Revised 2021 (Resolution 41)*

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

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

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

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[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 revised collaboratively by the American College of Radiology (ACR), the Society for Pediatric Radiology (SPR), and the Society of Skeletal Radiology (SSR).

Magnetic resonance imaging (MRI) is a proven imaging modality and useful tool for the detection, evaluation, staging, and follow-up of disorders of the elbow. When properly utilized and performed, MRI not only contributes to diagnosis but can also guide treatment planning and help predict outcomes in many situations. Nevertheless, elbow MRI should be performed for a valid medical reason and should address a specific medical concern. When indicated, it should be utilized in conjunction with other imaging modalities, such as radiographs.

Radiography should be the first imaging test performed to evaluate the elbow [1-4]. Radiography is an effective screening tool for many bone and joint conditions in and around the elbow. Radiography provides valuable information, such as general mineralization status and alignment of the elbow [5-9]. Because of its superior spatial resolution, radiography is imperative when characterizing bone lesions, and can be used to assess for mineralization in soft-tissue masses. Radiography can also be used in dynamic situations, such as stress views, when evaluating the integrity of the ulnar collateral ligament [10-12].

Conventional arthrography has mostly been replaced or augmented by CT or MR arthrography [13,14].

Scintigraphy is a sensitive tool for assessing early bony pathology that may be radiographically occult [3], but lacks specificity and has been replaced by MRI in most circumstances, being used in more specific situations on a case-by-case basis. It can be utilized to assess stress injuries, infections, and tumors [3,15,16].

Ultrasonography is a very valuable tool for assessing the soft tissues of the elbow [17,18]. Ultrasound can evaluate for joint effusions and synovitis, bursitis, tendon and ligament pathology, erosions, and enthesitis, as well as nerve abnormalities [2,19-27]. Dynamic ultrasound can assess the integrity of the ulnar collateral ligament, dislocating ulnar nerve, or snapping of the distal triceps tendon [22,31-33]. Ultrasound can be used in infants to assess immature bone cartilage and soft tissues [28-30]. Finally, ultrasound can be used for diagnostic and therapeutic injections [21,34].

Computed tomography (CT) is frequently used for preoperative planning and evaluation of complex fractures and articular surfaces [35-39]. CT arthrography is an effective test for locating intra-articular osteochondral fragments, identifying symptomatic synovial folds, and staging chondral and osteochondral lesions [3,6,40-42].

Arthroscopy, as an invasive procedure, provides direct visualization of the internal structures of the elbow joint, and is used for diagnosis and treatment.

MRI is a sensitive, noninvasive diagnostic test used to detect anatomic abnormalities of the elbow, and, when correlated with clinical history, physical examination, and physiologic testing, can be a valuable tool for identifying clinically important abnormalities and formulating a treatment plan.

II. INDICATIONS

A. Primary indications for MRI of the elbow include, but are not limited to, diagnosis, exclusion, and grading of suspected [46]:

1. Ligament disorders (ulnar collateral, lateral ulnar collateral, radial collateral, and annular ligaments): posterior lateral elbow instability, sprains, partial and complete tears[2] [14,39,47-59]

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

2. Disorders of the flexor and extensor tendon origins (epicondylitis): tendinopathy, partial and complete tears[3] [27,39,60-64]
3. Distal biceps tendon disease: tendinopathy, partial and complete tears [51,56,65-69]
4. Distal triceps tendon disease: tendinopathy, partial and complete tears, snapping, subluxation [51,56,70-72]
5. Muscle and myotendinous injuries [56]
6. Occult fractures [73-76]
7. Osteochondral lesions: osteochondral fractures and osteochondritis dissecans[2,3] [6,7,14,55,56,77-83]
8. Cartilage lesions: chondral fractures and flaps, chondromalacia, degenerative arthritis† [14,56,78,84]
9. Joint effusions and inflammatory or proliferative synovitis [3] [19,85-88]
10. Intra-articular bodies: chondral, osteochondral, osseous [2] [6,14,41,55,56,77,78,82]
11. Symptomatic plicae and synovial folds [14,89,90]
12. Olecranon and bicipitoradial bursitis: septic, traumatic, crystal-induced, inflammatory[2] [20,56,86,88,91,92]
13. Marrow abnormalities: bone contusions, osteonecrosis, apophysitis, marrow edema syndromes, stress fractures[2] [15,16,80,82,93,94]
14. Peripheral nerve disorders: entrapment, compression, cubital tunnel syndrome, muscle denervation[2] [23,39,51,67,73,95-103]
15. Congenital and developmental abnormalities [104]
16. Neoplasms of bone, joint, or soft tissue[2] [105]
17. Infections of bone, joint, or soft tissue[2] [88,106]
18. Abnormalities of the proximal forearm interosseous membrane and neuromuscular structures [97,107,108]

B. MRI of the elbow 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: primary inflammatory and erosive, infectious, neuropathic, degenerative, crystal-induced, posttraumatic[2] [87,88]
2. Primary and secondary bone and soft-tissue tumors[2] [105] (see also the ACR–SPR–SSR Practice Parameter for the Performance and Interpretation of Magnetic Resonance Imaging (MRI) of Bone and Soft-Tissue Tumors [109])
3. Fractures and stress fractures [4,16,39,50,74,75,78,80,110,111]
4. Soft-tissue injuries associated with a known fracture [112,113]

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

1. Prolonged, refractory, or unexplained elbow pain[3]
2. Sports injuries, especially in throwing athletes[3] [15,54,56,80,93,114,115]
3. Elbow instability: acute, recurrent, chronic (eg, posterolateral rotatory instability)[3] [50,53,57,116]
4. Painful elbow snapping or mechanical symptoms[3] [17,49,70,72,89,90]
5. Refractory tennis elbow [51,60,64]
6. Limited or painful range of motion, or contracture [117]
7. Unexplained elbow swelling, mass, or atrophy[2] [105,106]
8. Neuropathy whose cause is localized to the elbow[2] [23,39,51,67,73,95-100]
9. Patients for whom diagnostic or therapeutic arthroscopy or elbow surgery is planned[3] [64]
10. Patients with recurrent, residual, or new symptoms following elbow surgery[3]

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [118].

IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [118], the ACR Guidance Document on MR Safe Practices 2020 [119], and the ACR Manual on Contrast Media [120].

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[3] Conditions in which intravenous (IV) contrast may be useful

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [121,122].

V. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for MRI of the elbow 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 – revised in 2016, Resolution 12-b)

The supervising physician must have adequate understanding of the indications, risks, and benefits of the imaging 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 and gadolinium deposition. 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 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 telephone for consultation. Patients must be screened and interviewed prior to the examination to exclude individuals who may be at potential risk by exposure to the MR environment.

For certain indications, the administration of intravenous (IV) contrast media is beneficial. IV contrast enhancement should be performed using appropriate injection protocols and in accordance with the institution's policy on IV contrast use (see the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [123]).

Pediatric patients or patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of moderate sedation or general anesthesia may be infrequently needed to achieve a successful examination, particularly in young children, although patient education, mock scanner simulation, distraction with audiovisual media, and child life services are often successful in averting sedation use in children [124]. If moderate sedation is necessary, refer to the ACR–SIR Practice Parameter for Minimal and/or Moderate Sedation/Analgesia [125].

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

1. Equipment

Elbow MRI can be performed using a variety of magnet designs (closed or open) and field strengths (low, medium, or high), including dedicated extremity-only scanners [63,126]. Although arbitrary, 0.3T is designated as low field, 1T as medium field, and 1.5T to 3T as high field [127,128]. On lower field strength systems, poorer signal-to-noise ratio (SNR) may necessitate modifications in the imaging parameters to prevent image degradation [129,130]. For example, the number of signals averaged can be increased at the expense of longer acquisition times and increased risk of involuntary patient motion [130,131]. Alternatively, voxel size can be increased (through a combination of larger field of view (FOV), thicker slices, and/or decreased matrix) at the cost of lower spatial resolution. Fat-suppression techniques that rely on the difference between fat and water frequencies (chemical shift) are unreliable at low field strength, and substituting short tau inversion recovery (STIR) images may be necessary.

Regardless of system design, a local receiver coil is mandatory to maximize the SNR [132]. In general, the coil size should closely approximate the size of the elbow [133]. Thus, a wrist coil may be appropriate for a small child's elbow, whereas an adult who cannot completely straighten the elbow may require a knee coil [65]. Circumferential, cylindrical coils—constructed in saddle, birdcage, or phased-array configurations—provide the most homogenous receptive field [50,134]. Multichannel coils containing 8 or more coil elements increase SNRs and are necessary when using techniques like parallel imaging [135]. Other choices include an anterior neck, shoulder, or flexible coil or a pair of surface coils joined in a Helmholtz configuration [14,50,80,134]. Because it must be oriented perpendicular to the B_0 magnetic field, elbow MRI can only utilize a solenoid coil on a low-field system with a vertically oriented B_0 field [130].

2. Patient Positioning

Patient positioning for elbow MRI can be more difficult than for other joints [136]. Local equipment together with the patient's size and physical limitations will affect both patient and arm positioning, which in turn will influence the choice of imaging coil. Lying prone with the affected arm overhead allows the elbow to be placed near the magnet isocenter, where the field is most homogeneous. Additionally, the prone position may be easier to tolerate for some patients with severe claustrophobia [137]. Nevertheless, this position is uncomfortable for many patients, resulting in involuntary motion and associated imaging artifacts [80,130,136]. Having the patient pronate the forearm may alleviate some discomfort, but this position may distort the anatomy of the collateral ligaments and tendons in the coronal plane [50,80,130]. Conversely, lying supine with the affected elbow at the side is more comfortable for most patients, but this position places the elbow toward the side of the magnet where the magnetic field is less homogeneous, degrading image quality and hampering the ability to achieve effective chemical fat suppression [138]. Furthermore, many cylindrical coils are too large to be placed alongside a supine patient [134]. A third position for elbow MRI is the patient lying on the side with the elbow extended overhead [139]. The patient should extend the elbow as much as possible for routine MRI [130], but for some indications, performing part of the examination with the elbow flexed may assist in the diagnosis. Full elbow flexion may be necessary to demonstrate subluxation of the distal triceps or dislocation of the ulnar nerve in snapping elbow syndrome [72,139]. The contents and size of the cubital tunnel are also easier to visualize with elbow flexion [116]. Elbow flexion with forearm supination (achievable with the patient prone and the arm overhead) allows imaging of the entire distal biceps tendon in one long-axis plane [140].

3. Imaging Planes and Technical Considerations

Elbow MRI should usually include images in three imaging planes [50,80,116]. Short-axis (transverse) images, perpendicular to the humerus and forearm bones, should extend distally to include the radial tuberosity for the biceps brachii tendon attachment [80]. Coronal and sagittal images need to be prescribed from the transverse images, parallel and perpendicular, respectively, to the epicondylar axis of the distal humerus [14,50,130]. Some practices will also angle the coronal images posteriorly by 2 to 30 degrees (either by using the sagittal images as a second localizer or by flexing the elbow slightly) to better delineate the collateral ligaments [48,80,116]. When severe flexion contractures are present, acquiring separate transverse and coronal images for the humerus and forearm bones may be necessary.

Accurate diagnosis of elbow disorders requires high spatial resolution. The FOV should be 10 to 16 cm [50,80,134,136]; a FOV at the low end of this range is desirable if the coil provides a high enough SNR to support it [134]. Thin slices (1.5-4 mm thick) are also necessary; on most systems, obtaining a slice thickness <2 to 3 mm requires a 3-D sequence. A need to balance the desired in-plane resolution with adequate intravoxel SNR will affect the size of the imaging matrix selection. For imaging the elbow, the matrix should include at least 256 steps in the phase- and frequency-encoding directions. Smaller pixels are preferred, but available SNR limits the attainable resolution [130]. High-resolution images are especially important for evaluating the collateral ligaments when routine MRI is performed without arthrography [47,142]. Depending on the size of the elbow, a rectangular FOV can save imaging time without sacrificing in-plane resolution [136].

4. Conventional Pulse Sequences

Numerous pulse sequences—conventional spin-echo, fast (turbo) spin-echo, and gradient-recalled—are available for elbow MRI. The choice of sequences, like other aspects of the imaging protocol, can be tailored to answer the specific clinical questions [130,136] and may vary according to local preferences. A typical imaging protocol will be composed of several pulse sequences. The exact repetition time (TR), echo time (TE), and flip angle chosen will depend on the field strength of the magnet and the desired relative contrast weighting. T1-weighted sequences are useful for characterizing marrow abnormalities [105], various stages of hemorrhage [143], and muscle disorders [144]. T2-weighted images can identify tendon degeneration [60,136] as well as muscle and soft-tissue edema [136]. Including at least one T2-weighted sequence with fat suppression (or a STIR sequence) will increase the sensitivity of the examination for soft-tissue as well as marrow edema [80]. Some practices use high-resolution long-TR, short-effective-TE (proton-density–weighted) fast spin-echo images to examine the collateral ligaments [50,142]. Most elbow imaging protocols will combine short-TE (proton-density–weighted or T1-weighted) images and fluid-sensitive (T2-weighted or STIR) images [116]. An additional option is the use of gradient-recalled pulse sequences. Chemical shift (phase-dependent)-based sequences (eg, T2-weighted Dixon) can also be used to achieve homogeneous fat suppression and can provide in-phase, out-of-phase, water-, and fat-suppressed images in a single acquisition, yielding fat-suppressed fluid-sensitive images as well as providing marrow-specific information [145]. Two-dimensional T2*-weighted images can be used for diagnosing intra-articular loose bodies [14,139] and ligament tears [136] or to identify hemosiderin in disorders such as tenosynovial giant-cell tumor [85]. Gradient-echo imaging performed in 3-D mode, with volume acquisition of data, can create thin, contiguous sections. Images with thin slices (2 mm or less) are useful for analyzing the elbow tendons [62], physical injuries in children, and the collateral ligaments in patients with throwing injuries and/or elbow instability [50,53,116,136,146]. Susceptibility artifacts, however, severely affect gradient-recalled images, limiting their use in postoperative elbows [50,80], in which fixation hardware and/or microscopic metal shavings are often present.

5. IV and Intra-Articular Contrast

T1-weighted images are also used when gadolinium-based contrast is administered intravenously or injected directly into the joint for MR arthrography [82,139]. IV contrast may be helpful in diagnosing bursitis [86], tendinopathy [63], osteochondral lesions [82], and tumors and inflammation [139]. Elbow MR arthrography can be performed by direct injection of saline or dilute gadolinium into the joint [14,139] or by indirect diffusion of contrast into the joint following IV administration [147]. Exercising the elbow and a delay of 10 to 15 minutes after IV injection will enhance joint opacification for indirect MR arthrography [147]. Direct or indirect MR arthrography can be used to evaluate the elbow ligaments [39,47,50,52,55,80,142,148] and articular cartilage [84], to stage osteochondral lesions, and to identify intra-articular bodies [55,80,139]. While performing MR arthrography, fat-suppressed T1-weighted images are typically used with at least one additional fluid-sensitive sequence to detect pathology that does not communicate with the joint [14,80,147]. Including at least one T1-weighted sequence without fat suppression is useful for evaluating the bone marrow, detecting fatty replacement and atrophy of muscle, and characterizing soft-tissue lesions.

6. Advanced Pulse Sequences

Although diffusion tensor imaging (DTI) of the peripheral nerves at the elbow can be a highly sensitive technique to detect neuropathy [149], the technical requirements to apply DTI in the extremities currently limit its widespread use. Other promising techniques for sensitive evaluation for peripheral neuropathy include radiomics analysis of structural changes of nerves [150].

7. Fat Suppression

Suppressing the signal from fat may enhance the diagnostic yield of some MRI acquisitions [133]. Fat suppression can be performed using spectrally selective radiofrequency (RF) pulses, a phase-dependent method (eg, Dixon technique), or a STIR sequence [151-153]. The latter technique may be necessary on low-field systems. Adding fat suppression to T2-weighted images (or using a STIR sequence) increases the conspicuity of subtle marrow and soft-tissue edema [80]. Fat suppression is a useful adjunct to T1-weighted images when IV contrast is used or when MR arthrography is performed [154], especially indirect MR arthrography, because of the inherently low gadolinium concentration in the joint that is achieved after IV injection [147]. STIR imaging should be avoided in these cases because the signal intensity from gadolinium is usually suppressed along with fat with this technique.

8. Time Constraints

It is possible to shorten the time required for an elbow MRI examination without compromising diagnostic yield. Multichannel local coils allow the use of parallel imaging techniques, which decrease acquisition times for individual pulse sequences [135]. Additionally, fast 3-D isotropic imaging is possible with gradient-recalled and fast spin-echo sequences [155-157]. Using these methods, a single volumetric acquisition can be obtained in <10 minutes, and reconstructed images can be made in other imaging planes, decreasing the total number of pulse sequences needed to fully evaluate the joint. In the future, techniques such as compressed sensing may potentially further reduce scan times [158].

9. Artifact Reduction

Various techniques can minimize artifacts that reduce imaging quality. Aliasing is usually not a problem when the elbow is imaged over the head. However, with the elbow at the patient's side, phase-encoding in the left-to-right direction should be avoided; if that is not possible, phase oversampling should be used to prevent wraparound artifact [159]. Presaturation pulses or gradient moment nulling will reduce ghosting artifacts from flowing blood and other periodic motion [159,160]. Chemical shift artifact is most severe at high field strengths and may necessitate an increase in the receiver bandwidth [131,159]. Susceptibility artifacts, which originate from heterogeneity of the local field, are also more severe at higher field strengths, in the presence of metallic implants, and when gradient-recalled pulse sequences are used. 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 [159].

It is the responsibility of the supervising physician to determine whether additional or advanced pulse sequences and imaging techniques 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) [161], 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 [162].

At a minimum, the report should address the condition of the major elbow ligaments and tendons and the articular surfaces, as well as any abnormalities in the surrounding structures. In selected cases, a description of findings in the bone marrow, synovium, muscles, neurovascular structures, and subcutaneous tissue would be appropriate. The report should use standard anatomic nomenclature and precise terms for describing identified abnormalities whenever possible.

Specific policies and procedures related to MRI safety should be in place along 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 [121,122,163]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [164].

VII. EQUIPMENT SPECIFICATIONS

Equipment monitoring should be in accordance with the ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance (MR) Imaging Equipment [165].

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 *ACR Position Statement on Quality Control & 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 Practice Parameters – Body Imaging (Musculoskeletal) of the ACR Commission on Body Imaging and the Committee on Practice Parameters – Pediatric Radiology of the ACR Commission on Pediatric Radiology, in collaboration with the SPR, and the SSR.

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*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
2006 (Resolution 5, 35)
2011 (Resolution 24)
Amended 2014 (Resolution 39)
Revised 2016 (Resolution 6)
Revised 2021 (Resolution 41)
Amended 2023 (Resolution 2c, 2d)