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## **PRACTICE GUIDELINE FOR THE PERFORMANCE AND INTERPRETATION OF MAGNETIC RESONANCE IMAGING (MRI) OF THE SHOULDER**

### **PREAMBLE**

These guidelines are an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. They are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care. For these reasons and those set forth below, the American College of Radiology cautions against the use of these guidelines 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 physician or medical physicist in light of all the circumstances presented. Thus, an approach that differs from the guidelines, 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 the guidelines 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 the guidelines. However, a practitioner who employs an approach substantially different from these guidelines 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 these guidelines 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 these guidelines is to assist practitioners in achieving this objective.

### **I. INTRODUCTION**

This guideline was developed and written collaboratively by the American College of Radiology (ACR) and the Society of Skeletal Radiology (SSR).

Magnetic resonance imaging (MRI) is a proven and well-established 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 serves as an important guide to treatment planning and prognostication. However, it should be performed only for a valid medical reason and after careful consideration of alternative imaging modalities. An analysis of the strengths of MRI and other modalities should be weighed against their suitability for particular patients and particular clinical conditions. Radiographs frequently will be the first imaging test performed for suspected bone and soft tissue abnormalities in the shoulder and will often diagnose or exclude an abnormality or will direct further imaging work-up. Radionuclide bone scanning is often used when occult osseous disease is suspected or to screen the entire skeleton in addition to the shoulder for disease such as metastases. Other nuclear medicine examinations have a role for specific clinical scenarios (e.g., a labeled white

blood cell study for suspected osteomyelitis around the shoulder). Single-contrast or double-contrast arthrography can accurately depict 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 [3,4,5,6]. Computed tomography (CT) can show the detailed osseous anatomy and evaluate the alignment of the glenoid fossa, humerus, and glenohumeral joint. When combined with arthrography, CT can also be used for evaluation of the labrum and loose bodies [7]. Lastly, arthroscopy provides a detailed examination of the internal structures of the shoulder joint, allowing the surgeon to treat as well as diagnose many internal derangements.

While 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 the clinical history, clinical examination, and physiologic tests. Adherence to the following guideline will enhance the probability of detecting such abnormalities.

## II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

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

## III. INDICATIONS

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

1. Rotator cuff abnormalities: Supraspinatus, infraspinatus, and/or subscapularis full-thickness and partial-thickness tears, tendonopathy, tendonitis † [8,9,10,11,12].
2. Disorders of the long head of the biceps brachii: full-thickness and partial-thickness tears, tendonopathy, tendonitis, subluxation, dislocation † [13,14,15,16].
3. Conditions affecting the supraspinatus outlet: acromial shape, os acromiale, subacromial spurs, acromioclavicular joint disorders, subacromial bursitis † [17,18,19].
4. Labral abnormalities: cysts, degeneration, and tears, including superior labrum anterior posterior (SLAP) and Bankart lesions and their variants † [7,20,21,22,23,24,25,26,27,28,29,30].
5. Muscle disorders affecting the shoulder girdle: atrophy, hypertrophy, denervation, masses, injuries [10,31,32,33,34].

6. Osteochondral and articular cartilage infractions of the glenohumeral joint: osteochondral fractures, osteochondritis dissecans, degenerative chondrosis, chondromalacia, and chondral fissures, fractures, flaps, and separations † [35,36,37].
7. Loose bodies: chondral, osteochondral, osseous. †
8. Synovial-based disorders: synovitis, bursitis, metaplasia, and neoplasia \* [38,39].
9. Marrow abnormalities: avascular necrosis, marrow edema syndromes, and stress fractures \*.
10. Neoplasms of bone, joint, or soft tissue \* [40].
11. Infections of bone, joint, or soft tissue \* [41,42].
12. Congenital and developmental conditions: dysplasia, normal variants\* [43,44,45].
13. Vascular conditions: entrapment, aneurysm, stenosis, and occlusion \* [46].
14. Neurologic conditions: entrapment, compression, masses, and peripheral neuritis \* [27,47,48,49].

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:

1. Arthritides: inflammatory, infectious, neuropathic, degenerative, crystal-induced, post-traumatic \* [50,51,52].
2. Primary and secondary bone and soft tissue tumors \* [53].
3. Fractures and dislocations [54].

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

1. Prolonged, refractory, or unexplained shoulder pain \*†.
2. Acute shoulder trauma.
3. Impingement syndrome: subacromial, subcoracoid, internal [17,18,19,55,56,57] †.
4. Glenohumeral instability: chronic, recurrent, subacute, acute dislocation and subluxation † [58,59,60,61].
5. Shoulder symptoms in the overhead or throwing athlete [62,63,64,65] †.
6. Mechanical shoulder symptoms: catching, locking, snapping, crepitus †.
7. Limited or painful range of motion.
8. Swelling, enlargement, mass, or atrophy \*.
9. Patients for whom diagnostic or therapeutic arthroscopy is planned †.
10. Patients with recurrent, residual, or new symptoms following shoulder surgery † [10,34,66,67,68,69,70].

\* 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.

#### IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the [ACR Practice Guideline for Performing and Interpreting Magnetic Resonance Imaging \(MRI\)](#) and the ACR White Paper on Magnetic Resonance Safety<sup>1</sup>.

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [122,124].

#### 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 employed 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

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<sup>1</sup> In 2007 the following updated version was published: ACR Guidance Document for Safe MR Practices. AJR 2007;188:1-27.

when necessary. These protocols should be reviewed and updated periodically.

##### A. Patient Selection

The physician responsible for the examination shall supervise patient selection and preparation, and be available in person or by phone for consultation. Patients shall 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 Practice Guideline for the Use of Intravascular Contrast Media](#).)

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 Practice Guideline for Adult Sedation/Analgesia](#) or the [ACR Practice Guideline for Pediatric Sedation/Analgesia](#).

##### 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). Since the inherent signal-to-noise ratio is reduced with lower field strength MR systems, imaging parameters may require modifications. For example, the number of acquisitions can be increased, at the expense of longer imaging times and increased risk of involuntary patient motion [73,74,75,76]. 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 [73,75,77,78]. Fat suppression techniques that rely on the difference between fat and water frequencies (chemical shifts) are unreliable at low field strength, and substituting short-TI inversion recovery (STIR) images may be necessary [76,78]. 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 [75,78]. Various investigators using different equipment and scanning parameters 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 [78,79,80,81]. MR arthrography can further enhance the diagnostic yield for shoulder MRI performed on low-field strength systems [75,76]. Other investigators have found lower accuracy for the evaluation of disorders like SLAP tears, capsular abnormalities, and small rotator cuff tears with specific low-field systems compared to high-field ones [77,79,82].

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 [83, 84], paired coils in a Helmholtz configuration [23, 85], circularly polarized flexible coils [77], solenoid coils [73], and phased array designs [24, 26].

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 [59,84,86]. When MR arthrography is performed, repositioning the affected arm into the abduction external rotation (ABER) position may increase sensitivity for anterior inferior labral tears [7,22,87], and may increase accuracy for rotator cuff tears, especially partial-thickness ones [88,89].

Shoulder MR examinations usually include images acquired in the transverse, oblique sagittal, and oblique coronal planes. The oblique sections are prescribed orthogonal to either the glenoid face, or to the axis of the supraspinatus. The transverse images demonstrate the extra-articular portion of the long head of the biceps and the anterior and posterior glenoid labrum [7,16,21,23]. Evaluation of the rotator cuff is done using both oblique coronal and oblique sagittal images [90]; tilting 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 [91]. Transverse images may aid in the detection of anterior rotator cuff tears. Additionally, the oblique coronal images show the superior labrum and intra-articular segment of the biceps tendon to advantage [92], while the oblique sagittal images can be used to depict the acromial anatomy and supraspinatus outlet [17,18]. The use of radial imaging for the glenoid labrum has been reported [93], but it is not widely used.

The field of view (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; FOVs of up to 20 cm may be necessary to obtain an adequate signal-to-noise ratio on low-field scanners [75,78]. When larger FOVs are used, accuracy decreases [94], but can be partly compensated for with use of intravenous contrast. Occasionally, additional sequences with a larger FOV will be appropriate to more fully evaluate a detected or suspected abnormality, for example, in the scapulothoracic articulation. Slice thickness in the oblique sagittal and 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 [95], but should be no more than 50% of the slice width and should not impair complete visualization of the intra-articular structures. 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 2D imaging, for nontumor image. Some practices may use higher imaging matrices (up to 512 steps) to increase spatial resolution for the diagnosis of labral lesions, including SLAP tears [21,24].

Shoulder MRI can be performed with a wide variety of pulse sequences [96]. 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 exact TR, TE, and flip angle chosen will depend on the field strength of the magnet and the relative contrast weighting desired.

Fluid sensitive sequences such as long TR-long TE (T2-weighted) images with or without fat suppression or STIR images are typically used for evaluation of the rotator cuff, either with conventional spin-echo or fast (turbo) spin-echo technique [9,97,100,101]. 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 [102,103]. 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 used [21,23,104], 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 [84]. Lesions of the superior labrum, such as SLAP tears, can be visualized on fast

spin-echo, long-TR images [24,26], or with gadolinium-enhanced MR arthrography [25,28]. MR arthrography using intra-articular saline [59] or dilute gadolinium [58] may improve diagnostic accuracy in unstable shoulders. Gadolinium-enhanced MR arthrography additionally may improve diagnostic performance for some rotator cuff tendon tears, particularly partial-thickness tears and subscapularis tears [12,87,105,106]. T1-weighted images either without [7,58,105] or with fat suppression [22,25,106] are most frequently employed when MR arthrography is performed with gadolinium-based contrast. At least one fluid sensitive sequence is still necessary when performing MR arthrography to detect pathology that does not communicate with the joint. T1-weighted sequences also have a role in characterizing marrow abnormalities [54], various stages of hemorrhage [107,108], and muscle pathology [10,31,32,33,34,110].

Suppressing the signal from fat may enhance the diagnostic yield of some pulse sequences [96]. Fat suppression can be performed using spectrally selective RF pulses, a STIR sequence, or a phase-dependent method (e.g., the Dixon method) [76,78,110,111]. The latter two techniques may be necessary on low-field systems [78,88]. The addition of fat suppression may increase diagnostic accuracy for rotator cuff tears [97], especially partial-thickness tendon tears [9,112]. Fat suppression is a useful adjunct to T1-weighted images when MR arthrography is performed using a dilute gadolinium mixture [22,25, 106].

Additional imaging techniques may have a role for specific shoulder disorders. Applying axial traction to the affected arm via a weight attached to the wrist may aid in the visualization of SLAP lesions [113]. The ABER position may help with the MR arthrographic diagnosis of instability lesions and partial-thickness rotator cuff tears [7,22,87,88,89]. Direct MR arthrography may be beneficial for various internal shoulder derangements and for imaging postoperative conditions in the shoulder [7,12,15,25,27, 28,36,59,61,69,105,106,113].

Various techniques may be used to minimize artifacts that can reduce imaging quality. Wraparound artifact should be reduced by phase oversampling [114]. Involuntary patient motion is best controlled by ensuring patient comfort combined with gentle immobilization when necessary [96]. Securing the affected arm against the thigh may further reduce motion artifacts [59]. When available, software that compensates for motion by the use of navigator echoes can be useful [115]. Flowing blood and other periodic motion produce ghosting artifacts that can be reduced with presaturation pulses or gradient moment nulling [114,116]. Chemical shift artifact is more severe at higher field strengths, and may necessitate an increase in the receiver bandwidth [74, 114]. 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. Avoiding gradient-echo imaging and reducing the voxel size by increasing the imaging matrix and/or decreasing the slice thickness and FOV will help reduce the magnitude of susceptibility artifacts [114,115]. Vacuum phenomena in the shoulder joint can also result in artifact generation, especially when gradient-recalled pulse sequences are used [118]. 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 [119]. 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 or not additional pulse sequences or unconventional pulse sequences and imaging techniques would confer added benefit for the diagnosis and management of the patient. Examinations that employ techniques not approved by the Food and Drug Administration, such as the intra-articular injection of gadolinium chelates (direct MR arthrography) [120], can be considered when they are judged to be medically appropriate.

## VI. DOCUMENTATION

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

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 [121].

## VII. EQUIPMENT SPECIFICATIONS

The MRI equipment specifications and performance shall 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 elsewhere in the ACR Practice Guidelines and Technical Standards book.

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 [122,123,124]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [122,123,124,125].

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

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- \*Guidelines and standards are published annually with an effective date of October 1 in the year in which amended, revised or approved by the ACR Council. For guidelines and standards published before 1999, the effective date was January 1 following the year in which the guideline or standard was amended, revised, or approved by the ACR Council.
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