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Revised 2015 (Resolution 7)*

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

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 care[1]. 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 in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document is advised to document in the patient record information sufficient to explain the approach taken.

The practice of medicine involves not only the science, but also 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 sole purpose of this document is to assist practitioners in achieving this objective.

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[1] Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, ___ N.W.2d ___ (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. However, 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 contrast to identify hyperemic lesions or to create "indirect" arthrographic images by enhancing synovial-lined structures and their contents.

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 usually are 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 evaluation. 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). Conventional single-contrast or double-contrast arthrography can accurately depict most articular surface and full-thickness tears of the rotator cuff [1,2]. Sonography can be used to evaluate the rotator cuff and biceps tendon and has the advantage of imaging during physiologic motion [3-7]. Computed tomography (CT) is used to evaluate the bone integrity of the glenoid fossa and humerus and the alignment and congruence of the glenohumeral joint [8]. When combined with arthrography, CT can also be used for evaluating the labrum, articular cartilage, and loose bodies [9]. Lastly, arthroscopy provides a detailed examination of the internal structures of the shoulder, allowing the surgeon to treat as well as diagnose many internal derangements.

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 such abnormalities.

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

10. Marrow abnormalities: osteonecrosis, marrow edema syndromes, and stress fractures* [57]
11. Neoplasms, masses, and cysts of bone, joint, or soft tissue* [27,37,58]
12. Infections of bone, joint, or soft tissue* [59,60]
13. Congenital and developmental conditions including dysplasia and normal variants* [61-64]
14. Vascular conditions: entrapment, aneurysm, stenosis, and occlusion* [65]
15. Neurologic conditions: entrapment, compression, masses, and peripheral neuritis* [35,40,66]

B. MRI of the shoulder may be indicated to further clarify and stage conditions diagnosed clinically and/or suggested by other imaging modalities including, but not limited to, the following:

1. Arthritides: inflammatory, infectious, neuropathic, degenerative, crystal-induced, post-traumatic* [27,67,68]
2. Frozen shoulder (adhesive capsulitis)† [43]
3. Primary and secondary bone and soft tissue tumors* [58]
4. Fractures and dislocations [24,69,70]

C. MRI of the shoulder may be useful to evaluate specific clinical scenarios, including but not limited to the following:

1. Prolonged, refractory, or unexplained shoulder pain*†
2. Acute shoulder trauma [24,70]
3. Impingement syndromes: subacromial, subcoracoid, internal† [13,25,26,71-74]
4. Glenohumeral instability: chronic, recurrent, subacute, and acute dislocation and subluxation† [41,61,70,75-77]
5. Shoulder symptoms in the overhead or throwing athlete† [78-80]
6. Mechanical shoulder symptoms: catching, locking, snapping, crepitus†
7. Limited or painful range of motion
8. Swelling, enlargement, mass, or atrophy* [37]
9. Patients for whom diagnostic or therapeutic arthroscopy is planned†
10. Patients with recurrent, residual, or new symptoms following shoulder surgery† [12,16,18,20,49,81,82]

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* Conditions in which intravenous contrast may be useful.

† Conditions in which intra-articular contrast (performed by direct intra-articular injection or indirect joint opacification following intravenous administration) may be useful.

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [83]. The interpreting physician needs a thorough knowledge and understanding of the anatomy of the shoulder, including the numerous normal variations in the glenohumeral capsular and labral configurations and their corresponding MR imaging appearances.

IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [83], the ACR Guidance Document on MR Safe Practices [84], and the ACR Manual on Contrast Media [85].
Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [86,87].

V. SPECIFICATIONS OF THE EXAMINATION

The supervising physician must have complete understanding of the indications, risks, and benefits of the examination, as well as alternative imaging procedures. The physician must be familiar with potential hazards associated with MRI, including potential adverse reactions to contrast media. The physician should be familiar with relevant ancillary studies that the patient may have undergone. The physician performing MRI interpretation must have a clear understanding and knowledge of the anatomy and pathophysiology relevant to the MRI 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 its proper performance and interpretation.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). 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's scope of practice requirements. (ACR Resolution 35, adopted in 2006)

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 image artifacts. Standard imaging protocols may be established and varied on a case-by-case basis when necessary. These protocols should be reviewed and updated periodically.

A. Patient Selection

The physician responsible for the examination should supervise patient selection and preparation and be available in person or by phone for consultation. Patients must be screened and interviewed prior to the examination to exclude individuals who may be at risk by exposure to the MR environment.

Certain indications require administration of intravenous (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 [88].)

Patients suffering from 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 [89].

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) [14,36,90-94]. Since the inherent signal-to-noise ratio is reduced with lower field strength MR systems, imaging practice parameters may require modifications. For lower field strength systems, for example, the number of acquisitions can be increased at the expense of longer imaging times and increased risk of involuntary patient motion [90,92,95,96]. 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 spatial resolution [92,93,96,97]. Fat-suppression techniques that rely on the difference between fat and water frequencies (chemical shifts) are unreliable at low field strength, and substituting short-T1 inversion recovery (STIR) images may be necessary [90,93]. 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 [93,96]. 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 [91,93,94,98]. MR arthrography can further enhance the diagnostic yield for shoulder MRI performed on low-field-strength systems [90,96]. 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 to high-field ones [97-99].

Regardless of system design, a local coil is mandatory to maximize the signal-to-noise ratio. Commercially available coils appropriate for shoulder imaging include single-loop contoured or flat-surface coils [100,101], paired coils in a Helmholtz configuration [34,102], circularly polarized flexible coils [97], solenoid coils [92], 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 [77,101,103]. When MR arthrography is performed, repositioning the affected arm into the abduction external rotation (ABER) position may increase sensitivity for anterior inferior labral tears [9,30,104,105] and may increase accuracy for rotator cuff tears, especially partial-thickness undersurface tears [106-108]. Images with the patient's arm in this position are obtained parallel to the humeral shaft prescribed from a coronal localizer image [30].

Shoulder MR examinations usually include images acquired in the transverse, oblique sagittal, and oblique coronal planes. The oblique sections are prescribed orthogonal to the glenoid fossa or the supraspinatus tendon. Evaluation of the rotator cuff is performed using both oblique coronal and oblique sagittal images [109]. Prescribing the oblique sagittal images in the frontal plane so that they are perpendicular to the distal supraspinatus tendon may be useful for identifying subtle partial-thickness rotator cuff tears [110]. The oblique coronal and oblique sagittal images can be used to evaluate the labrum, biceps tendon, acromial anatomy, supraspinatus outlet, acromioclavicular joint, and rotator interval [21,25,44]. The transverse images best display the subscapularis tendon, the long head of the biceps tendon in the intertubercular groove, glenohumeral articulation, and the glenoid labrum [9,22,31,34]. Transverse images may aid in detecting anterior rotator cuff tears. Radial imaging for the glenoid labrum has been reported [111], but it is not widely used.

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 [93,96]. Occasionally, additional sequences with a larger FOV will be appropriate to more fully evaluate a specific suspected or detected abnormality, for example, in the scapulothoracic articulation or in the anterior chest wall, ie, the pectoralis major muscle. 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. An interslice gap may be selected to decrease signal loss due to cross talk [112] but should be no more than 33% of the slice width. Two interleaved scans may allow imaging without gaps at the expense of an increase in scan time. The imaging matrix should balance intravoxel signal-to-noise ratio 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 diagnosing labral lesions, including SLAP tears [29,31].

Shoulder MRI can be performed with a wide variety of pulse sequences [113]. The choice of sequences can be tailored to optimize the examination for specific clinical questions and may vary due to 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 TR, 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 [19,114-116]. T2*-weighted gradient-echo recalled sequences can also be used for diagnosing rotator cuff abnormalities but probably with lower accuracy compared with conventional spin-echo or fast spin-echo sequences [117,118]. To show labral abnormalities, long-TR (proton-density weighted or T2-weighted) spin-echo or fast spin-echo images or T2*-weighted gradient-recalled images are typically performed [31,34,119], although gradient-echo imaging may be less accurate when used in isolation for anterior labrum abnormalities compared with conventional spin-echo or fast spin-echo imaging [101]. Lesions of the superior labrum such as SLAP tears can be visualized on fast spin-echo, long-TR images [29,39], or with MR arthrography [28,32]. T1-weighted sequences (short TR/short TE) have a role in characterizing marrow abnormalities [69], various stages of hemorrhage [120,121], and muscle pathology [20,45,46,49,50]. 3-D T1-weighted fast field-echo and 3-D MR reconstruction using axial Dixon 3-D-T1W-FLASH sequences as well as 3-D VIBE MR arthrography have proven accurate in quantifying glenoid bone loss when compared to CT and surgical measurements [122-124].

MR arthrography using direct intra-articular injection of saline [77] or dilute gadolinium-containing contrast [75] 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 [12,17,104,106,125-127]. Contrast opacification of the glenohumeral joint can also be accomplished indirectly by allowing contrast injected intravenously to diffuse across the synovial membrane; MR imaging in this circumstance is performed after a short delay (during which time the patient may be asked to move or exercise the shoulder) following intravenous injection of a gadolinium-containing agent [106,128]. T1-weighted images either without [9,75,125] or with fat suppression [28,30,126] are most frequently used when direct or indirect MR arthrography is performed with gadolinium-containing contrast. At least one fluid-sensitive sequence is still necessary when performing MR arthrography to detect pathology that does not communicate with the joint.

Suppressing the signal from fat may enhance the diagnostic yield of some pulse sequences [113]. Fat suppression can be performed using spectrally selective RF pulses, selective water excitation, a STIR sequence, or a phase-dependent method (eg, the Dixon method) [90,93,129,130]. The latter two techniques may be necessary on low-field systems [93,108]. The addition of fat suppression may increase diagnostic accuracy for rotator cuff tendon tears [115,129], especially partial-thickness tears [19]. Fat suppression is a useful adjunct to T1-weighted images when MR arthrography is performed using gadolinium-containing contrast [28,30,126].

Additional imaging techniques have specific roles for certain shoulder disorders. Applying axial traction to the affected arm via a weight attached to the wrist may aid in the visualization of SLAP lesions [131]. The ABER position may help with the MR arthrographic diagnosis of instability lesions and partial-thickness, articular-surface rotator cuff tears [9,30,104-108]. 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 [132].

Various techniques are used to minimize artifacts that can reduce imaging quality. Wraparound artifact should be reduced by phase oversampling [133]. Involuntary patient motion is best controlled by ensuring patient comfort combined with gentle immobilization when necessary [113]. Securing the affected arm against the thigh may further reduce motion artifacts [77]. When available, software that compensates for motion by the use of navigator echoes can be useful [134]. Flowing blood and other periodic motions produce ghosting artifacts, which can be reduced with presaturation pulses or gradient moment nulling [133,135]. Chemical shift artifact is more severe at higher field strengths and may necessitate an increase in the receiver bandwidth [14,95,133]. 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 MR imaging using 1.5T over 3T units. Avoiding gradient-echo imaging and reducing the voxel size will help reduce the magnitude of susceptibility artifacts [133,134]. 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 FSE technique rather than SE imaging, keeping the echo train length low and increasing bandwidth [136]. Newer techniques include the use of view angle tilting (VAT) to correct the in plane distortions, slice encoding for metal artifact correction (SEMAC), and multi-acquisition variable-resonance image combination (MAVRIC), which correct both the in-plane and through slice distortions [137]. Vacuum phenomena in the shoulder joint can also result in artifact generation, especially when gradient-recalled pulse sequences are used [138]. Lastly, magic angle artifact can produce apparent increased signal intensity on short-TE images within the supraspinatus tendon as it curves over the humeral head, mimicking intratendinous pathology [139]. This pitfall is best avoided by confirming abnormal signal intensity in the tendon on long-TR 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 Food and Drug Administration, such as the intra-articular injection of gadolinium chelates (direct MR arthrography) [140], can be considered when they are judged to be medically appropriate.

VI. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [141].

At a minimum, the report should address the condition of the rotator cuff muscles and tendons, supraspinatus outlet, biceps tendon, and labrum. In selected cases, a description of findings in the major ligaments and capsule, articular cartilage, 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 [142].

VII. 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 radiofrequency power deposition (specific absorption rate), and maximum acoustic noise levels.

VIII. 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 *Position Statement on QC & Improvement, Safety, Infection Control, and Patient Education* on the ACR website (http://www.acr.org/guidelines).

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 [86,87,143]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [86,87,143,144].

Equipment monitoring should be in accordance with the ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment [145].

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