Revised 2020 (Resolution 31) *

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

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 of Pediatric Radiology (SPR), and the Society of Skeletal Radiology (SSR).

Magnetic resonance imaging (MRI) is a proven imaging modality for the detection, evaluation, assessment, staging, and follow-up of disorders of the knee. Properly performed and interpreted, MRI not only contributes to diagnosis but also serves as an important guide to treatment planning and prognostication. However, it should be performed only for a valid medical reason and after careful consideration of alternative imaging modalities. Radiographs will be the first imaging test performed for most suspicious bone and soft-tissue abnormalities of the knee and will often suffice to diagnose or exclude an abnormality or direct further imaging workup. Computed Tomography (CT) provides better details of bone trabeculae, cortex, and periosteal new bone formation compared to radiographs. With multiplanar reformatting capabilities, CT can be helpful to demonstrate radiographically occult fracture or osseous loose body within the joint [1]. Ultrasound can evaluate the extra-articular soft tissues around the knee, including tendons and bursae, assess for joint effusion, and document synovitis [1]. In children, who often have an abundance of unossified epiphyseal cartilage and periarticular soft tissues that can limit the clinical assessment, ultrasound is particularly helpful to confirm or exclude a clinically suspected joint effusion. Bone scintigraphy is often used when radiographically occult bone disease is suspected or to screen the entire skeleton for conditions such as metastases. Other nuclear medicine (NM) examinations have a role for specific clinical scenarios (eg, a labeled white blood cell study or Positron Emission Tomography (PET)/CT for suspected osteomyelitis). Dual-energy CT techniques have also be used in evaluation of crystalline arthropathy, such as gout [2].

Although MRI is a sensitive, noninvasive diagnostic test for detecting anatomic abnormalities of the knee, its findings may be misleading if not closely correlated with clinical history, symptomatology, physical examination, and radiographs. Adherence to the following practice parameters will enhance the probability of detecting such abnormalities.

II. INDICATIONS

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

1. Meniscal disorders: nondisplaced and displaced tears, discoid menisci, parameniscal cysts; complications of meniscal surgery [3] [3-11]
2. Ligament abnormalities: cruciate and collateral sprains and tears; complications following ligament repair or reconstruction [3] [12-17]
3. Extensor mechanism abnormalities: quadriceps and patellar tendon degeneration, partial and complete tears; patellar fractures and sleeve avulsions; and retinacular sprains and tears [18-22]
4. Osteochondral abnormalities: osteochondral fractures, osteochondritis dissecans, and treated osteochondral defects [3] [23-25]
5. Articular cartilage abnormalities: degeneration, chondromalacia, chondral fissures, fractures, flaps, and separations; complications following chondral surgery [3] [26-33]
6. Loose bodies and impinging structures: Hoffa syndrome, patellar and quadriceps impingement [34]
7. Evaluation of prefemoral fat pad in appropriate clinical scenarios [35]
8. Synovial-based disorders: synovitis, bursitis, symptomatic plicae[†], and popliteal cysts [2] [36-39]
9. Osseous abnormalities: osteonecrosis, marrow edema syndromes, stress fractures, radiographically occult fractures, physeal and transphyseal injuries, and transphyseal osseous and nonosseous tethering [2] [40-43]
10. Muscle and tendon disorders: strains, partial and complete tears, tendonitis, tendinopathy, inflammation, and ischemia [44,45]

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

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

11. Iliotibial band friction syndrome [46,47]
12. Neoplasms of bone, joint, or soft tissue [2] [48,49]
13. Infections of bone, joint, or soft tissue [2] [50,51]
14. Congenital and developmental conditions: Blount disease, dysplasia, normal variants [2] [52,53]
15. Vascular conditions: popliteal artery entrapment, aneurysm, stenosis, occlusion, cystic adventitial disease [2] [54-56]
16. Neurologic conditions: common peroneal or tibial nerve traumatic injury, entrapment, compression injury, denervation, and peripheral neuropathy [2] [57]

B. MRI of the knee 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] [58-62]
2. Primary and secondary bone and soft-tissue tumors [2] [48,49]
3. Fractures and dislocations [63-65]

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

1. Prolonged, refractory, or unexplained knee pain [66]
2. Acute knee trauma [67]
3. Mechanical knee symptoms: catching, differentiating a stiff versus a locked knee (fixed extension block), painful range of motion, snapping, crepitus [3] [68,69]
4. Tibiofemoral and/or patellofemoral instability: chronic, recurrent, subacute, acute dislocation, and subluxation [3] [64,65,70-72]
5. Tibiofemoral malalignment and/or patellofemoral malalignment or maltracking [73-75]
6. Swelling, enlargement, mass, or atrophy [2]
7. Patients for whom diagnostic or therapeutic arthroscopy is planned [3] [66,76-81]
8. Patients with recurrent, residual, or new symptoms following knee surgery [3] [10,13,14,27,82-86]
9. Patients with selected complications following knee arthroplasty [87,88] using appropriate metal artifact reduction strategies [89]

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [90].

IV. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for MRI of the knee 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 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 the 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 by qualified personnel prior to the examination to exclude individuals who may have contraindication 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 [91]).

Patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of conscious sedation may be needed to achieve a successful examination. If moderate sedation is necessary, refer to the ACR–SIR Practice Parameter for Sedation/Analgesia [92].

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 knee MRI is possible using a variety of magnet designs (closed-bore whole-body, open whole-body, dedicated extremity) and field strengths [5,7,93,94]. Regardless of magnet design, a local coil is mandatory to maximize signal-to-noise ratio (SNR). Typically, a cylindrical coil (often called an "extremity" or "knee" coil) surrounds the knee. Newer multichannel knee coils or flexible surface coils containing 8 or more coil elements will further increase SNRs and are required when using techniques like parallel imaging, which can be used to increase spatial resolution and/or decrease the time of the scan [95]. Occasionally, a very large extremity may require a slightly larger coil (a posterior neck coil, for example), but every attempt should be made to ensure that the size of the coil closely matches that of the knee circumference [96]. In children with smaller knee joints, a multichannel flexible surface coil may provide superior SNR than a one-size-fits-all dedicated knee coil. The coil's placement should allow imaging of the major structures in and around the knee; at times, repositioning the coil and/or extremity will be necessary to demonstrate additional pertinent anatomy.

Certain MR systems (eg, those using low-field-strength magnets) have inherently lower SNRs than others. When using such a system to perform knee MRI, other imaging parameters, such as the receiver bandwidth and number of acquisitions, will require modification to ensure adequate spatial and contrast resolution for confident diagnosis, often at the expense of longer examination times [97-99]. It may also be more difficult to achieve uniform chemical fat suppression on low-field-strength systems, necessitating the use of Dixon [100] or short tau- inversion recovery (STIR) techniques. Other systems may be more prone to imaging artifacts (eg, chemical shift artifact on high-field magnets), again necessitating that imaging parameters, such as readout bandwidth, be modified to ensure that these artifacts do not detract from the diagnostic quality of the resultant images [5]. For some indications, like high-resolution imaging of articular cartilage, images obtained with a low-field system will be of lower quality compared with those acquired on a high-field system [94,100-104].

Typically, the patient is positioned supine with the affected knee completely or nearly completely extended in the coil. Mild external rotation of the leg is often comfortable for the patient. Gentle immobilization of the extremity and use of comfort measures for the entire body will help to reduce involuntary patient motion and resultant artifacts.

Knee MRI examinations usually include images acquired in appropriate transverse (axial), sagittal, and coronal imaging planes [105,106]. Multiplanar images can be acquired directly or reconstructed electronically from volumetric data acquired in one imaging plane. Some practices obtain standard sagittal and coronal images orthogonal to the anatomic planes of the knee, whereas others may angle the planes to better identify specific anatomic structures, such as the posterolateral corner ligaments [107,108]. The coverage should include all the anterior, posterior, medial, and lateral supporting structures of the knee, though not all structures need to be included in every imaging plane. Superiorly, the distal aspects of the quadriceps tendon and suprapatellar joint recess should be included. The distal insertions of the patellar tendon and pes anserinus tendons should be included inferiorly [109].

The field of view (FOV) should be tailored to the size of the knee and the structures being examined, but for the standard sequences, the FOV should be 16 cm or smaller. Occasionally, additional sequences with a larger FOV will be appropriate to completely evaluate a detected or suspected abnormality, for example, in the extensor mechanism or bone marrow. Slice thickness in the sagittal and coronal planes of 4 mm or less is necessary to demonstrate subtle meniscal pathology, but even thinner sections may be advantageous for detailed analysis of other structures, such as the articular cartilage. An interslice gap can be used – with its size dependent on equipment, time considerations, and need for anatomic coverage – but should not impair complete visualization of the intra-articular structures. In younger children, the imaged structures are often smaller in size; thus, smaller FOV (<14 cm), thinner slice thickness (2.5-3.5 mm), and lower interslice gap (<20%) are often preferred. The imaging matrix should balance intravoxel SNR with desired in-plane spatial resolution and reduction of truncation artifacts but should be at least 192 steps in the phase direction and 256 steps in the frequency direction for 2-D imaging. Three-dimensional sequences with near isotropic voxels allow for multiplanar reconstructions from a single acquisition [110-112].

Knee MRI uses a wide variety of pulse sequences [96]. Many practices tailor the specifics of each study to optimize the examination for specific clinical questions. The choice of sequences will vary because of local preferences and/or available equipment or software limitations. Spin-echo, fast (turbo) spin-echo (FSE), and gradient-recalled sequences each may have a role for knee MRI. A typical imaging protocol will be composed of one or more of these pulse sequence types. The exact repetition time (TR), echo time (TE), and flip angle chosen will depend on the field strength of the magnet and the relative contrast weighting desired.

The literature supports that, for FSE and meniscal tears, a short effective TE, short echo train length, and narrow echo spacing reduces blurring and is “equivalent” to conventional spin echo (CSE). Two-dimensional and 3-D gradient-recalled images can also demonstrate meniscal disorders [109,110,112]. To show ligament pathology, water-sensitive images obtained using conventional or FSE long-TE sequences [113,114] or T2*-weighted gradient-recalled sequences [112] may be used. Including at least one plane of T1-weighted sequences is useful for characterizing marrow abnormalities [115], various stages of hemorrhage [116], and muscle pathology [44,45]. Additionally, T1-weighted images (often with fat suppression) are used after IV administration of gadolinium-based contrast agents to show tissue enhancement [117].

Imaging of articular cartilage disorders can be accomplished with a variety of pulse sequences [27,29], including FSE proton density–weighted, intermediate-weighted, T2-weighted sequences with or without fat suppression [26-28,118,119], 3-D gradient-recalled sequences, or 3-D FSE sequences [112,120-122]. Newer sequences that may be advantageous to assess articular cartilage include modified steady-state free precession or spoiled gradient-recalled sequences that create separate water and lipid images [123-125] that selectively excite water protons [126,127] or that average 2 separate echoes to increase T2 weighting [128,129]. In contrast to these traditional pulse sequences that are optimized to detect sites of morphologic change, quantitative cartilage imaging tools such as T1-

rho or T2 relaxation time mapping can detect microstructural changes within the cartilage matrix, which occur prior to irreversible damage [32,33].

In skeletally immature children with a history of knee trauma that involved the physis, development of physeal bar is a complication that can lead to growth disturbances, angular deformities, and limb length discrepancies. The resulting deformity depends on several factors: the nature and severity of the initial insult, residual growth potential, location and extent of physeal involvement. The latter can be "mapped" and better quantified using a 3-D fat-suppressed spoiled gradient-recalled echo sequence [42,43]. Additional specialty sequences have been advocated for cartilage imaging and may require product licenses and postprocessing equipment and software. In addition, MR arthrography may be useful for evaluating articular surfaces in the knee [87], especially following articular cartilage transplantation [127], or on low-field systems where many of the newer sequences are not available [130]. IV contrast-enhanced MRI administration is typically recommended for the diagnosis of cartilage involvement in infants and young children because infection manifests differently than in older children**.** In infants and young children, skeletal infection particularly (*S. aureus*) has a propensity for involvement of the unossified cartilage**,** which may be occult on unenhanced MRI sequences.[122].

Suppressing the signal from fat may enhance the diagnostic yield of some pulse sequences [96]. Fat suppression techniques include spectral suppression of water protons, a phase-dependent method, such as the Dixon method or STIR [100,131-135]. The latter 2 techniques may be necessary on low-field systems. Methods also exist for generating separate water and lipid images [123-125] or for selectively exciting water protons, which essentially nulls the contribution of fat in the final images [126,127]. Fat suppression is useful for identifying marrow abnormalities [131,132] and may be a useful adjunct when performing MR arthrography [14,84] or when FSE sequences are used to examine the menisci, ligaments, and articular surfaces of the knee [26,118,134].

It may be possible to shorten the time required for a knee MR examination without compromising diagnostic yield when using high field-strength systems and multichannel surface coils [136]. Reduced sampling of k-space using parallel imaging, compressed sensing, and machine-learning acceleration techniques can decrease acquisition times for individual pulse sequences [95,111,124,137,138]. Additionally, high-resolution 3-D imaging with near-isotropic voxels is possible using newer gradient-recalled and FSE sequences on the latest generation MR systems [110,111,125]. Using these methods, a single volumetric acquisition obtained and reconstructed into multiple imaging planes can eliminate the need to obtain multiplanar 2-D sequences and thereby decrease the total number of pulse sequences needed. Synthetic MRI of the knee may allow a single sequence to provide T1-, proton density, and T2-weighted images to also shorten the overall scan times [139].

Additional imaging techniques may have a role for specific knee disorders. Direct and indirect MR arthrography may be beneficial for various internal knee derangements and for imaging postoperative conditions [14,24,34,83,84,87,140]. In cases in which the etiology of a focal marrow lesion is uncertain, comparing the lesion signal intensity on a pair of gradient-recalled images with TE values chosen so that fat and water protons are in phase and out of phase, respectively, may help show fat within the lesion, thus supporting benignity [141].

Various techniques are useful to reduce artifacts that can degrade imaging quality. Wraparound artifact, including that originating from signal received from the contralateral knee, can be reduced by phase oversampling, by swapping the phase and frequency orientations, or by using radiofrequency shielding between the knees [142,143]. Truncation (Gibbs) artifacts may obscure or mimic meniscal tears; changing the phase-encoding direction or increasing the imaging matrix will reduce this artifact [142,144]. Ensuring patient comfort combined with gentle immobilization when necessary may reduce involuntary patient motion [96]. Presaturation pulses or the use of gradient moment nulling will reduce ghosting artifacts from flowing blood [142,145]. Chemical shift artifact is more severe at higher field strengths and may necessitate an increase in the receiver bandwidth [5,146]. Susceptibility artifacts, which originate from local field heterogeneity, are also more severe at higher field strengths and when using gradient-recalled pulse sequences. Avoiding gradient-echo imaging and reducing the voxel size by increasing the imaging matrix and/or decreasing the slice thickness and FOV will help reduce the magnitude of susceptibility artifacts [142].

In knees containing large metallic implants, a combination of longer echo trains, increased receiver bandwidth, decreased FOV, decreased slice thickness, increased matrix size in the frequency-encoding direction, and control of the phase and frequency encoding directions will reduce, but typically not completely eliminate, metal artifacts [83,88,147]. Vendor specific pulse sequences have been developed which can further reduce metal artifacts [148-150]. The term "metal artifact reduction sequences" (MARS) has been applied to such strategies. Lower magnet strength (1.5T rather than 3T) and use of nonfat-suppressed pulse sequences is preferred. In the presence of metal hardware, STIR imaging is often preferred over spectral fat suppression techniques, and gradient echo (GRE) techniques should be avoided [147,151].

It is the responsibility of the supervising physician to determine whether additional or unconventional 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) [152-154], 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 [155].

The report should address the condition of the menisci, major ligaments, articular cartilage, osseous structures, and extensor mechanism. In selected cases, a description of findings in the neurovascular structures, muscles and tendons, synovium, and cortical bone would be appropriate.

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 [156-159]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [156-159].

For additional recommendations on safety, see the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [90], the ACR Guidance Document on MR Safe Practices 2020 [160], and the ACR Manual on Contrast Media [161].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [157,158].

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 radiofrequency 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 [139].

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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