ACR–SPR–SSR PRACTICE PARAMETER FOR THE PERFORMANCE AND INTERPRETATION OF MAGNETIC RESONANCE IMAGING (MRI) OF BONE, JOINT, AND SOFT-TISSUE INFECTIONS IN THE EXTREMITIES

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

Bone, joint, and soft-tissue infections of the extremities are challenging conditions for the treating clinicians and

radiologists. Efficient diagnosis and timely treatment are important to prevent long-term morbidity. Evaluation of the patient with suspected musculoskeletal (MSK) infection affecting an extremity requires complementary information from clinical assessment, laboratory investigations, and diagnostic imaging.

Osteomyelitis (bone infection), septic arthritis (infection of a joint) [1-4], and deep and superficial soft-tissue infections [5-15] occur in all age groups. They are caused by a variety of bacteria and less commonly by viruses, fungi, and parasites. The routes of infection include hematogenous, direct inoculation, and contiguous spread.

Radiography, computed tomography (CT), ultrasound, and combined bone and labeled leukocyte scintigraphy [16-21] have complementary roles in the evaluation of MSK infections.

Radiography should be the initial imaging examination, because it is both accessible and relatively inexpensive. It may demonstrate findings suggesting osteomyelitis-- late acute, subacute, or chronic osteomyelitis and may demonstrate the presence of gas in tissue infections. Initial radiographs may suggest other diagnoses that account for the clinical symptoms. . These include fracture, infection, crystalline/other arthropathies. Additionally, radiographs may help in the interpretation of MRI studies, especially in the diabetic, neuropathic, or postoperative foot, in which infection is often superimposed on neuropathic disease and surgically altered anatomy [22, 23]

Magnetic resonance imaging (MRI) has proven to be one of the most comprehensive imaging modalities in the evaluation of MSK infections [1, 6, 7, 9, 23-27]. In the extremities, MRI is usually the study of choice for detection, characterization, and follow-up of infections, and to exclude other etiologies of symptoms. Compared with other imaging modalities, the power of MRI is that it is comprehensive for imaging infection. It provides excellent soft tissue detail and its high spatial resolution allows detection and characterization marrow, joint, cartilaginous, and soft tissue alterations and involvement. It is more sensitive than radiograph, more specific than nuclear medicine studies, and evaluates both bone and soft tissue (unlike ultrasound) without ionizing radiation [20]. It is sensitive and specific for detecting and defining bone, joint, and soft tissue infections [2, 25]. For osteomyelitis, the negative predictive value of an appropriately performed MRI approximates 100%; a normal study excludes active infection [23, 24]. As it relates to soft tissue infection, this MRI-based practice parameter is more directed toward deep infection or suspected deeper extension of a superficial infection or an area with complex anatomy. Cellulitis or subcutaneous abscesses can usually be diagnosed without imaging.

Nuclear medicine examinations, including bone scintigraphy and labeled leukocyte scans, have been used to evaluate multifocal osteomyelitis. Total body MRI can replace scintigraphy for that indication. [28].

Single-photon PET (SPECT)/CT imaging has provided improved diagnostic accuracy over that of planar or SPECT-alone scans. The main value of SPECT/CT is more of precise anatomical localization of infection and accurate delineation of the infection extent after its diagnosis with planar scintigraphy [29]. Additionally, in patients with contraindications precluding MRI, nuclear medicine imaging may be used for primary diagnosis. Fluorine-18-2-fluoro-2-deoxy-D-glucose positron emission tomography (FDG-PET) has also shown promising results in identifying MSK infections in specific situations [1, 27, 30-36]. The FDG-PET test is sensitive and has a high negative predictive value. It also reliably differentiates degenerative from infectious vertebral body end plate abnormalities. MRI using diffusion imaging can also be used for this indication.[35, 37, 38].

CT may better depict sequestra than MRI. The viability of infected bone in acute and subacute infection and the presence of intraosseous abscesses are better defined using MRI [36, 39] than CT. CT is the preferred modality for the initial imaging workup in patients with clinically suspected necrotizing fasciitis, as it is accessible and will reliably detect superficial and deep soft tissue gas [40-42]. Although CT is highly sensitive for the detection of gas, the absence of gas does not exclude necrotizing fasciitis [43-45]. CT can also be used to evaluate for soft tissue fluid collections. Because metal artifact may hinder CT less than MRI, imaging around orthopedic hardware may be easier using CT. It can be useful for assessing hardware complications, including fluid collections, in the setting of suspected orthopedic hardware infection.

Ultrasound is useful in detecting the presence of joint effusions which can be targeted for diagnostic aspiration to assess for septic arthritis. It may be used to detect and drain other soft tissue collections/abscesses. Ultrasound is

particularly good for evaluating foreign bodies as a potential source of a superficial abscess.

Patients with contraindications to MRI will require other modalities for evaluation in addition to initial radiographs. Additionally, although most metallic implants are not a contraindication to MRI, they cause imaging artifacts that may limit evaluation. Metal artifact reduction techniques should be used to reduce those artifacts [46-48]. In selected cases, use of more than one imaging modality will be needed for a complete evaluation [49-52]. Furthermore, CT and ultrasound play an important role in guiding aspiration and biopsy of infected bones, joints, and soft tissues [23, 39].

Despite its strengths, MRI should be performed only for a valid medical reason, and its findings need to be interpreted in conjunction with clinical history, physical examination, and laboratory results to avoid misinterpretations [15, 53]. Adherence to the following practice parameter will increase the probability of detecting clinically relevant abnormalities in patients with bone, joint, and soft-tissue infections in the extremities.

II. INDICATIONS

Indications for MRI of bone, joint, and soft-tissue infections of the extremities include, but are not limited to, screening, staging, and follow-up of:

1. Bone infection including, but not limited to:
    a. Acute osteomyelitis [1, 27]
    b. Subacute osteomyelitis [1, 27]
    c. Chronic osteomyelitis [1, 27]
    d. Complications of osteomyelitis [2, 54, 55]

2. Septic arthritis and its complications [1, 27]

3. Soft-tissue infections including, but not limited to:
    a. Cellulitis refractory to initial treatment [15, 23, 56-59]
    b. Superficial fasciitis [15, 26, 59]
    c. Deep fasciitis, including necrotizing fasciitis [15, 47, 59, 60]
    d. Soft-tissue abscess and/or pyomyositis [15, 59, 61, 62]
    e. Septic tenosynovitis [15, 26, 63]
    f. Septic bursitis [15, 26]
    g. Infectious lymphadenitis [5, 15]
    h. Deep and superficial septic thrombophlebitis [62]
    i. Complications of soft-tissue infections [62]

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [63].

IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [63] and the ACR Manual on MR Safety [64].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [65, 66].

V. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for MRI of bone, joint and soft tissue infections of the extremities 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 understand 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. 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 should also understand the pulse sequences to be used and their effect on the appearance of the images, including the generation of image artifacts. Standard imaging protocols may be established and vary on a case-by-case basis. These protocols should be reviewed and updated periodically.

V. SPECIFICATIONS OF THE EXAMINATION

A. Patient Selection

The physician responsible for the examination should be aware of patient selection and preparation and be available in person or by phone for consultation. Patients must be screened and interviewed before 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]).

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, particularly in young children. If minimal or moderate sedation is necessary, refer to the ACR–SIR Practice Parameter for Minimal and/or Moderate Sedation/Analgesia [68].

V. SPECIFICATIONS OF THE EXAMINATION

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 regularly monitored for inventory and drug expiration dates. The equipment, medications, and other emergency support must also be appropriate for the range of ages and sizes in the patient population.

V. SPECIFICATIONS OF THE EXAMINATION

C. Examination Technique

Diagnostic-quality MRI of suspected bone, joint, and soft-tissue infections of the extremities can be performed using a variety of magnet designs (closed-bore whole body, open-bore whole body, dedicated extremity) and a variety of field strengths [7, 46, 53, 69-74]. Regardless of system design, efforts should be made to obtain high-quality images [69]. Field of view (FOV) should be tailored to the size of the patient and the size of the suspected abnormality [69, 75-77]. In patients with a diabetic foot infection, the FOV should be centered upon the soft tissue ulcer. For example, a 48-cm FOV may be appropriate for evaluating a suspected large focus of infection in the pelvis or thigh, whereas a 12-cm or smaller FOV may be appropriate for a suspected focal infection in a finger or toe. At times, additional sequences with a larger FOV will be necessary to evaluate extent of disease. An initial survey sequence with a large FOV is also appropriate in infants and young [75, 76] children because of the difficulty in localizing sites of involvement by clinical examination and the frequent multifocality of involvement in this population [78, 79]. Slice thicknesses also will vary depending on the size of the region of interest and/or extent of pathology. For example, a small, infected focus might require 3-mm-thick slices or thinner, whereas infection that involves the majority of one extremity may be appropriately imaged with thicker slices and potentially with the

addition of an interslice gap. The imaging matrix should balance intravoxel signal-to-noise ratio (SNR) with desired in-plane spatial resolution.

The size of the lesion and desired spatial resolution will also dictate the choice of coil, which might be a local surface or cylindrical coil for a small lesion or a multicoil array to completely image a more extensive area (eg, the entire lower extremity for suspected necrotizing fasciitis). For patients with suspected multifocal infection, it may be necessary to perform separate MRI examinations of the affected parts of the extremities, each using a separate coil. For example, a patient with infection involving both the hip and hand will require 2 separate studies.

Whole body MRI is the imaging test of choice for evaluation and follow-up of chronic nonbacterial osteomyelitis also known as chronic relapsing multifocal osteomyelitis. This test is performed with large FOV overlapping sequences of the skeleton. Exact protocols will vary, but non-T1 fat-suppressed sequences (such as T2 with fat saturation, short tau inversion recovery (STIR), Dixon) are the most useful and may be the only ones performed [80, 81].

Other imaging parameters—such as the receiver bandwidth and number of acquisitions—can be adjusted to obtain adequate spatial and contrast resolution, often at the expense of longer examination times [77, 78]. It may be more difficult to achieve uniform fat suppression on low-field systems using spectrally selective radiofrequency presaturation pulses, potentially necessitating the use of Dixon or STIR techniques [79, 82-84]. Additionally, specific systems may be more prone to artifacts (eg, chemical shift artifact on high-field magnets), again requiring that parameters like receiver bandwidth be optimized to ensure that these artifacts do not detract from the diagnostic quality of the resultant images. Finally, some MRI systems may not be appropriate for specific indications. For example, high-resolution evaluation of a small focal lesion in a digit may not be feasible with a low-field open magnet, regardless of the chosen imaging parameters [85].

The examination should include images in both short and long axes. The imaging planes should be oriented to the specific anatomy and pathology. The coverage of the lesion should include the entire infection focus [77, 86] n addition to as much of the surrounding inflammatory process as is reasonably feasible.

MRI of extremity infections can be performed with a variety of pulse sequences. The choice of sequences may be tailored to optimize the examination for specific clinical questions and according to local preferences. Fast spin-echo or turbo spin-echo images are typical [74, 77, 86]. Gradient-recalled sequences may also be valuable, particularly in evaluating for internal areas of hemorrhage, gas, ossification, foreign material, or calcification [77]. Gradient-echo images, however, are relatively insensitive to changes in marrow composition and would need to be supplemented by other sequences when evaluating for osteomyelitis. Imaging sequences using isotropic or near-isotropic 3-D sequences can produce images with shorter scan duration but have not been evaluated for imaging extremity MSK infections [87]. For any chosen sequence, the exact recovery time, echo time, and flip angle used will depend on the field strength of the magnet and the relative contrast weighting desired.

An imaging protocol for a MSK infection typically will comprise more than one pulse sequence type but should include, at a minimum, a fluid-sensitive sequence. A T1-weighted sequence without fat suppression is useful to evaluate for bone infections. Although the fluid-sensitive images are the most sensitive for areas of marrow and soft-tissue edema, they may overestimate the amount of osteomyelitis; the extent of infected bone (as opposed to reactive bone) is more accurately determined with T1-weighted sequences without fat suppression [88-90].

In many cases it is advantageous to administer a gadolinium-based IV contrast agent to increase conspicuity of infected tissues and to depict rim enhancement in intraosseous subperisteal, soft-tissue abscesses and to delineate areas of bone and soft tissue devitalization. Typically, T1-weighted fat-suppressed sequences are obtained before and after contrast administration [15, 25]. Subtraction of nonfat suppressed precontrast and postcontrast images may also be helpful to highlight enhancement, especially when fat suppression techniques are likely to fail, such as in patients with metallic hardware [91]. Additionally, isolated infection

within the completely or predominantly cartilaginous epiphyses of infants and younger children may be only conspicuous on postcontrast images, appearing as hypoenhancing or nonenhancing foci within the cartilage [90, 92]. The slice orientation on the contrast-enhanced images depends on the imaged regional anatomy but is usually in the short-axis plane; many practices obtain additional contrast-enhanced images in a second (long-axis) plane [23, 25, 69, 93]. In addition to showing areas of enhancement, detecting nonenhancement in infected bones and soft tissues impacts management because these nonviable tissues may require surgical debridement or revascularization [58]. The decision to use IV contrast should be based on medical appropriateness (see the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [67]) and should be undertaken only after consideration of potential adverse reactions (see the ACR Manual on Contrast Media [94]).

More advanced imaging techniques, such as diffusion-weighted imaging, dynamic contrast-enhanced [27, 95, 96] MRI, MR spectroscopy, and PET-MR, can be used in the evaluation of bone, joint, and soft-tissue infections as well; however, their role is currently being defined [95-97]. Diffusion-weighted imaging has been shown to be comparable with contrast-enhanced MRI in the detection of soft-tissue abscesses and thus can be used when gadolinium-based IV contrast is contraindicated [59].

Various techniques may be used to minimize artifacts that can reduce image quality [98]. Wraparound artifact, including that which originated from signal received from other parts of the body, can be reduced by phase oversampling by switching the phase and frequency readout directions, by presaturation pulses, or by radiofrequency shielding. Achieving uniform T1 and T2 spectral fat suppression when imaging the hand/wrist and foot/ankle is often challenging. Current Dixon techniques often provide superior fat suppression in these locations [99]. Involuntary patient motion is best controlled by ensuring patient comfort combined with gentle immobilization when necessary [77, 100]. The use of high field-strength systems and multichannel coil or coil array may allow the use of parallel imaging, compressed sensing, and machine-learning acceleration techniques to reduce overall scan time and/or improve SNR, and may be useful in reducing motion-related artifacts [77, 86, 101, 102]. These acceleration techniques may, however, introduce new artifacts or change the appearance of conventional artifacts, although many of these artifacts can be minimized by optimizing protocols. It is important to have an understanding of the benefits and limitations of these techniques and when they should and should not be performed [103, 104]. Flowing blood can produce ghosting artifacts, which can be reduced with presaturation pulses or the use of gradient moment nulling.

Artifacts also occur at interfaces between structures with different magnetic susceptibilities, especially where ferromagnetic materials are present in the body. Common examples include vascular filters, dental restorations, and orthopedic implants [105]. Techniques that can reduce metal artifacts include positioning of the patient with the long axis of instrumentation parallel to the main magnetic field, using fast spin-echo sequences with relatively long echo train lengths and short interecho spacing, substituting inversion recovery for chemical fat suppression, controlling phase and frequency encoding direction, employing view angle tilting, increasing bandwidth during slice selection or readout, and decreasing voxel size [106, 107]. Specific metal artifact-reducing sequences, such as slice encoding for metal artifact correction and multiacquisition variable-resonance image combination provide both in and through plane distortion corrections [107-110]. Susceptibility artifacts from surgical implants are more prevalent at higher field strengths (3T), and patients with known metallic implants are often scheduled at lower field strengths (1.5T or lower).

MRI examinations in patients with suspected extremity infections should be interpreted in conjunction with all available clinical data and relevant imaging studies, including current and prior radiographs, when available. Inflammatory, metabolic, and neoplastic conditions can mimic infections based on their MRI appearances alone. For example, inflammatory or crystal arthropathies may be impossible to distinguish from septic arthritis on MRI [22]. It may also be difficult to distinguish soft-tissue abscesses from diabetic myonecrosis, necrotic soft-tissue tumors, and posttraumatic or postoperative seromas [15]. The signal intensity of reactive marrow edema (eg, in neuropathic arthropathy) can mimic that of osteomyelitis and can enhance with IV contrast agents, thus causing false-positive results [111]. Furthermore, imaging artifacts also can contribute to incorrect staging/evaluation of MSK infections [105].

VI. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [112].

The report should address the presence or absence of a bone, joint, or soft-tissue infection, the extent of the infection, and enhancement characteristics (when contrast is given). A description of the anatomic location of a lesion, including its relationships to adjacent bone, joint, and soft-tissue structures (including the skin and neurovascular bundles) should be provided. The presence or absence of any regional lymphadenopathy should be noted. Other coexistent MSK abnormalities, especially those that may impact treatment planning, should also be recorded. This includes but is not limited to venous thrombosis; pathologic fracture; nonviability of tissues; and, in children, physeal spread/damage. It is recommended that the perceived drainability of a soft tissue abscess not be described in the imaging report but should instead be left to the discretion of the consulted interventional team. Specific nomenclature for infection has been addressed by the SSR [42].

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, if available, MRI physicist. Guidelines that deal with potential hazards associated with MRI examination to the patient as well as to others in the immediate area should be provided [65, 66, 113, 114]. Screening forms must also be provided to detect those patients who may be at risk of adverse events associated with the MRI examination [65, 66, 113, 114].

The use of artificial intelligence (AI) and machine learning in imaging is quickly advancing. Active research is leading to several areas in which AI is being applied to MSK MRI. They include ordering, scheduling, acquisition/reconstruction, presentation, interpretation/analysis, and reporting [115, 116]. In MRI of MSK infection, work has specifically been done to identify infections in hip arthroplasties [117]. Applications have been designed to determine infection type in the spine [118].

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 [119].

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 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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*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.

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