Revised 2020 (Resolution 32)*

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.

[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. 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 (IV) 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. 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 [1]. When combined with arthrography, CT can also be used for evaluating the labrum, articular cartilage, and loose bodies [2]. Sonography can be used to evaluate the rotator cuff and biceps tendon and has the advantage of imaging during physiologic motion [3-7]. 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 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 [8,9]. Ultrasound and fluoroscopy can be used to guide arthrographic injection [10,11].

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: massive**,** full-thickness, partial-thickness, and recurrent (postoperative) tears, tendinopathy, calcific tendinitis, and cuff tear arthropathy[2] [3] [12-22]
2. Disorders of the long head of the biceps brachii: full-thickness, partial-thickness, and recurrent (postoperative) tears, tendinopathy, calcific tendinitis, subluxation, and dislocation[3] [10,11,20,23-25]
3. Conditions affecting the supraspinatus outlet: acromial shape, os acromiale, subacromial spurs, acromioclavicular joint disorders, coracoacromial ligament integrity, subacromial bursitis[3] [15,26-29]
4. Labral abnormalities: tears**,** cysts, and degeneration, including superior labrum anterior posterior (SLAP) lesions, Bankart lesions and variants, and recurrent (postoperative) labral tears[3] [2,20,30-44] Abnormalities of the rotator interval and biceps pulley[3] [23,45,46]
5. Muscle disorders affecting the shoulder girdle: atrophy, hypertrophy, denervation, masses, and injuries [18,22,47-53]

---

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

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

6. Glenohumeral chondral and osteochondral abnormalities: osteochondral fractures and osteochondritis dissecans, articular cartilage degeneration, fissures, fractures, flaps, and separations[3] [54-56] Intra-articular bodies[3]
7. Synovial-based disorders: synovitis, bursitis, metaplasia, and neoplasia[2] [3] [57,58]
8. Marrow abnormalities: osteonecrosis, marrow replacement and edema syndromes, and osseous contusion and stress fractures[2] [59]
9. Neoplasms, masses, and cysts of bone, joint, or soft tissue[2] [29,39,60]
10. Infections of bone, joint, or soft tissue[2] [61-63]
11. Congenital and developmental conditions, including dysplasia and normal variants[2] [64-67]
12. Vascular conditions: entrapment, aneurysm, stenosis, and occlusion[2] [68]
13. Neurologic conditions: entrapment, compression, masses, and peripheral neuritis[2] [37,42,69]
14. Pathology in the shoulder following arthroplasty [70]

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, posttraumatic[2] [29,71,72]
2. Frozen shoulder (adhesive capsulitis)[3] [45]
3. Primary and secondary bone and soft-tissue tumors[2] [60]
4. Fractures and dislocations [26,73,74]

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] [3]
2. Acute shoulder trauma [26,74]
3. Impingement syndromes: subacromial, subcoracoid, internal[3] [15,27,28,75-78]
4. Glenohumeral instability [43,64,74,79-81]
5. Shoulder symptoms in the overhead motion athlete[3] [82-84]
6. Mechanical shoulder symptoms: catching, locking, snapping, crepitus[3]
7. Limited or painful range of motion
8. Swelling, enlargement, mass, or atrophy[2] [39]
9. Patients for whom diagnostic or therapeutic arthroscopy is planned[3]
10. Patients with recurrent, residual, or new symptoms following shoulder surgery[3] [14,18,20,22,51,85,86]

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [87].

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 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 alternative imaging procedures. 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 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 for consultation by direct communication. Patients must be screened and interviewed prior to 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 [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) [16,38,90-94]. 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 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 tau 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 with high-field ones [97-99].

Regardless of system design, a local coil is mandatory to maximize the SNR. Commercially available coils appropriate for shoulder imaging include single-loop contoured or flat-surface coils [100,101], paired coils in a Helmholtz configuration [36,102], circularly polarized flexible coils [97], solenoid coils [92], and phased array designs [31,41].

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 [81,101,103]. When MR arthrography is performed, repositioning the affected arm into the abduction external rotation (ABER) position may increase sensitivity for anterior inferior labral tears [2,32,104,105] 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 [32].

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. 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 [23,27,46]. 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 [2,24,33,36]. Transverse images may aid in detecting anterior rotator cuff tears. The use of multiple imaging planes increases the accuracy of detecting subscapularis tendon tears [111]. Radial imaging can be used to evaluate the rotator cuff, especially the subscapularis tendon, long head biceps tendon, rotator interval, and glenoid labrum [112-114], 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, 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 field of view. 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 diagnosing labral lesions, including SLAP tears [31,33].

Shoulder MRI can be performed with a wide variety of pulse sequences [115]. 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 [21,116-118]. 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 [119,120]. 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 [33,36,121], 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 [31,41,114], or with MR arthrography [30,34]. T1-weighted sequences (short TR/short TE) have a role in characterizing marrow abnormalities [73], various stages of hemorrhage [122,123], and muscle pathology [22,47,48,51,52]. 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 [124-128]. 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 (FLASH) sequences as well as 3-D VIBE MR arthrography have proven accurate in quantifying glenoid bone loss when compared with CT and surgical measurements [135-138]. T2 relaxation maps of glenoid articular cartilage are possible and provide quantitative measures that reflect early structural change in articular cartilage.

MR arthrography using dilute gadolinium-containing contrast [79] may improve diagnostic accuracy in unstable shoulders [44]. Additionally, MR arthrography may improve diagnostic performance for some rotator cuff tendon tears, particularly partial-thickness tears, postoperative recurrent tears, and subscapularis tears [14,19,104,106,139-141]. 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 [106,142]. T1-weighted images either without (valuable to assess presence and degree of muscle fatty infiltration and/or volume loss) [2,79,139] or with fat suppression [30,32,140] 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 [115]. 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) [90,93,143,144]. The latter two techniques may be necessary on low-field systems [93,108]. Fat suppression is useful for identifying marrow abnormalities and may be a useful adjunct when performing MR arthrography [145]. The addition of fat suppression may increase diagnostic accuracy for rotator cuff tendon tears [117,143], especially partial-thickness tears [21]. Fat suppression is a useful adjunct to T1-weighted images when MR arthrography is performed using gadolinium-containing contrast [30,32,140]. 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 [146].

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 [147]. Applying axial traction to the affected arm via a weight attached to the wrist may aid in the visualization of SLAP lesions [148]. The ABER position may help with the MR arthrographic diagnosis of instability lesions and partial-thickness, articular-surface rotator cuff tears [2,32,104-108]. 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 [149].

Various techniques are used to minimize artifacts that can reduce imaging quality. Wraparound artifact should be reduced by phase oversampling [150]. Involuntary patient motion is best controlled by ensuring patient comfort combined with gentle immobilization when necessary [115]. Securing the affected arm against the thigh may further reduce motion artifacts [81]. When available, software that compensates for motion by the use of navigator echoes can be useful [151]. Flowing blood and other periodic motions produce ghosting artifacts, which can be reduced with presaturation pulses or gradient moment nulling [150,152]. Chemical shift artifact is more severe at higher field strengths and may necessitate an increase in the receiver bandwidth [16,95,150]. 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 [150,151]. 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 (FSE) technique rather than spin-echo (SE) imaging and increasing bandwidth [153,154]. Newer techniques include the use of view angle tilting (VAT) to correct the in-plane distortions, slice encoding for metal artifact correction (SEMAC), and multiacquisition variable-resonance image combination (MAVRIC), which correct both the in-plane and through-slice distortions [155]. Vacuum phenomena in the shoulder joint can also result in artifact generation, especially when gradient-recalled pulse sequences are used [156]. Lastly, 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 [157,158]. 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 (FDA), such as the intra-articular injection of gadolinium chelates (direct MR arthrography) [159], 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 [160].

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, 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 [161].

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 [162-164]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [162-165].

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [87], the ACR Guidance Document on MR Safe Practices 2020 [166], and the ACR Manual on Contrast Media [167].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [163,164].

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 [89].

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).

ACKNOWLEDGEMENTS

This practice parameter was revised according to the process described under the heading *The Process for Developing ACR Practice Parameters and Technical Standards* on the ACR website (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) by the Committee on Body Imaging (Musculoskeletal) of the ACR Commission on Body Imaging and by the Committee on Practice Parameters – Pediatric Radiology of the ACR Commission on Pediatric Radiology in collaboration with the SPR and the SSR.

Collaborative Committee
Members represent their societies in the initial and final revision of this practice parameter.

ACR
Christine B. Chung, MD, Chair
Laura W. Bancroft, MD, FACR
Timothy J. Carmody, MD, FACR
Soterios Gyftopoulos, MD

SPR
Siddharth Jadhav, MD
Jie C. Nguyen, MD, MS

SSR
Padmaja Jonnalagadda, MD
Tony Wong, MD

Committee on Body Imaging (Musculoskeletal)
(ACR Committee responsible for sponsoring the draft through the process)

Catherine C. Roberts, MD, Chair
Jeffrey M. Brody, MD, FACR
Bethany U. Casagranda, DO
Elaine S Gould, MD, FACR
Mary K. Jesse, MD
Kenneth S. Lee, MD
Suzanne S. Long, MD
Kambiz Motamedi, MD
Carlos A. Rivera, BSc
Aleksandr Rozenberg, MD
Naveen Subhas, MD

Committee on Practice Parameters – Pediatric Radiology
(ACR Committee responsible for sponsoring the draft through the process)

Beverley Newman, MB, BCh, BSc, FACR, Chair
Terry L. Levin, MD, FACR, Vice Chair
John B. Amodio, MD, FACR
Tara M. Catanzano, MB, BCh
Harris L. Cohen, MD, FACR
Kassa Darge, MD, PhD
Dorothy L. Gilbertson-Dahdal, MD
Lauren P. Golding, MD
Safwan S. Halabi, MD
Jason Higgins, DO
Jane Sun Kim, MD
Jessica Kurian, MD
Matthew P. Lungren, MD, MPH
Helen R. Nadel, MD
Erica Poletto, MD
Richard B. Towbin, MD, FACR
Andrew T. Trout, MD
Esben S. Vogelius, MD

Lincoln L. Berland, MD, FACR, Chair, Commission on Body Imaging
Richard A. Barth, MD, FACR, Chair, Commission on Pediatric Radiology
Jacqueline A. Bello, MD, FACR, Chair, Commission on Quality and Safety
Mary S. Newell, MD, FACR, Chair, Committee on Practice Parameters and Technical Standards

Comments Reconciliation Committee

Daniel Ortiz, MD– Chair
Adam Specht, MD, FACR– Vice Chair
Laura W. Bancroft, MD, FACR
Richard A. Barth, MD, FACR
Jacqueline Anne Bello, MD
Lincoln L. Berland, MD, FACR
Timothy J. Carmody, MD, FACR
Christine B. Chung, MD
Richard Duszak, Jr., MD
Soterios Gyftopoulos, MD
Siddharth Jadhav, MD
Padmaja Jonnalagadda, MD
Amy L. Kotsenas, MD
Paul A. Larson, MD, FACR
Robert W. Morris, MD
Mary S. Newell, MD
Beverley Newman, MB, BCh, BSc, FACR
Jie Chen Nguyen, MD, MS
Catherine C. Roberts, MD
Michael I. Rothman, MD, FACR
G. Scott Stacy, MD
Tony Wong, MD

REFERENCES

1. Griffith JF, Yung PS, Antonio GE, Tsang PH, Ahuja AT, Chan KM. CT compared with arthroscopy in quantifying glenoid bone loss. AJR. American journal of roentgenology 2007;189:1490-3.
2. Chandnani VP, Yeager TD, DeBerardino T, et al. Glenoid labral tears: prospective evaluation with MRI imaging, MR arthrography, and CT arthrography. AJR. American journal of roentgenology 1993;161:1229-35.
3. Farin P, Jaroma H. Sonographic detection of tears of the anterior portion of the rotator cuff (subscapularis tendon tears). Journal of ultrasound in medicine : official journal of the American Institute of Ultrasound in Medicine 1996;15:221-5.
4. Farin PU, Jaroma H, Harju A, Soimakallio S. Medial displacement of the biceps brachii tendon: evaluation with dynamic sonography during maximal external shoulder rotation. Radiology 1995;195:845-8.
5. Teefey SA, Middleton WD, Bauer GS, Hildebolt CF, Yamaguchi K. Sonographic differences in the appearance of acute and chronic full-thickness rotator cuff tears. Journal of ultrasound in medicine : official journal of the American Institute of Ultrasound in Medicine 2000;19:377-8; quiz 83.
6. Teefey SA, Rubin DA, Middleton WD, Hildebolt CF, Leibold RA, Yamaguchi K. Detection and quantification of rotator cuff tears. Comparison of ultrasonographic, magnetic resonance imaging, and arthroscopic findings in seventy-one consecutive cases. The Journal of bone and joint surgery. American volume 2004;86-A:708-16.
7. Nazarian LN, Jacobson JA, Benson CB, et al. Imaging algorithms for evaluating suspected rotator cuff disease: Society of Radiologists in Ultrasound consensus conference statement. Radiology 2013;267:589-95.
8. Farin PU, Kaukanen E, Jaroma H, Vaatainen U, Miettinen H, Soimakallio S. Site and size of rotator-cuff tear. Findings at ultrasound, double-contrast arthrography, and computed tomography arthrography with surgical correlation. Investigative radiology 1996;31:387-94.
9. Mink JH, Harris E, Rappaport M. Rotator cuff tears: evaluation using double-contrast shoulder arthrography. Radiology 1985;157:621-3.
10. Park J, Chai JW, Kim DH, Cha SW. Dynamic ultrasonography of the shoulder. Ultrasonography 2018;37:190-99.
11. Rastogi AK, Davis KW, Ross A, Rosas HG. Fundamentals of Joint Injection. American Journal of Roentgenology 2016;207:484-94.
12. Bergin D, Parker L, Zoga A, Morrison W. Abnormalities on MRI of the subscapularis tendon in the presence of a full-thickness supraspinatus tendon tear. AJR. American journal of roentgenology 2006;186:454-9.
13. Deutsch A, Altchek DW, Veltri DM, Potter HG, Warren RF. Traumatic tears of the subscapularis tendon. Clinical diagnosis, magnetic resonance imaging findings, and operative treatment. The American journal of sports medicine 1997;25:13-22.
14. Duc SR, Mengiardi B, Pfirrmann CW, Jost B, Hodler J, Zanetti M. Diagnostic performance of MR arthrography after rotator cuff repair. AJR. American journal of roentgenology 2006;186:237-41.

15. Hambly N, Fitzpatrick P, MacMahon P, Eustace S. Rotator cuff impingement: correlation between findings on MRI and outcome after fluoroscopically guided subacromial bursography and steroid injection. AJR. American journal of roentgenology 2007;189:1179-84.
16. Magee T, Williams D. 3.0-T MRI of the supraspinatus tendon. AJR. American journal of roentgenology 2006;187:881-6.
17. Meister K, Thesing J, Montgomery WJ, Indelicato PA, Walczak S, Fontenot W. MR arthrography of partial thickness tears of the undersurface of the rotator cuff: an arthroscopic correlation. Skeletal radiology 2004;33:136-41.
18. Mellado JM, Calmet J, Olona M, et al. Surgically repaired massive rotator cuff tears: MRI of tendon integrity, muscle fatty degeneration, and muscle atrophy correlated with intraoperative and clinical findings. AJR. American journal of roentgenology 2005;184:1456-63.
19. Pfirrmann CW, Zanetti M, Weishaupt D, Gerber C, Hodler J. Subscapularis tendon tears: detection and grading at MR arthrography. Radiology 1999;213:709-14.
20. Probyn LJ, White LM, Salonen DC, Tomlinson G, Boynton EL. Recurrent symptoms after shoulder instability repair: direct MR arthrographic assessment--correlation with second-look surgical evaluation. Radiology 2007;245:814-23.
21. Singson RD, Hoang T, Dan S, Friedman M. MR evaluation of rotator cuff pathology using T2-weighted fast spin-echo technique with and without fat suppression. AJR. American journal of roentgenology 1996;166:1061-5.
22. Thomazeau H, Boukobza E, Morcet N, Chaperon J, Langlais F. Prediction of rotator cuff repair results by magnetic resonance imaging. Clinical orthopaedics and related research 1997:275-83.
23. Morag Y, Jacobson JA, Shields G, et al. MR arthrography of rotator interval, long head of the biceps brachii, and biceps pulley of the shoulder. Radiology 2005;235:21-30.
24. Spritzer CE, Collins AJ, Cooperman A, Speer KP. Assessment of instability of the long head of the biceps tendon by MRI. Skeletal radiology 2001;30:199-207.
25. Zanetti M, Weishaupt D, Gerber C, Hodler J. Tendinopathy and rupture of the tendon of the long head of the biceps brachii muscle: evaluation with MR arthrography. AJR. American journal of roentgenology 1998;170:1557-61.
26. Alyas F, Curtis M, Speed C, Saifuddin A, Connell D. MR imaging appearances of acromioclavicular joint dislocation. Radiographics : a review publication of the Radiological Society of North America, Inc 2008;28:463-79; quiz 619.
27. Epstein RE, Schweitzer ME, Frieman BG, Fenlin JM, Jr., Mitchell DG. Hooked acromion: prevalence on MR images of painful shoulders. Radiology 1993;187:479-81.
28. Park JG, Lee JK, Phelps CT. Os acromiale associated with rotator cuff impingement: MR imaging of the shoulder. Radiology 1994;193:255-7.
29. Tshering Vogel DW, Steinbach LS, Hertel R, Bernhard J, Stauffer E, Anderson SE. Acromioclavicular joint cyst: nine cases of a pseudotumor of the shoulder. Skeletal radiology 2005;34:260-5.
30. Bencardino JT, Beltran J, Rosenberg ZS, et al. Superior labrum anterior-posterior lesions: diagnosis with MR arthrography of the shoulder. Radiology 2000;214:267-71.
31. Connell DA, Potter HG, Wickiewicz TL, Altchek DW, Warren RF. Noncontrast magnetic resonance imaging of superior labral lesions. 102 cases confirmed at arthroscopic surgery. The American journal of sports medicine 1999;27:208-13.
32. Cvitanic O, Tirman PF, Feller JF, Bost FW, Minter J, Carroll KW. Using abduction and external rotation of the shoulder to increase the sensitivity of MR arthrography in revealing tears of the anterior glenoid labrum. AJR. American journal of roentgenology 1997;169:837-44.
33. Gusmer PB, Potter HG, Schatz JA, et al. Labral injuries: accuracy of detection with unenhanced MR imaging of the shoulder. Radiology 1996;200:519-24.
34. Jee WH, McCauley TR, Katz LD, Matheny JM, Ruwe PA, Daigneault JP. Superior labral anterior posterior (SLAP) lesions of the glenoid labrum: reliability and accuracy of MR arthrography for diagnosis. Radiology 2001;218:127-32.
35. Jin W, Ryu KN, Kwon SH, Rhee YG, Yang DM. MR arthrography in the differential diagnosis of type II superior labral anteroposterior lesion and sublabral recess. AJR. American journal of roentgenology 2006;187:887-93.

36. Legan JM, Burkhard TK, Goff WB, 2nd, et al. Tears of the glenoid labrum: MR imaging of 88 arthroscopically confirmed cases. Radiology 1991;179:241-6.
37. Ludig T, Walter F, Chapuis D, Mole D, Roland J, Blum A. MR imaging evaluation of suprascapular nerve entrapment. European radiology 2001;11:2161-9.
38. Magee TH, Williams D. Sensitivity and specificity in detection of labral tears with 3.0-T MRI of the shoulder. AJR. American journal of roentgenology 2006;187:1448-52.
39. O'Connor EE, Dixon LB, Peabody T, Stacy GS. MRI of cystic and soft-tissue masses of the shoulder joint. AJR. American journal of roentgenology 2004;183:39-47.
40. Stetson WB, Templin K. The crank test, the O'Brien test, and routine magnetic resonance imaging scans in the diagnosis of labral tears. The American journal of sports medicine 2002;30:806-9.
41. Tuite MJ, Cirillo RL, De Smet AA, Orwin JF. Superior labrum anterior-posterior (SLAP) tears: evaluation of three MR signs on T2-weighted images. Radiology 2000;215:841-5.
42. Tung GA, Entzian D, Stern JB, Green A. MR imaging and MR arthrography of paraglenoid labral cysts. AJR. American journal of roentgenology 2000;174:1707-15.
43. Waldt S, Burkart A, Imhoff AB, Bruegel M, Rummeny EJ, Woertler K. Anterior shoulder instability: accuracy of MR arthrography in the classification of anteroinferior labroligamentous injuries. Radiology 2005;237:578-83.
44. Waldt S, Burkart A, Lange P, Imhoff AB, Rummeny EJ, Woertler K. Diagnostic performance of MR arthrography in the assessment of superior labral anteroposterior lesions of the shoulder. AJR. American journal of roentgenology 2004;182:1271-8.
45. Mengiardi B, Pfirrmann CW, Gerber C, Hodler J, Zanetti M. Frozen shoulder: MR arthrographic findings. Radiology 2004;233:486-92.
46. Vinson EN, Major NM, Higgins LD. Magnetic resonance imaging findings associated with surgically proven rotator interval lesions. Skeletal radiology 2007;36:405-10.
47. Connell DA, Potter HG, Sherman MF, Wickiewicz TL. Injuries of the pectoralis major muscle: evaluation with MR imaging. Radiology 1999;210:785-91.
48. Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C. Fatty degeneration of the muscles of the rotator cuff: assessment by computed tomography versus magnetic resonance imaging. Journal of shoulder and elbow surgery / American Shoulder and Elbow Surgeons ... [et al.] 1999;8:599-605.
49. Huang CC, Ko SF, Ko JY, et al. Contracture of the deltoid muscle: sonographic evaluation with MRI correlation. AJR. American journal of roentgenology 2005;185:364-70.
50. Ogawa K, Takahashi M, Naniwa T. Deltoid contracture: MR imaging features. Clinical radiology 2001;56:146-9.
51. Schaefer O, Winterer J, Lohrmann C, Laubenberger J, Reichelt A, Langer M. Magnetic resonance imaging for supraspinatus muscle atrophy after cuff repair. Clinical orthopaedics and related research 2002:93-9.
52. Zanetti M, Gerber C, Hodler J. Quantitative assessment of the muscles of the rotator cuff with magnetic resonance imaging. Investigative radiology 1998;33:163-70.
53. Zvijac JE, Schurhoff MR, Hechtman KS, Uribe JW. Pectoralis major tears: correlation of magnetic resonance imaging and treatment strategies. The American journal of sports medicine 2006;34:289-94.
54. Carroll KW, Helms CA, Speer KP. Focal articular cartilage lesions of the superior humeral head: MR imaging findings in seven patients. AJR. American journal of roentgenology 2001;176:393-7.
55. Sanders TG, Tirman PF, Linares R, Feller JF, Richardson R. The glenolabral articular disruption lesion: MR arthrography with arthroscopic correlation. AJR. American journal of roentgenology 1999;172:171-5.
56. Yu JS, Greenway G, Resnick D. Osteochondral defect of the glenoid fossa: cross-sectional imaging features. Radiology 1998;206:35-40.
57. Matsuzaki S, Yoneda M, Kobayashi Y, Fukushima S, Wakitani S. Dynamic enhanced MRI of the subacromial bursa: correlation with arthroscopic and histological findings. Skeletal radiology 2003;32:510-20.
58. Schraner AB, Major NM. MR imaging of the subcoracoid bursa. AJR. American journal of roentgenology 1999;172:1567-71.
59. Sakai T, Sugano N, Nishii T, Hananouchi T, Yoshikawa H. Extent of osteonecrosis on MRI predicts humeral head collapse. Clinical orthopaedics and related research 2008;466:1074-80.
60. Ritchie DA, Davies AM. MR imaging of tumors and tumor-like lesions of the shoulder girdle. Magnetic resonance imaging clinics of North America 2004;12:125-41, vii.

61. Kothari NA, Pelchovitz DJ, Meyer JS. Imaging of musculoskeletal infections. Radiologic clinics of North America 2001;39:653-71.
62. Struk DW, Munk PL, Lee MJ, Ho SG, Worsley DF. Imaging of soft tissue infections. Radiologic clinics of North America 2001;39:277-303.
63. Browne LP, Guillerman RP, Orth RC, Patel J, Mason EO, Kaplan SL. Community-acquired staphylococcal musculoskeletal infection in infants and young children: necessity of contrast-enhanced MRI for the diagnosis of growth cartilage involvement. AJR. American journal of roentgenology 2012;198:194-9.
64. Harper KW, Helms CA, Haystead CM, Higgins LD. Glenoid dysplasia: incidence and association with posterior labral tears as evaluated on MRI. AJR. American journal of roentgenology 2005;184:984-8.
65. Park YH, Lee JY, Moon SH, et al. MR arthrography of the labral capsular ligamentous complex in the shoulder: imaging variations and pitfalls. AJR. American journal of roentgenology 2000;175:667-72.
66. Tirman PF, Feller JF, Palmer WE, Carroll KW, Steinbach LS, Cox I. The Buford complex--a variation of normal shoulder anatomy: MR arthrographic imaging features. AJR. American journal of roentgenology 1996;166:869-73.
67. Tuite MJ, Blankenbaker DG, Seifert M, Ziegert AJ, Orwin JF. Sublabral foramen and buford complex: inferior extent of the unattached or absent labrum in 50 patients. Radiology 2002;223:137-42.
68. Mochizuki T, Isoda H, Masui T, et al. Occlusion of the posterior humeral circumflex artery: detection with MR angiography in healthy volunteers and in a patient with quadrilateral space syndrome. AJR. American journal of roentgenology 1994;163:625-7.
69. Bredella MA, Tirman PF, Fritz RC, Wischer TK, Stork A, Genant HK. Denervation syndromes of the shoulder girdle: MR imaging with electrophysiologic correlation. Skeletal radiology 1999;28:567-72.
70. Nwawka OK, Konin GP, Sneag DB, Gulotta LV, Potter HG. Magnetic resonance imaging of shoulder arthroplasty: review article. HSS J 2014;10:213-24.
71. Hermann KG, Backhaus M, Schneider U, et al. Rheumatoid arthritis of the shoulder joint: comparison of conventional radiography, ultrasound, and dynamic contrast-enhanced magnetic resonance imaging. Arthritis and rheumatism 2003;48:3338-49.
72. Weishaupt D, Schweitzer ME. MR imaging of septic arthritis and rheumatoid arthritis of the shoulder. Magnetic resonance imaging clinics of North America 2004;12:111-24, vii.
73. Mason BJ, Kier R, Bindleglass DF. Occult fractures of the greater tuberosity of the humerus: radiographic and MR imaging findings. AJR. American journal of roentgenology 1999;172:469-73.
74. Saupe N, White LM, Bleakney R, et al. Acute traumatic posterior shoulder dislocation: MR findings. Radiology 2008;248:185-93.
75. Giaroli EL, Major NM, Higgins LD. MRI of internal impingement of the shoulder. AJR. American journal of roentgenology 2005;185:925-9.
76. Giaroli EL, Major NM, Lemley DE, Lee J. Coracohumeral interval imaging in subcoracoid impingement syndrome on MRI. AJR. American journal of roentgenology 2006;186:242-6.
77. Tan V, Moore RS, Jr., Omarini L, Kneeland JB, Williams GR, Jr., Iannotti JP. Magnetic resonance imaging analysis of coracoid morphology and its relation to rotator cuff tears. Am J Orthop (Belle Mead NJ) 2002;31:329-33.
78. Tirman PF, Bost FW, Garvin GJ, et al. Posterosuperior glenoid impingement of the shoulder: findings at MR imaging and MR arthrography with arthroscopic correlation. Radiology 1994;193:431-6.
79. Palmer WE, Caslowitz PL. Anterior shoulder instability: diagnostic criteria determined from prospective analysis of 121 MR arthrograms. Radiology 1995;197:819-25.
80. Tung GA, Hou DD. MR arthrography of the posterior labrocapsular complex: relationship with glenohumeral joint alignment and clinical posterior instability. AJR. American journal of roentgenology 2003;180:369-75.
81. Willemsen UF, Wiedemann E, Brunner U, et al. Prospective evaluation of MR arthrography performed with high-volume intraarticular saline enhancement in patients with recurrent anterior dislocations of the shoulder. AJR. American journal of roentgenology 1998;170:79-84.
82. Beltran J, Kim DH. MR imaging of shoulder instability injuries in the athlete. Magnetic resonance imaging clinics of North America 2003;11:221-38.
83. Roger B, Skaf A, Hooper AW, Lektrakul N, Yeh L, Resnick D. Imaging findings in the dominant shoulder of throwing athletes: comparison of radiography, arthrography, CT arthrography, and MR arthrography with arthroscopic correlation. AJR. American journal of roentgenology 1999;172:1371-80.

84. Schickendantz MS, Ho CP, Keppler L, Shaw BD. MR imaging of the thrower's shoulder. Internal impingement, latissimus dorsi/subscapularis strains, and related injuries. Magnetic resonance imaging clinics of North America 1999;7:39-49.
85. Major NM, Banks MC. MR imaging of complications of loose surgical tacks in the shoulder. AJR. American journal of roentgenology 2003;180:377-80.
86. Sugimoto H, Suzuki K, Mihara K, Kubota H, Tsutsui H. MR arthrography of shoulders after suture-anchor Bankart repair. Radiology 2002;224:105-11.
87. American College of Radiology. ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI). Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/MR-Perf-Interpret.pdf. Accessed February 26, 201.
88. American College of Radiology. ACR-SPR Practice Parameter for the Use of Intravascular Contrast Media. Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/IVCM.pdf. Accessed February 26, 2019.
89. American College of Radiology. ACR-AAPM Technical Standard for Diagnostics Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment. Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/MR-Equip.pdf. Accessed February 26, 2019.
90. Kreitner KF, Loew R, Runkel M, Zollner J, Thelen M. Low-field MR arthrography of the shoulder joint: technique, indications, and clinical results. European radiology 2003;13:320-9.
91. Merl T, Scholz M, Gerhardt P, et al. Results of a prospective multicenter study for evaluation of the diagnostic quality of an open whole-body low-field MRI unit. A comparison with high-field MRI measured by the applicable gold standard. European journal of radiology 1999;30:43-53.
92. Sasaki M, Ehara S, Nakasato T, et al. MR of the shoulder with a 0.2-T permanent-magnet unit. AJR. American journal of roentgenology 1990;154:777-8.
93. Shellock FG, Bert JM, Fritts HM, Gundry CR, Easton R, Crues JV, 3rd. Evaluation of the rotator cuff and glenoid labrum using a 0.2-Tesla extremity magnetic resonance (MR) system: MR results compared to surgical findings. Journal of magnetic resonance imaging : JMRI 2001;14:763-70.
94. Zlatkin MB, Hoffman C, Shellock FG. Assessment of the rotator cuff and glenoid labrum using an extremity MR system: MR results compared to surgical findings from a multi-center study. Journal of magnetic resonance imaging : JMRI 2004;19:623-31.
95. Erickson SJ. High-resolution imaging of the musculoskeletal system. Radiology 1997;205:593-618.
96. Loew R, Kreitner KF, Runkel M, Zoellner J, Thelen M. MR arthrography of the shoulder: comparison of low-field (0.2 T) vs high-field (1.5 T) imaging. European radiology 2000;10:989-96.
97. Tung GA, Entzian D, Green A, Brody JM. High-field and low-field MR imaging of superior glenoid labral tears and associated tendon injuries. AJR. American journal of roentgenology 2000;174:1107-14.
98. Allmann KH, Walter O, Laubenberger J, et al. Magnetic resonance diagnosis of the anterior labrum and capsule. Effect of field strength on efficacy. Investigative radiology 1998;33:415-20.
99. Magee T, Shapiro M, Williams D. Comparison of high-field-strength versus low-field-strength MRI of the shoulder. AJR. American journal of roentgenology 2003;181:1211-5.
100. Glickstein MF. MR imaging of the shoulder: optimizing surface-coil positioning. AJR. American journal of roentgenology 1989;153:431-2.
101. Tuite MJ, De Smet AA, Norris MA, Orwin JF. MR diagnosis of labral tears of the shoulder: value of T2*-weighted gradient-recalled echo images made in external rotation. AJR Am J Roentgenol 1995;164:941-4.
102. Farley TE, Neumann CH, Steinbach LS, Jahnke AJ, Petersen SS. Full-thickness tears of the rotator cuff of the shoulder: diagnosis with MR imaging. AJR. American journal of roentgenology 1992;158:347-51.
103. Davis SJ, Teresi LM, Bradley WG, Ressler JA, Eto RT. Effect of arm rotation on MR imaging of the rotator cuff. Radiology 1991;181:265-8.
104. Flannigan B, Kursunoglu-Brahme S, Snyder S, Karzel R, Del Pizzo W, Resnick D. MR arthrography of the shoulder: comparison with conventional MR imaging. AJR. American journal of roentgenology 1990;155:829-32.
105. Saleem AM, Lee JK, Novak LM. Usefulness of the abduction and external rotation views in shoulder MR arthrography. AJR. American journal of roentgenology 2008;191:1024-30.
106. Herold T, Bachthaler M, Hamer OW, et al. Indirect MR arthrography of the shoulder: use of abduction and external rotation to detect full- and partial-thickness tears of the supraspinatus tendon. Radiology 2006;240:152-60.

107. Lee SY, Lee JK. Horizontal component of partial-thickness tears of rotator cuff: imaging characteristics and comparison of ABER view with oblique coronal view at MR arthrography initial results. Radiology 2002;224:470-6.
108. Tirman PF, Bost FW, Steinbach LS, et al. MR arthrographic depiction of tears of the rotator cuff: benefit of abduction and external rotation of the arm. Radiology 1994;192:851-6.
109. Patten RM, Spear RP, Richardson ML. Diagnostic performance of magnetic resonance imaging for the diagnosis of rotator cuff tears using supplemental images in the oblique sagittal plane. Investigative radiology 1994;29:87-93.
110. Tuite MJ, Asinger D, Orwin JF. Angled oblique sagittal MR imaging of rotator cuff tears: comparison with standard oblique sagittal images. Skeletal radiology 2001;30:262-9.
111. Gyftopoulos S, J OD, Shah NP, Goss J, Babb J, Recht MP. Correlation of MRI with arthroscopy for the evaluation of the subscapularis tendon: a musculoskeletal division's experience. Skeletal radiology 2013;42:1269-75.
112. Munk PL, Holt RG, Helms CA, Genant HK. Glenoid labrum: preliminary work with use of radial-sequence MR imaging. Radiology 1989;173:751-3.
113. Furukawa R, Morihara T, Arai Y, et al. Diagnostic accuracy of magnetic resonance imaging for subscapularis tendon tears using radial-slice magnetic resonance images. Journal of Shoulder and Elbow Surgery 2014;23:e283-e90.
114. Honda H, Morihara T, Arai Y, et al. Clinical application of radial magnetic resonance imaging for evaluation of rotator cuff tear. Orthopaedics & Traumatology: Surgery & Research 2015;101:715-19.
115. Rubin DA, Kneeland JB. MR imaging of the musculoskeletal system: technical considerations for enhancing image quality and diagnostic yield. AJR. American journal of roentgenology 1994;163:1155-63.
116. Carrino JA, McCauley TR, Katz LD, Smith RC, Lange RC. Rotator cuff: evaluation with fast spin-echo versus conventional spin-echo MR imaging. Radiology 1997;202:533-9.
117. Quinn SF, Sheley RC, Demlow TA, Szumowski J. Rotator cuff tendon tears: evaluation with fat-suppressed MR imaging with arthroscopic correlation in 100 patients. Radiology 1995;195:497-500.
118. Sonin AH, Peduto AJ, Fitzgerald SW, Callahan CM, Bresler ME. MR imaging of the rotator cuff mechanism: comparison of spin-echo and turbo spin-echo sequences. AJR. American journal of roentgenology 1996;167:333-8.
119. Parsa M, Tuite M, Norris M, Orwin J. MR imaging of rotator cuff tendon tears: comparison of T2*-weighted gradient-echo and conventional dual-echo sequences. AJR Am J Roentgenol 1997;168:1519-24.
120. Sahin-Akyar G, Miller TT, Staron RB, McCarthy DM, Feldman F. Gradient-echo versus fat-suppressed fast spin-echo MR imaging of rotator cuff tears. AJR. American journal of roentgenology 1998;171:223-7.
121. McCauley TR, Pope CF, Jokl P. Normal and abnormal glenoid labrum: assessment with multiplanar gradient-echo MR imaging. Radiology 1992;183:35-7.
122. Bush CH. The magnetic resonance imaging of musculoskeletal hemorrhage. Skeletal radiology 2000;29:1-9.
123. De Smet AA, Fisher DR, Heiner JP, Keene JS. Magnetic resonance imaging of muscle tears. Skeletal radiology 1990;19:283-6.
124. Thomazeau H, Rolland Y, Lucas C, Duval JM, Langlais F. Atrophy of the supraspinatus belly. Assessment by MRI in 55 patients with rotator cuff pathology. Acta Orthop Scand 1996;67:264-8.
125. Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures. Pre- and postoperative evaluation by CT scan. Clinical orthopaedics and related research 1994:78-83.
126. Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C. Fatty degeneration of the muscles of the rotator cuff: Assessment by computed tomography versus magnetic resonance imaging. Journal of Shoulder and Elbow Surgery 1999;8:599-605.
127. Slabaugh MA, Friel NA, Karas V, Romeo AA, Verma NN, Cole BJ. Interobserver and Intraobserver Reliability of the Goutallier Classification Using Magnetic Resonance Imaging:Proposal of a Simplified Classification System to Increase Reliability. The American journal of sports medicine 2012;40:1728-34.
128. Schiefer M, Mendonça R, Magnanini MM, et al. Intraobserver and interobserver agreement of Goutallier classification applied to magnetic resonance images. Journal of Shoulder and Elbow Surgery 2015;24:1314-21.
129. Hu HH, Kan HE. Quantitative proton MR techniques for measuring fat. NMR Biomed 2013;26:1609-29.

130. Santago AC, 2nd, Vidt ME, Tuohy CJ, et al. Quantitative Analysis of Three-Dimensional Distribution and Clustering of Intramuscular Fat in Muscles of the Rotator Cuff. Ann Biomed Eng 2016;44:2158-67.
131. Gilbert F, Böhm D, Eden L, et al. Comparing the MRI-based Goutallier Classification to an experimental quantitative MR spectroscopic fat measurement of the supraspinatus muscle. BMC Musculoskeletal Disorders 2016;17:355.
132. Lee YH, Kim S, Lim D, Song H-T, Suh J-S. MR Quantification of the Fatty Fraction from T2*-corrected Dixon Fat/Water Separation Volume-interpolated Breathhold Examination (VIBE) in the Assessment of Muscle Atrophy in Rotator Cuff Tears. Academic Radiology 2015;22:909-17.
133. Nardo L, Karampinos DC, Lansdown DA, et al. Quantitative assessment of fat infiltration in the rotator cuff muscles using water-fat MRI. Journal of magnetic resonance imaging : JMRI 2014;39:1178-85.
134. Nozaki T, Tasaki A, Horiuchi S, et al. Quantification of Fatty Degeneration Within the Supraspinatus Muscle by Using a 2-Point Dixon Method on 3-T MRI. American Journal of Roentgenology 2015;205:116-22.
135. Gyftopoulos S, Hasan S, Bencardino J, et al. Diagnostic accuracy of MRI in the measurement of glenoid bone loss. AJR. American journal of roentgenology 2012;199:873-8.
136. Lee RK, Griffith JF, Tong MM, Sharma N, Yung P. Glenoid bone loss: assessment with MR imaging. Radiology 2013;267:496-502.
137. Tian CY, Shang Y, Zheng ZZ. Glenoid bone lesions: comparison between 3D VIBE images in MR arthrography and nonarthrographic MSCT. Journal of magnetic resonance imaging : JMRI 2012;36:231-6.
138. Kang Y, Choi JA. T2 mapping of articular cartilage of the glenohumeral joint at 3.0 T in healthy volunteers: a feasibility study. Skeletal radiology 2016;45:915-20.
139. Hodler J, Kursunoglu-Brahme S, Snyder SJ, et al. Rotator cuff disease: assessment with MR arthrography versus standard MR imaging in 36 patients with arthroscopic confirmation. Radiology 1992;182:431-6.
140. Palmer WE, Brown JH, Rosenthal DI. Rotator cuff: evaluation with fat-suppressed MR arthrography. Radiology 1993;188:683-7.
141. Magee T. MR versus MR arthrography in detection of supraspinatus tendon tears in patients without previous shoulder surgery. Skeletal radiology 2014;43:43-8.
142. Dinauer PA, Flemming DJ, Murphy KP, Doukas WC. Diagnosis of superior labral lesions: comparison of noncontrast MRI with indirect MR arthrography in unexercised shoulders. Skeletal radiology 2007;36:195-202.
143. Kijowski R, Farber JM, Medina J, Morrison W, Ying J, Buckwalter K. Comparison of fat-suppressed T2-weighted fast spin-echo sequence and modified STIR sequence in the evaluation of the rotator cuff tendon. AJR. American journal of roentgenology 2005;185:371-8.
144. Rybicki FJ, Chung T, Reid J, Jaramillo D, Mulkern RV, Ma J. Fast three-point dixon MR imaging using low-resolution images for phase correction: a comparison with chemical shift selective fat suppression for pediatric musculoskeletal imaging. AJR. American journal of roentgenology 2001;177:1019-23.
145. Mirowitz SA, Apicella P, Reinus WR, Hammerman AM. MR imaging of bone marrow lesions: relative conspicuousness on T1-weighted, fat-suppressed T2-weighted, and STIR images. American Journal of Roentgenology 1994;162:215-21.
146. Subhas N, Benedick A, Obuchowski NA, et al. Comparison of a Fast 5-Minute Shoulder MRI Protocol With a Standard Shoulder MRI Protocol: A Multiinstitutional Multireader Study. American Journal of Roentgenology 2017;208:W146-W54.
147. Poyhia TH, Nietosvaara YA, Remes VM, Kirjavainen MO, Peltonen JI, Lamminen AE. MRI of rotator cuff muscle atrophy in relation to glenohumeral joint incongruence in brachial plexus birth injury. Pediatr Radiol 2005;35:402-9.
148. Chan KK, Muldoon KA, Yeh L, et al. Superior labral anteroposterior lesions: MR arthrography with arm traction. AJR. American journal of roentgenology 1999;173:1117-22.
149. Chiavaras MM, Harish S, Burr J. MR arthrographic assessment of suspected posteroinferior labral lesions using flexion, adduction, and internal rotation positioning of the arm: preliminary experience. Skeletal radiology 2010;39:481-8.
150. Peh WC, Chan JH. Artifacts in musculoskeletal magnetic resonance imaging: identification and correction. Skeletal radiology 2001;30:179-91.
151. McGee KP, Grimm RC, Felmlee JP, Rydberg JR, Riederer SJ, Ehman RL. The shoulder: adaptive motion correction of MR images. Radiology 1997;205:541-5.

152. Haacke EM, Lenz GW. Improving MR image quality in the presence of motion by using rephasing gradients. AJR. American journal of roentgenology 1987;148:1251-8.
153. Toms AP, Smith-Bateman C, Malcolm PN, Cahir J, Graves M. Optimization of metal artefact reduction (MAR) sequences for MRI of total hip prostheses. Clinical radiology 2010;65:447-52.
154. Kumar NM, de Cesar Netto C, Schon LC, Fritz J. Metal Artifact Reduction Magnetic Resonance Imaging Around Arthroplasty Implants: The Negative Effect of Long Echo Trains on the Implant-Related Artifact. Investigative radiology 2017;52:310-16.
155. Hargreaves BA, Worters PW, Pauly KB, Pauly JM, Koch KM, Gold GE. Metal-induced artifacts in MRI. AJR. American journal of roentgenology 2011;197:547-55.
156. Patten RM. Vacuum phenomenon: a potential pitfall in the interpretation of gradient-recalled-echo MR images of the shoulder. AJR. American journal of roentgenology 1994;162:1383-6.
157. Timins ME, Erickson SJ, Estkowski LD, Carrera GF, Komorowski RA. Increased signal in the normal supraspinatus tendon on MR imaging: diagnostic pitfall caused by the magic-angle effect. AJR. American journal of roentgenology 1995;165:109-14.
158. Richardson ML, Amini B, Richards TL. Some new angles on the magic angle: what MSK radiologists know and don't know about this phenomenon. Skeletal radiology 2018;47:1673-81.
159. Schulte-Altedorneburg G, Gebhard M, Wohlgemuth WA, et al. MR arthrography: pharmacology, efficacy and safety in clinical trials. Skeletal radiology 2003;32:1-12.
160. American College of Radiology. ACR Practice Parameter for Communication of Diagnostic Imaging Findings. Available at: https://www.acr.org/-/media/ACR/Files/Practice-Parameters/CommunicationDiag.pdf. Accessed February 26, 2019.
161. Shellock FG, Stoller D, Crues JV. MRI of the shoulder: a rational approach to the reporting of findings. Journal of magnetic resonance imaging : JMRI 1996;6:268-70.
162. Shellock FG. *Guide to MR Procedures and Metallic Objects: Update 2001*. 7th ed. Philadelphia, Pa: Lippincott, Williams & Wilkins; 2001.
163. Shellock FG. *Reference Manual for Magnetic Resonance Safety, Implants and Devices.* 2009 ed. Los Angeles, Calif: Biomedical Research Publishing Group; 2009.
164. Shellock FG, Crues JV. MR procedures: biologic effects, safety, and patient care. Radiology 2004;232:635-52.
165. Sawyer-Glover AM, Shellock FG. Pre-MRI procedure screening: recommendations and safety considerations for biomedical implants and devices. Journal of magnetic resonance imaging : JMRI 2000;12:92-106.
166. American College of Radiology. ACR guidance document for safe MR practices: 2020. Available at: https://www.acr.org/-/media/ACR/Files/Radiology-Safety/MR-Safety/Manual-on-MR-Safety.pdf. Accessed June 26, 2020.
167. American College of Radiology. Manual on Contrast Media. Available at: https://www.acr.org/-/media/ACR/Files/Clinical-Resources/Contrast_Media.pdf. Accessed February 26, 2019.

---

*Practice parameters and technical 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 practice parameters and technical standards published before 1999, the effective date was January 1 following the year in which the practice parameter or technical standard was amended, revised, or approved by the ACR Council.

Development Chronology for this Practice Parameter
2005 (Resolution 10)
Amended 2006 (Resolution 35)
Revised 2010 (Resolution 17)
Amended 2014 (Resolution 39)
Revised 2015 (Resolution 7)
Revised 2020 (Resolution 32)