

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Sagittal oblique
Central slice or volume center	Perpendicular to the spine of the scapula
Echo time (T_E)	13.6 msec
Echo train length (ETL)	2
Repeat time (T_R)	600 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	140 mm, 140 mm
Resolution (Δx, Δy)	0.55 mm, 0.55 mm
Number of data points collected (N_x, N_y)	256, 256
Display matrix (D_x, D_y)	512, 512
Slice thickness (Δz)	4 mm
Number of slices	20
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Swap read and phase encoding	No
Saturation pulses	Inferior
Scan time	4 min, 34 sec

Sequence 5: Coronal oblique fast spin echo (FSE) T_1-weighted

19. The coronal oblique images are also planned from the transverse images in one of two ways. Either choose a high transverse section at the level of the supraspinatus tendon allowing direct parallel alignment of the graphic prescription with the tendon. The lines should extend to the soft tissue margins both anteriorly and posteriorly. Alternatively, perform a mid transverse localizer. In this case, place the localizer lines

Table A22.1.5 Primary Clinical Imaging Parameters for Sequence 4: Sagittal Oblique Fat-Suppressed Fast Spin Echo (FSE) T_2-Weighted

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Sagittal oblique
Central slice or volume center	Perpendicular to the spine of the scapula
Echo time (T_E)	75 msec
Echo train length (ETL)	4–8
Repeat time (T_R)	2500 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	140 mm, 140 mm
Resolution (Δx, Δy)	0.55 mm, 0.73 mm
Number of data points collected (N_x, N_y)	256, 192
Display matrix (D_x, D_y)	512, 512
Slice thickness (Δz)	4 mm
Number of slices	20
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Swap read and phase encoding	No
Saturation pulses	Inferior
Scan time	3 min, 40 sec

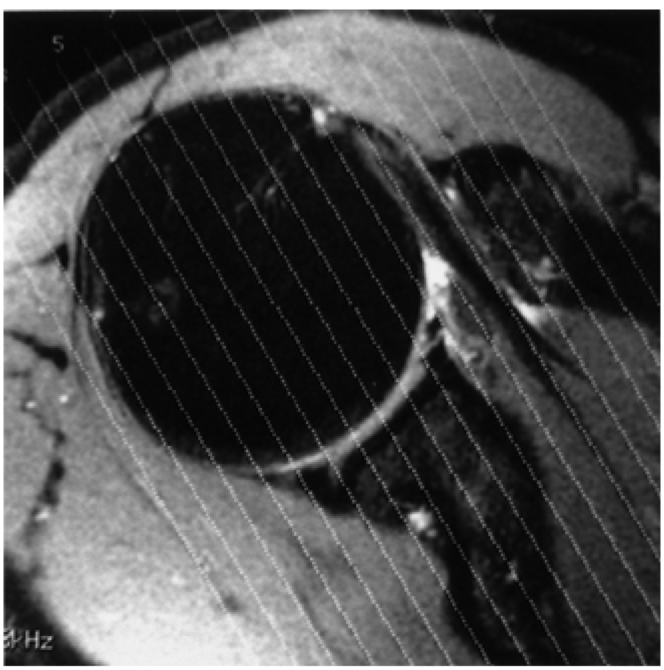

Figure A22.1.4 The grid lines are placed parallel to the spine of the scapula to perform the coronal oblique images.

along the long axis of the visualized scapular spine, and perpendicular to the glenoid articular surface (see Fig. A22.1.4). Extend the lines 2 cm anterior and posterior to the humeral head. The latter method underestimates the degree of obliquity needed to section the supraspinatus tendon along its true long axis (see Fig. A22.1.5). Run sequence 5 following the parameters in Table A22.1.6.

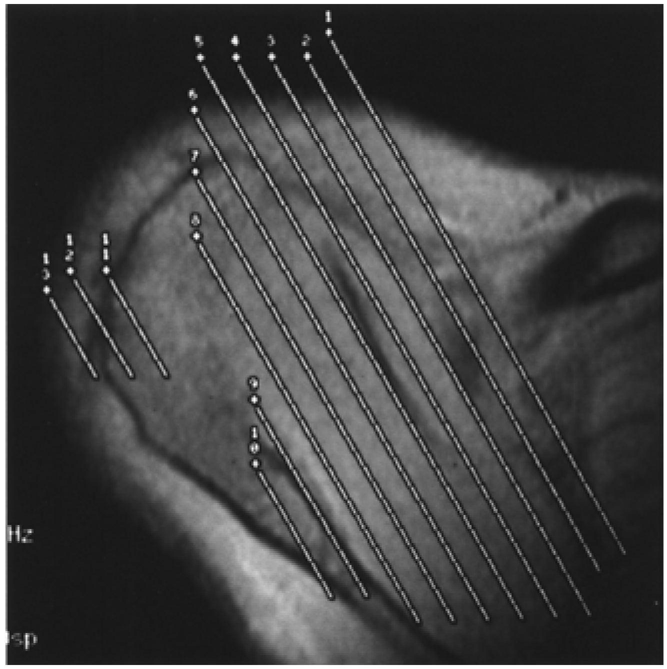

Figure A22.1.5 The grid lines are located parallel to the supraspinatus tendon to perform the coronal oblique images.

Table A22.1.6 Primary Clinical Imaging Parameters for Sequence 5: Coronal Oblique Fast Spin Echo (FSE) T_1-Weighted

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Coronal oblique
Central slice or volume center	Parallel to the long axis of the spine of the scapula
Echo time (T_E)	13 msec
Echo train length (ETL)	2
Repeat time (T_R)	625 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	140 mm, 140 mm
Resolution (Δx, Δy)	0.55 mm, 0.55 mm
Number of data points collected (N_x, N_y)	256, 256
Display matrix (D_x, D_y)	512, 512
Slice thickness (Δz)	4 mm
Number of slices	22
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Swap read and phase encoding	Yes
Saturation pulses	Inferior
Scan time	5 min, 21 sec

Table A22.1.7 Primary Clinical Imaging Parameters for Sequence 6: Coronal Oblique Fat-Suppressed FSE Proton Density

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Coronal oblique
Central slice or volume center	Parallel to the long axis of the spine of the scapula
Echo time (T_E)	12 msec
Echo train length (ETL)	4–8
Repeat time (T_R)	2500 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	140 mm, 140 mm
Resolution (Δx, Δy)	0.55 mm, 0.55 mm
Number of data points collected (N_x, N_y)	256, 256
Display matrix (D_x, D_y)	512, 512
Slice thickness (Δz)	4 mm
Number of slices	22
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Swap read and phase encoding	Yes
Saturation pulses	Inferior fat saturated
Scan time	4 min, 25 sec

Table A22.1.8 Primary Clinical Imaging Parameters for Sequence 7: Coronal Oblique STIR

Patient position	Supine
Scan type	Inversion recovery fast spin echo
Imaging plane (orientation)	Coronal oblique
Central slice or volume center	Parallel to the long axis of the spine of the scapula
Echo time (T_E)	34 msec
Echo train length (ETL)	3–8
Repeat time (T_R)	2600 msec
Inversion time (T_I)	150 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	140 mm, 140 mm
Resolution (Δx, Δy)	0.55 mm, 0.73 mm
Number of data points collected (N_x, N_y)	256, 192
Display matrix (D_x, D_y)	512, 512
Slice thickness (Δz)	4 mm
Number of slices	22
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Swap read and phase encoding	Yes
Saturation pulses	Inferior
Scan time	6 min, 25 sec

Sequence 6: Coronal oblique fat-suppressed FSE proton density

20. Use the same localizer for this sequence. Once again, follow the appropriate sequence prescribed and name. Run sequence 6 according to the parameters in Table A22.1.7.

Sequence 7: Coronal oblique short inversion time (tau) inversion recovery (STIR)

21. The set of imaging sequences presented in the protocol above is an effective means to evaluate the glenohumeral joint. The addition of an STIR sequence, as previously mentioned, confers the added advantage of excellent fat suppression with exquisite sensitivity to free water protons. This can prove extremely helpful for evaluation of signal abnormalities in the rotator cuff. It can be performed in any imaging plane, but usually proves most helpful in the coronal oblique plane. Follow Table A22.1.8 for parameters to run sequence 7.

COMMENTARY

Background Information

The rotator cuff is a set of muscles and tendons composed of the supraspinatus, infraspinatus, subscapularis, and teres minor groups. These muscles arise from the scapula to insert on the tuberosities of the humeral head and serve to both facilitate motion of the shoulder girdle and stabilize this cup and saucer type articulation. MR imaging of the glenohumeral joint is second only to the knee, reflecting the common nature of pathology in this articulation. It is considered the imaging study of choice for evaluation of the rotator cuff, largely due to its multiplanar imaging capabilities and superior soft tissue contrast, accounting for its high sensitivity, specificity, and accuracy in this realm.

Other methods for evaluation of the glenohumeral joint and rotator cuff include conventional radiographs, standard arthrography, ultrasound, and computed tomography with and without arthrography. Though all of these studies serve a purpose in evaluation of the shoulder and offer useful information in diagnosis of its pathology, none approaches the level of completeness achieved with MR imaging.

Critical Parameters and Troubleshooting

The application of the protocol and interpretation of the images acquired from this unit is generally done with ease. Perhaps the most troublesome factor to consider for the radiologist is that of the magic angle phenomenon (Timins et al., 1995). When collagen fibers are oriented at ~55° with respect to the main magnetic field (as in the case of the inserting fibers of the portions of the rotator cuff), they may display artifactually increased signal intensity on T_1 and proton density weighted sequences. This creates some confusion with the presence of hyperintense signal on short T_E sequences and makes close scrutiny of the T_2-weighted sequences imperative before an abnormality is diagnosed.

Iatrogenic changes can prove misleading in the MR evaluation of the rotator cuff. Steroid or local anesthetic injections can cause increased signal intensity in and around the rotator cuff. Post-surgical changes can result in a host of findings that could easily be misinterpreted as primary abnormalities in the absence of thorough clinical history.

Anticipated Results

Injury to the rotator cuff leads to shoulder pain and dysfunction, a common clinical complaint. The spectrum of pathology affecting this articulation is quite variable and ranges from the acute partial or full thickness tear to chronic intrinsic or extrinsic tendon changes. The goal of MR imaging in evaluation of the rotator cuff is to identify and characterize the extent of disease in an attempt to guide treatment and treat patients. MR imaging has emerged as the imaging method of choice for evaluation of the rotator cuff and its pathology, primarily due to its superior soft tissue contrast.

Acknowledgement

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Editor's Note

This unit has been written by the authors clearly for high field scanners with fat saturation sequences. For those users who do not have fat saturation capability, such as on mid- or low-field scanners, a reasonable alternative protocol might be: 1) oblique coronal proton density weighted and T_2-weighted fast/turbo spin echo images; 2) oblique sagittal proton density weighted and T_2-weighted fast/turbo spin echo images; 3) transverse T_2^* gradient echo images; and 4) transverse STIR (short tau inversion recovery) images. In the future, we expect to have a separate unit discussing low field protocols.

Also, for a given field strength, the field of view should be adjusted to the size of the patient, within the constraints of the scanner. On a high field scanner, 12 to 14 cm or smaller fields of view are easily achievable and can cover the entire shoulder in a average sized patient to give the best resolution. The field of view should be adjusted down for smaller patients and up for larger patients as necessary. On mid- and low-field scanners, these smaller fields of view may not be achievable in reasonable scan times and with sufficient signal to noise. In that case, the smallest field of view should be used (sacrificing some resolution as needed) to maintain sufficient signal to noise and the images then magnified (zoomed).

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