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# ACR–SPR–SSR PRACTICE PARAMETER FOR THE PERFORMANCE AND INTERPRETATION OF MAGNETIC RESONANCE IMAGING (MRI) OF BONE AND SOFT-TISSUE TUMORS

## 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 parameter was developed and written 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 and well-established imaging modality in the detection, evaluation, assessment, staging, and follow-up of tumors of the musculoskeletal system. Properly performed and interpreted, MRI not only contributes to initial diagnosis and identification of local recurrence but is also useful to guide biopsy, inform treatment planning, and assess response to therapy. MRI of a tumor or suspected mass should be performed for a valid medical reason and after careful consideration of alternative imaging modalities. An analysis of the strengths of MRI and other modalities should be weighed against their suitability for particular patients and particular clinical conditions. Radiographs should be the initial imaging study obtained for clinical suspicion of bone tumors. In addition, radiographs are usually the first imaging test performed for most suspected soft-tissue masses and are particularly valuable for identifying the presence and character of calcification, fat, or other radiopaque material. For superficial palpable soft-tissue masses, ultrasound may be useful to characterize lesion location, detect internal vascularity, and differentiate solid from cystic lesions [1-3]. Technetium-99m–labeled diphosphonates with bone scintigraphy and single-photon emission computed tomography (SPECT), with or without CT co-registration, is often used when occult bone disease is suspected and to screen the entire skeleton for polyostotic disease conditions such as metastasis . Other nuclear medicine examinations have a role for specific clinical scenarios (eg, Indium-111 oxine, a labeled white blood cell (WBC) scan for suspected osteomyelitis). CT shows detailed bone anatomy and aids in identifying osteoid and chondroid matrix. CT can also be useful to demonstrate the presence of fat within both bone and soft-tissue lesions. Conventional, MR, or CT angiography remains useful for evaluating tumor vascularity, identifying the relationship of the lesion to adjacent major blood vessels, planning resection and reconstruction, and providing a road map for presurgical embolization [4]. Positron emission tomography (PET) with or without CT or MR co-registration can help stage and grade tumors [5-10], assess response to therapy [11-14], and detect tumor recurrence [8,15], but it may not reliably discriminate between benign and malignant tumors [6,16].

Although MRI is one of the most sensitive, noninvasive diagnostic tests for detecting anatomic abnormalities of the musculoskeletal system, findings may be misleading if not closely correlated with radiographs, clinical history, physical examination, and physiologic tests [17,18]. Adherence to the following guidelines will enhance the probability of detecting such abnormalities.

## II. INDICATIONS

Indications for MRI of soft-tissue and bone tumors include, but are not limited to, the following:

1. Initial characterization, detection, or exclusion of tumors [19-34]
2. Follow-up and re-evaluation of tumors
3. Local staging of tumors [35-39]
4. Evaluation of tumors prior to biopsy, surgery, chemotherapy, and/or radiotherapy [27,35,40-44]
5. Evaluation of the response of tumors to treatment, including neoadjuvant chemotherapy, postresection chemotherapy, and radiotherapy [45-56]
6. Detection and evaluation of complications related to tumors or their treatment, including hemorrhage, infection, and neurologic and vascular conditions [27,52,55-65]
7. Posttreatment and long-term surveillance and characterization of local, regional, and distant tumor recurrences [53,54]

## III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [66].

## IV. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for MRI of bone and soft-tissue tumors 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's scope of practice requirements. (ACR Resolution 35 adopted in 2006 – revised in 2016, Resolution 12-b)

The supervising physician must have complete understanding of the indications, risks, and benefits of the examination, as well as alternative imaging procedures. The physician must be familiar with potential hazards associated with MRI, including potential adverse reactions to contrast media. The physician should be familiar with relevant 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 should 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 intravenous (IV) contrast media. IV contrast enhancement should be performed using appropriate injection protocols and in accordance with the institution's policy on IV contrast utilization (See the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [67] and the ACR Manual on Contrast Media [68]).

Pediatric patients or patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of sedation or general anesthesia may be needed to achieve a successful examination. If minimal or moderate sedation is necessary, refer to the ACR–SIR Practice Parameter for Sedation/Analgesia [69]**.** Young children may require sedation or general anesthesia in order to prevent patient motion during the MR examination. Strategies should be employed to mitigate the use of sedation whenever possible and should include motion-insensitive imaging acquisitions and the use of a child life specialist support [70].

### 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

Diagnostic-quality MRI of suspected bone and soft-tissue masses can be performed using a variety of magnetic designs (closed-bore whole body, open whole body) and a variety of field strengths [21,23,26,29]. Regardless of system design, efforts should be made to maximize signal-to-noise ratios (SNR). Field of view (FOV) should be tailored to the size of the patient and the size of the suspected mass [23,63,71,72]. For example, a 48-cm FOV would be appropriate for an extremely large tumor of the pelvis or thigh, whereas a 12-cm FOV may be appropriate for a small mass in the foot. At times, additional sequences with a larger FOV will be necessary to evaluate proximal or distal spread of disease. It is important to obtain as many transverse, sagittal, or coronal images through the lesion as is reasonable. Slice thicknesses will also vary depending on the size of the lesion [23]. For example, a 1-cm mass might require 3-mm-thick slices, whereas a tumor greater than 30 cm in size may be appropriately imaged with 1-cm slice thickness [23]. An interslice gap may be used but should not impair complete visualization of the mass. The imaging matrix should balance the intravoxel SNR with desired in-plane spatial resolution.

The size and location of the lesion will often dictate the most appropriate coil to use for imaging. Small lesions or lesions located in the extremities will often be best imaged using a local surface coil, a cylindrical coil, or a dedicated joint coil. For extremely large lesions or lesions involving the torso, the body or torso coil may be a more appropriate choice [23,39,43]. The entire soft-tissue or bone tumor and associated marrow signal abnormality in association with the possible tumor should be captured within the imaged volume. For some tumors, two separate but overlapping volumes might be necessary. The entire bone, including the adjacent joints, should be imaged to evaluate for skip lesions and regional metastases. The use of a multiple-channel receiver coil unit may allow the use of parallel imaging and compressed sensing imaging techniques to reduce overall scan time or improve SNR and may be useful in reducing motion-related artifacts [73-75].

For patients with more than one suspected bone or soft-tissue mass, it may be necessary to perform separate MR examinations. For example, a patient with a mass involving both the pelvis and leg may require two separate studies.

When imaging bone and soft-tissue tumors at field strength**s** less than 1.5T, imaging parameters, such as the receiver bandwidth and number of acquisitions, will require modification to ensure adequate spatial and contrast resolution for confident diagnosis. This is often at the expense of longer examination times [63,76]. It may also be more difficult to achieve uniform fat suppression on low-field systems using spectrally selective radiofrequency (RF) presaturation pulses, potentially necessitating the use of Dixon or short tau inversion recovery (STIR) techniques [77-80]. Other systems may be more prone to imaging artifacts (eg, chemical shift artifact on high-field magnets), again necessitating modification of imaging parameters, such as receiver bandwidth, to ensure that these artifacts do not detract from the diagnostic quality of the resultant images. Some MRI systems may not be appropriate for specific indications. For example, high-resolution evaluation of a small mass may not be feasible with a low-field, open magnet, regardless of the chosen imaging parameters [81].

MRI of bone and soft-tissue tumors usually includes images in at least two orthogonal planes (transverse, sagittal, and coronal) [21,23,24,30,63]. The long axis images may be oriented orthogonal to the magnetic bore. Coverage of the tumor must include all of the anterior, posterior, medial, lateral, superior, and inferior margins of the mass, unless clinically impractical [21,23,44].

MRI of suspected bone and soft-tissue tumors can be performed with a variety of pulse sequences. The choice of sequences can be tailored to optimize the examination for specific clinical questions and according to local preferences. An imaging protocol would usually be composed of at least one T1-weighted pulse sequence and one fluid-sensitive T2-weighted sequence with or without fat suppression.

Short echo time (TE) images with a relatively short repetition time (TR) (T1-weighted) are commonly used to evaluate tumors [21,23,71,76]. Properly optimized, most institutions use fast spin-echo sequences for T1-weighted imaging. If image blurring with fast spin-echo imaging occurs with a short effective TE, conventional spin-echo imaging can be utilized [21,23,71,76]. To demonstrate pathologic tissues, T2-weighted (fluid-sensitive) imaging using conventional spin-echo or fast spin-echo sequences are most commonly used [77-80,82]. T1-weighted spoiled gradient-echo chemical shift imaging (ie, water-fat in-phase/opposed-phase imaging) can be used to demonstrate the presence of lipid components in tissues and may help discriminate benign from malignant disease processes, such as in evaluation of fractures and bone marrow infiltration [83,84]. Gradient-recalled sequences may also be valuable, in particular in evaluating for internal areas of hemorrhage, gas, ossification, or calcification. Diffusion-weighted imaging (DWI) may also be useful to quantitatively and qualitatively assess bone and soft-tissue masses [85-87]. DWI uses the variability of Brownian motion of water to characterize lesions as having restricted or unrestricted motion of water, which correlates with lesion cellularity [88].

T1-weighted sequences are routinely done without fat suppression to depict anatomic relationships; however, the addition of fat suppression may be helpful to detect hemorrhage or fat within a mass and enhancement when IV contrast is given [89]. Fluid-sensitive images, obtained with long TR using conventional or fast spin-echo sequences, can be used to characterize bone and soft-tissue tumors, providing complementary information to the T1-weighted images. Therefore, a combination of both T1-weighted and T2-weighted images is typically performed in each imaging plane [21,78-80,82]. Lesion conspicuity may be increased with the addition of fat suppression to fluid-sensitive images; however, fat-suppressed imaging decreases the variation in tumor signal intensities that may be useful in tissue characterization. T2-weighted sequences can be performed with or without fat suppression, or STIR sequences can be used [78,79,82]. A combination of techniques may prove advantageous. For example, the transverse images may be obtained without fat suppression and the long axis planes (sagittal and/or coronal images) performed with fat suppression or STIR sequences. The exact TR, TE, and flip angle chosen will depend on the field strength of the magnet and the relative contrast weighting desired [90-92].

Various techniques may be used to minimize the MR artifacts that can reduce imaging quality. Wraparound artifact, including that originating from signal received from other parts of the body, can be reduced by using phase oversampling, by switching the phase and frequency readout directions, by presaturation pulses, or by using RF shielding. Truncation (Gibbs) artifacts may obscure or mimic intralesional detail and can be reduced by changing the phase-encoding direction. Involuntary patient motion is best controlled by ensuring patient comfort combined with gentle immobilization or sedation when necessary and often requires sedation or general anesthesia for young children [63,93]. Desensitizing "practice runs" orchestrated by a child life specialist may also be effective for children [70] as well as the use of MR video goggles. Use of MR systems and coils that provide a high SNR, such as high-field (3T) MR systems and multichannel coils, with or without parallel imaging and/or compressed sensing, can reduce overall scan duration and individual sequence scan times and may help reduce bulk motion artifacts and patient discomfort [73,74]. Motion artifact can also be reduced by sampling k-space in a rotating fashion, utilizing radially directed imaging planes [94]. Flowing blood can produce ghosting artifacts, which can be reduced with presaturation pulses or the use of gradient moment nulling [63,93].

In many cases, it may be advantageous to administer a gadolinium-based IV contrast agent [95-101]. IV contrast may be helpful to differentiate cysts from solid masses and may provide additional details of the imaging features of bone and soft-tissue masses [82,96,97]. Subtracting the precontrast images from the postcontrast images may be beneficial to show subtle areas of enhancement and to distinguish enhancement from adjacent fat or hemorrhage [102]. Fast, multiphase dynamic contrast-enhanced imaging can provide analysis of tumor perfusion kinetics, including parametric perfusion data, that may help to distinguish malignant from benign tumors [103-105], to stage tumors and response to therapy [49,106-108], to determine an optimal site for biopsy [108] improve tumor detection, or evaluate potential extension of tumor cells along related fascial planes [109]. The decision to use IV contrast should be based on medical appropriateness.

Follow-up MR imaging of musculoskeletal tumors is generally performed using sequences similar to those used for initial diagnosis, including T1-weighted and T2-weighted images [53,54]. Because local recurrence may often appear similar to the original tumor, MRI following treatment or surgery should ideally be interpreted with comparison to prior MRI examinations, including the preoperative or pretreatment MRI, if available. Follow-up MR examinations of patients with previously treated soft-tissue tumors often benefit from the addition of IV contrast agents [52,53]. Protocols for follow-up and interpretation of MRI findings vary depending on the type of tumor, the therapeutic methods used, and the aggressiveness of the tumor (see the ACR Appropriateness Criteria®, Follow-up of Malignant or Aggressive Musculoskeletal Tumors [110]).

MR spectroscopy may be useful in gauging therapy response and tumor staging [111-116]. It may also be used to detect certain metabolites in tumors to help in lesion characterization [113,117-122], but caution should be used in interpretation because some metabolites that were thought to be specific may not be (eg, choline for malignant tumors [123]). Newer imaging sequences employing isotropic or near-isotropic 3-D sequences produce images with shorter scan duration but have not been thoroughly evaluated for imaging of musculoskeletal tumors at this time. Whole-body MR screening examinations can be useful both for staging of disseminated or hematologic tumors, such as multiple myeloma, and to limit radiation dose to pediatric and pregnant patients [124-129].

For interpretation, images are most commonly viewed electronically on a workstation but may be printed on film. If hard copy viewing is used, some practices may film the images with magnified or narrowed window settings, but this can be left to local preferences. MR examinations in patients with suspected tumors should be read cautiously and preferably in conjunction with available radiographs. There are many pitfalls and artifacts that can suggest that a nonneoplastic mass is an aggressive tumor or that a malignant tumor appears to be a benign lesion based on the MR appearance alone [82,130,131]. Furthermore, imaging artifacts can also contribute to incorrect staging of tumors [82,130,131].

## V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [132].

The report should address the presence or absence of a mass, the size of the lesion and description of anatomic extent, composition (hemorrhage, necrosis, etc), signal intensity, and enhancement characteristics when IV contrast is administered. A diagnosis or differential diagnosis should be provided. A description of the anatomic location of a tumor, including its intracompartmental and extracompartmental extent, as well as its relationships to adjacent major muscles, vessels, and nerves, will contribute to the tumor's staging. The presence or absence of fascial extension of tumor should be described, which will contribute to the surgical resection planning. The presence or absence of any regional lymphadenopathy or skip lesions should be noted.

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [66], the ACR Guidance Document on MR Safe Practices: 2013 [133], and the ACR Manual on Contrast Media [68].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [134,135].

## VI. EQUIPMENT SPECIFICATIONS

Equipment monitoring should be in accordance with the ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment [136].

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 and/or MR safety officer. Guidelines should be provided that deal with potential hazards associated with MRI examination to the patient as well as to others in the immediate area [134,135,137]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [134,135,137,138].

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.

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

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


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<u>Development Chronology for this Parameter</u>
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