

ACR–SPR–SSR PRACTICE PARAMETER FOR THE PERFORMANCE AND INTERPRETATION OF MAGNETIC RESONANCE IMAGING (MRI) OF THE SHOULDER

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PREAMBLE

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care¹. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the practitioner considering all the circumstances presented. Thus, an approach that differs from the guidance in this document, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in this document when, in the reasonable judgment of the practitioner, such course of action is indicated by variables such as the condition of the patient, limitations of available resources, or advances in knowledge or technology after publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document may consider documenting in the patient record information sufficient to explain the approach taken.

The practice of medicine involves the science, and the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment. Therefore, it should be recognized that adherence to the guidance in this document will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The purpose of this document is to assist practitioners in achieving this objective.

¹ *Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing*, 831 N.W.2d 826 (Iowa 2013) Iowa Supreme Court refuses to find that the "ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures (Revised 2008)" sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, *Stanley v. McCarver*, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.

I. INTRODUCTION

This practice parameter was developed and written collaboratively by the American College of Radiology (ACR), the Society of Pediatric Radiology (SPR), and the Society of Skeletal Radiology (SSR).

Magnetic resonance imaging (MRI) is an established and proven imaging modality for the detection, evaluation, assessment, staging, and follow-up of disorders of the shoulder. Properly performed and interpreted, MRI contributes not only to diagnosis but also to treatment planning and prognostication. It should be performed only for a valid medical reason and after careful consideration of alternative diagnostic modalities. MRI of the shoulder may be performed without contrast, following intra-articular contrast injection ("direct" MR arthrography) to increase conspicuity of intra-articular abnormalities, or with intravenous (IV) contrast to identify enhancing lesions or to create "indirect" arthrographic images by diffusion of contrast into the joint. It should be noted that intra-articular gadolinium-based contrast is not an approved use by the Food and Drug Administration (FDA) but is commonly used without issue.

An analysis of the strengths and potential risks of MRI and other diagnostic modalities should be weighed against their suitability for specific patients and particular clinical conditions. Radiographs are usually the first imaging test performed for most suspected abnormalities in the shoulder and will often suffice to diagnose or exclude an abnormality or to direct further imaging. Computed tomography (CT) can be used to evaluate the bones of the shoulder — their integrity, position, and quantity (bone stock). [1]. When combined with arthrography, CT can also be used for evaluating the labrum, articular cartilage, and intra-articular bodies [2]. Ultrasound can be used to evaluate the rotator cuff, biceps tendon, and subacromial/subdeltoid bursa, and has the advantage of imaging during physiologic motion [3-7]. Radionuclide bone scanning can screen the entire skeleton in addition to the shoulder for radiographically occult bone disease, such as metastases. Other nuclear medicine examinations have a role for specific clinical scenarios (eg, a labeled white blood cell study for suspected osteomyelitis). Ultrasound and fluoroscopy can be used to guide arthrographic injection [8,9].

Although MRI is one of the most sensitive diagnostic tests for detecting anatomic abnormalities of the extremities, findings may be misleading if not closely correlated with other imaging studies, clinical history, clinical examination, and physiologic tests. Adherence to the following practice parameter will enhance the probability of accurately diagnosing pathology.

II. INDICATIONS

A. Primary indications for MRI of the shoulder include, but are not limited to, diagnosis, exclusion, and grading of suspected:

1. Rotator cuff tendon abnormalities: massive, full-thickness, partial-thickness, and recurrent (postoperative) tears, tendinopathy, calcific tendinitis, and rotator cuff arthropathy ^{1,2} [10-20]
2. Disorders of the long head of the biceps brachii tendon: full-thickness, partial-thickness, and recurrent (postoperative) tears, tendinopathy, calcific tendinitis, subluxation, and dislocation [8,9,18,21-23]
3. Conditions affecting the supraspinatus outlet: acromial shape, os acromial, subacromial enthesophytes, acromioclavicular joint disorders, coracoacromial ligament integrity, subacromial bursitis ² [13,24-27]
4. Labral abnormalities: tears, degeneration, including superior labrum anterior posterior (SLAP) lesions, Bankart lesions and variants, and recurrent (postoperative) labral tears, and paralabral cysts ² [2,18,28-42]
5. Abnormalities of the rotator interval and biceps pulley ² [21,43,44]
6. Muscle disorders affecting the shoulder girdle: atrophy, hypertrophy, denervation, strains/tears, and masses [16,20,45-51]
7. Glenohumeral chondral and osteochondral abnormalities: osteochondral injuries, including osteochondral fractures and osteochondritis dissecans, articular cartilage degeneration, fissures, fractures, flaps, and separations, and intra-articular bodies ² [52-54]
8. Synovial-based disorders: synovitis, bursitis, metaplasia, and neoplasia ^{1,2} [55,56]

9. Marrow abnormalities: osteonecrosis, marrow replacement and edema syndromes ² [57]
10. Neoplasms, masses, and cysts of bone, joint, or soft tissue ¹ [27,37,58]
11. Infections of bone, joint, or soft tissue ¹ [59-61]
12. Congenital and developmental conditions, including dysplasia and normal variants ¹ [62-65]
13. Vascular conditions: entrapment, aneurysm, stenosis, and occlusion ¹ [66]
14. Neurologic conditions: entrapment, compression, masses, and peripheral neuritis ¹ [35,40,67]
15. Pathology in the shoulder following arthroplasty [68] and other surgeries.
16. Posttraumatic pathology: acute fracture, bone contusion, stress fractures, and chronic stress physeal injuries.
17. Disorders of the joint capsule

[1] Conditions in which IV contrast may be useful.

[2] Conditions in which intra-articular contrast (performed by direct intra-articular injection or indirect joint opacification following IV administration) may be useful.

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the [ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging \(MRI\)](#) [85].

The interpreting physician needs a thorough knowledge and understanding of shoulder anatomy, including the normal variations in the glenohumeral capsular and labral configurations and their corresponding MRI appearances.

IV. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for MRI of the shoulder should provide sufficient information to demonstrate the medical necessity of the examination and allow for the proper performance and interpretation of the examination.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). The provision of additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient's clinical problem or question and consistent with the state scope of practice requirements. (ACR Resolution 35 adopted in 2006 – revised in 2016, Resolution 12-b)

The supervising physician must have adequate understanding of the indications, risks, and benefits of the examination as well as other imaging options. The physician must be familiar with the potential hazards associated with MRI, including potential adverse reactions to contrast media. The physician should be familiar with relevant prior ancillary studies. The physician performing MRI interpretation must have a clear understanding and knowledge of the relevant anatomy and pathophysiology.

The supervising physician must also understand the pulse sequences to be used and their effect on the appearance of the images, including the potential generation of imaging artifacts. Standard imaging protocols may be established and varied when necessary. These protocols should be reviewed and updated periodically.

A. Patient Selection

The physician responsible for the examination should be available for consultation by direct communication. Patients must be screened and interviewed before the examination to exclude individuals who may have contraindications to MRI, in which the risks may outweigh the benefits.

Certain indications require administration of IV contrast media. IV contrast enhancement should be performed using appropriate injection protocols and in accordance with the institution's policy on IV contrast utilization. (See the [ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media](#) [86].)

Patients experiencing anxiety or claustrophobia may require sedation or additional assistance. Administration of moderate sedation may be needed to achieve a successful examination. If moderate sedation is necessary, refer to the [ACR–SIR Practice Parameter for Sedation/Analgesia](#) [87].

For pediatric patients, support from child life specialists can be beneficial and may avoid sedation in some cases.

B. Facility Requirements

Appropriate emergency equipment and medications must be immediately available to treat adverse reactions associated with administered medications. The equipment and medications should be monitored for inventory and drug expiration dates on a regular basis. The equipment, medications, and other emergency support must also be appropriate for the range of ages and sizes in the patient population.

C. Examination Technique

Shoulder MRI can be performed using a variety of magnet designs (closed or open) and field strengths (low, medium, or high) [14,36,88-92]. Because the inherent signal-to-noise ratio (SNR) is reduced with lower field strength MR systems, imaging practice parameters may require modifications. With lower field strength systems, for example, the overall signal can be increased at the expense of longer imaging times and increased risk of involuntary patient motion [88,90,93,94]. Alternatively, the voxel size can be increased (by a combination of larger field of view [FOV], thicker slices, and/or decreased matrix) at the expense of decreased spatial resolution [90,91,94,95]. Fat-suppression techniques that rely on the difference between fat and water frequencies (chemical shifts) are unreliable at low field strength, and substituting short tau inversion recovery (STIR) images may be necessary [88,91]. Even when the imaging protocol is optimized for shoulder imaging on a low-field open system, subjective image quality will likely be inferior to that obtained with a high-field system [91,94]. Various investigators using different equipment and scanning protocols have reached contradictory conclusions regarding the diagnostic performance of low-field strength MR scanners for shoulder disorders. Some studies have found that the accuracy for complete and partial rotator cuff tears and for labral abnormalities is not significantly different for open, low-field and closed, high-field systems, with careful attention to technique [89,91,92,96]. MR arthrography can further enhance the diagnostic yield for shoulder MRI performed on low field strength systems [88,94]. Other investigators have found lower accuracy for evaluating disorders like SLAP tears, capsular abnormalities, and small rotator cuff tears with specific low-field systems compared with high-field ones [95-97]. Regardless of system design, a surface coil should be used to maximize the SNR. Commercially available coils appropriate for shoulder imaging include single-loop contoured or flat-surface coils [98,99], paired coils in a Helmholtz configuration [34,100], circularly polarized flexible coils [95], solenoid coils [90], and phased array designs [29,39].

Patients are positioned supine with the affected arm at the side. For evaluation of the rotator cuff and anterior labrum, internal rotation of the arm should be avoided [79,99,101]. Standard shoulder MR examinations usually include images acquired in the transverse (axial), oblique sagittal, and oblique coronal planes. The oblique sagittal and oblique coronal planes are prescribed orthogonal to each other using either the glenoid fossa or the supraspinatus tendon as reference anatomic landmarks. When MR arthrography is performed, repositioning the affected arm into the abduction external rotation (ABER) position may increase sensitivity for anterior inferior labral tears [2,30,102,103] and may increase accuracy for rotator cuff tears, especially partial-thickness undersurface tears [104-106]. The benefits of ABER imaging should be considered in the context of potentially predisposing the patient to anterior shoulder instability, a rare but important complication. Images with the patient's arm in this position are obtained parallel to the humeral shaft prescribed from a coronal localizer image [30]. Radial imaging can also be used to evaluate the shoulder, but it is not widely used [107-109].

Shoulder anatomic structures should be evaluated in all planes.

FOV should be tailored to the size of the patient and the structures being examined, but for the standard sequences, the FOV should be 16 cm or smaller on medium-field and high-field units. Larger FOVs and smaller imaging matrices may be necessary on lower-field systems but will result in lower spatial resolution, limiting the sensitivity of the examination [91,94]. Occasionally, additional sequences or a larger FOV will be appropriate to more fully evaluate a specific suspected or detected abnormality, for example, scapulothoracic bursitis or pectoralis major tear in the anterior chest wall. Slice thickness in the oblique sagittal and oblique coronal planes of 4 mm or less is needed to demonstrate subtle tendon pathology, but thinner sections may be advantageous for detailed analysis of other structures, such as the labrum and articular cartilage. The size of an interslice gap, if used, would depend on hardware, software, time considerations, and need for anatomic coverage. Imaging with no gap has the advantage of imaging all of the anatomy in the covered FOV. The imaging matrix should balance intravoxel SNR with desired in-plane spatial resolution and reduction of truncation artifacts but should be at least 160 steps in the phase direction and 256 steps in the frequency direction for 2-D imaging, other than when imaging a large tumor. Some practices may use higher imaging matrices (up to 512 steps) to increase spatial resolution for more detailed evaluation [29,31].

Shoulder MRI can be performed with a wide variety of pulse sequences [112]. The choice of sequences can be tailored to optimize the examination for specific clinical questions and may vary because of local preferences. Conventional spin-echo, fast (turbo) spin-echo, and gradient-recalled sequences have all been used successfully for shoulder MRI. A typical imaging protocol will be composed of one or more of these pulse sequence types. The prescribed repetition time (TR), echo time (TE), and flip angle will depend on the field strength of the magnet and the relative contrast weighting desired.

Fluid-sensitive sequences, such as long-TR/moderate-to-long TE (proton-density weighted or T2-weighted) images with or without fat suppression or STIR images, are typically used for evaluating the rotator cuff, with either conventional spin-echo or fast (turbo) spin-echo technique [19,113-115]. T2*-weighted gradient-echo recalled sequences can also be used for diagnosing rotator cuff or labral abnormalities but probably with lower accuracy compared with conventional spin-echo or fast spin-echo sequences [99,116,117]. To show labral abnormalities, long-TR (proton-density weighted or T2-weighted) spin-echo or fast spin-echo images are typically performed. Lesions of the superior labrum such as SLAP tears can be visualized on fast spin-echo, long-TR images [29,39,109], or with MR arthrography [28,32]. T1-weighted sequences (short TR/short TE) have a role in characterizing marrow abnormalities [71], fractures, various stages of hemorrhage [118,119], and muscle pathology [20,45,46,49,50]. T1-weighted sequences have been used to characterize the degree of rotator cuff muscle atrophy in patients with tendon tears, which can be used to predict patient outcomes after surgery [120-124]. Shoulder MRI imaging with 3-D fast spin echo sequences have also demonstrated the ability to accurately evaluate shoulder anatomy and pathology [125,126]. Accelerated MR imaging of the shoulder, produced using varying techniques, have demonstrated accurate assessments of shoulder anatomy and pathology in shorter scan times [125,127,128].

Additional imaging methods, such as spectroscopic MRI, T2-mapping, and 3-D volume-interpolated breathhold examination (VIBE) with 2-point Dixon, have been used to provide a more quantitative measure of muscle atrophy [129-134]. 3-D T1-weighted fast field-echo and 3-D MR reconstruction using axial Dixon 3-D-T1-weighted-fast low angle shot sequences, zero TE sequences, and 3-D VIBE MR arthrography have proven accurate in quantifying glenoid bone loss when compared with CT and surgical measurements [135-139]. T2 relaxation maps of glenoid articular cartilage are possible and provide quantitative measures that reflect early structural change in articular cartilage. 3-D spoiled gradient and VIBE both can depict physeal cartilage and are useful to assess growth plate patency and physeal disturbances in skeletally immature patients [140,141].

MR arthrography using dilute gadolinium-containing contrast [77] may improve diagnostic accuracy in unstable shoulders [42]. Additionally, MR arthrography may improve diagnostic performance for some rotator cuff tendon tears, particularly partial-thickness tears, postoperative recurrent tears, and subscapularis tears [12,17,102,104,142-144]. Contrast opacification of the glenohumeral joint can also be accomplished indirectly by allowing IV-injected contrast to diffuse across the synovial membrane; MRI in this circumstance is performed after a short delay (during which time the patient may be asked to move or exercise the shoulder) following IV injection of a gadolinium-containing agent [104,145]. T1-weighted images either without (valuable to assess presence and degree of muscle fatty infiltration and/or volume loss) [2,77,142] or with fat suppression [28,30,143] are most frequently used when direct or indirect MR arthrography is performed with gadolinium-containing contrast. At least one fluid-sensitive sequence with fat suppression is still necessary when performing MR arthrography to detect pathology that does not

communicate with the joint as well as to identify altered bone marrow signal intensity. Suppressing the signal from fat may enhance the diagnostic yield of some pulse sequences [112]. Fat suppression can be performed using spectrally selective radiofrequency (RF) pulses, selective water excitation, a STIR sequence, or a phase-dependent method (eg, the Dixon method) [88,91,146,147]. The latter two techniques may be necessary on low-field systems [91,106]. Fat suppression is useful for identifying marrow abnormalities and may be a useful adjunct when performing MR arthrography [148]. The addition of fat suppression may increase diagnostic accuracy for rotator cuff tendon tears [114,146], especially partial-thickness tears [19]. Fat suppression is a useful adjunct to T1-weighted images when MR arthrography is performed using gadolinium-containing contrast [28,30,143]. Recent advances have demonstrated the ability to shorten MRI shoulder acquisition time without decreasing diagnostic yield, using the combination of high-field strength systems and parallel imaging [149].

Additional imaging techniques have specific roles for certain shoulder disorders. Both shoulders are imaged together for evaluation of glenohumeral dysplasia related to brachial plexus birth injury allowing evaluation of associated rotator cuff muscle atrophy, glenohumeral alignment, and glenoid version [150]. For evaluation of glenohumeral dysplasia, 3-D volumetric MRI sequences are recommended to reformat axial images perpendicular to the scapular plane [151]. Applying axial traction to the affected arm via a weight attached to the wrist may aid in the visualization of SLAP lesions [152]. The ABER position may help with the MR arthrographic diagnosis of instability lesions and partial-thickness, articular-surface rotator cuff tears [2,30,102-106]. Flexion-adduction and internal rotation of the shoulder can increase conspicuity of posterior labral tears if they are suspected and not seen on routine positioning [153].

Various techniques are used to minimize artifacts that can reduce imaging quality. Wraparound artifact should be reduced by phase oversampling [154]. Involuntary patient motion is best controlled by ensuring patient comfort combined with gentle immobilization when necessary [112]. Securing the affected arm against the thigh may further reduce motion artifacts [79]. When available, software that compensates for motion by the use of navigator echoes can be useful [155]. Flowing blood and other periodic motions produce ghosting artifacts, which can be reduced with presaturation pulses or gradient moment nulling [154,156]. Chemical shift artifact is more severe at higher field strengths and may necessitate an increase in the receiver bandwidth [14,93,154]. Susceptibility artifacts, which originate from heterogeneity of the local field, are also more severe at higher-field strengths and when using gradient-recalled pulse sequences. In clinical practice, patients with known metallic implants should be scheduled for MRI using 1.5T rather than 3T units. Avoiding gradient-echo imaging and reducing the voxel size will help reduce the magnitude of susceptibility artifacts [154,155]. Other techniques to reduce susceptibility artifact include the avoidance of spectral fat suppression and the use of a STIR sequence as well as the use of a fast spin-echo technique rather than spin-echo imaging, decreasing slice thickness, decreasing matrix size, increasing number of acquisitions, increasing echo train length, increasing FOV, and increasing bandwidth [157,158]. Newer techniques include the use of view angle tilting to correct the in-plane distortions, slice encoding for metal artifact correction, advanced metal artifact reduction, and [159] multi acquisition variable-resonance image combination, which correct both the in-plane and through-slice distortions [160]. Vacuum phenomena in the shoulder joint can also result in artifact generation, especially when gradient-recalled pulse sequences are used [161].

Magic angle artifact can produce increased signal intensity within the supraspinatus tendon as it curves over the humeral head, mimicking intratendinous pathology particularly on short-TE images [162,163]. This pitfall is best avoided by confirming abnormal signal intensity in the tendon on long-TE images and correlating apparent signal intensity abnormalities with changes in tendon thickness.

It is the responsibility of the supervising physician to determine whether additional pulse sequences or imaging techniques would confer added benefit for the diagnosis and management of the patient. Examinations that use techniques not approved by the FDA, such as the intra-articular injection of gadolinium chelates (direct MR arthrography) [164], can be considered when they are judged to be medically appropriate.

V. DOCUMENTATION

Reporting should be in accordance with the [ACR Practice Parameter for Communication of Diagnostic Imaging Findings](#) [165].

At a minimum, the report should address the condition of the rotator cuff muscles and tendons, supraspinatus

outlet (as defined in Section II. A. 3), biceps tendon, articular surfaces and labrum. In selected cases, a description of findings in the major ligaments and capsule, bone marrow, synovium, and cortical bone would be appropriate. An effort should be made to adopt a standardized lexicon of terms, and the report should use precise anatomic descriptions of identified abnormalities whenever possible [166].

Specific policies and procedures related to MRI safety should be in place with documentation that is updated annually and compiled under the supervision and direction of the supervising MRI physician. Guidelines should be provided that deal with potential hazards associated with the MRI examination of the patient as well as to others in the immediate area [167-169]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [167-170].

See the [ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging \(MRI\)](#) [85], the [ACR Manual on MR Safety](#) [171], and the [ACR Manual on Contrast Media](#) [172].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [168,169].

VI. EQUIPMENT SPECIFICATIONS

The MRI equipment specifications and performance must meet all state and federal requirements. The requirements include, but are not limited to, specifications of maximum static magnetic strength, maximum rate of change of the magnetic field strength (dB/dt), maximum RF power deposition (specific absorption rate), and maximum acoustic noise levels.

Equipment monitoring should be in accordance with the [ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging \(MRI\) Equipment](#) [87].

VII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *ACR Position Statement on Quality Control and Improvement, Safety, Infection Control and Patient Education* on the ACR website (<https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement>).

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