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

PREAMBLE

These practice parameters are 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 cautions against the use of these s 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 physician or medical physicist in light of all the circumstances presented. Thus, an approach that differs from the practice parameters, 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 the practice parameters 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 the practice parameters. However, a practitioner who employs an approach substantially different from these practice parameters 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 these practice parameters 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

[1] Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, ___ N.W.2d ___ (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.

and safe medical care. The sole purpose of these practice parameters is to assist practitioners in achieving this objective.

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 suspected bone and soft-tissue abnormalities of the knee and will often suffice to diagnose or exclude an abnormality or direct further imaging workup. 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 examinations have a role for specific clinical scenarios (eg, a labeled white blood cell study for suspected osteomyelitis). Computed tomography can show detailed bone trabecular and cortical anatomy, whereas sonography may be appropriate to examine superficial soft-tissue structures around the knee, such as tendons, bursae, and joint effusion. Lastly, arthroscopy provides a detailed examination of the internal structures of the knee joint, allowing the surgeon to treat as well as to diagnose many internal derangements.

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 radiographs, clinical history, physical examination, and physiologic tests. 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, diagnosis, exclusion, and grading of suspected:

1. Meniscal disorders: nondisplaced and displaced tears, discoid menisci, parameniscal cysts; complications of meniscal surgery † [1-8]
2. Ligament abnormalities: cruciate and collateral sprains and tears; complications following ligament repair or reconstruction †[9-13]
3. Extensor mechanism abnormalities: quadriceps and patellar tendon degeneration, partial and complete tears; patellar fractures and sleeve avulsions; and retinacular sprains and tears [14-18]
4. Osteochondral abnormalities: osteochondral fractures and treated osteochondral defects † [19,20]
5. Articular cartilage abnormalities: degeneration, chondromalacia, chondral fissures, fractures, flaps, and separations; complications following chondral surgery † [21-25]
6. Loose bodies and impinging structures: Hoffa syndrome patellar and quadriceps impingement [26]
7. Synovial-based disorders: synovitis, bursitis, symptomatic plicae†, and popliteal cysts* [27-30]
8. Osseous abnormalities: osteonecrosis, marrow edema syndromes, stress fractures, radiographically occult fractures, transphyseal injury, physeal bar evaluation, and mapping for growth disturbance and limb-length discrepancy* [31-34]
9. Muscle and tendon disorders: strains, partial and complete tears, tendonitis, tendinopathy, inflammation, and ischemia [35,36]
10. Iliotibial band friction syndrome [37,38]
11. Neoplasms of bone, joint, or soft tissue* [39,40]
12. Infections of bone, joint, or soft tissue* [41,42]
13. Congenital and developmental conditions: Blount disease, dysplasia, normal variants* [43,44]
14. Vascular conditions: entrapment, aneurysm, stenosis, occlusion, cystic adventitial disease* [45-47]

15. Neurologic conditions: entrapment, compression, denervation, and peripheral neuropathy* [48]

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, post-traumatic* [49-53]
2. Primary and secondary bone and soft-tissue tumors* [39,40]
3. Fractures and dislocations [54-56]

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 [57]
2. Acute knee trauma [58]
3. Mechanical knee symptoms: catching, locking, limited or painful range of motion, snapping, crepitus† [59]
4. Tibiofemoral and/or patellofemoral instability: chronic, recurrent, subacute, acute dislocation, and subluxation† [55,56,60]
5. Tibiofemoral malalignment and/or patellofemoral malalignment or maltracking [61-63]
6. Swelling, enlargement, mass, or atrophy*
7. Patients for whom diagnostic or therapeutic arthroscopy is planned † [57,64-69]
8. Patients with recurrent, residual, or new symptoms following knee surgery† [8,10,11,22,70-72]
9. Patients with selected complications following knee arthroplasty [73,74] using appropriate metal artifact reduction strategies[75]

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

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [76].

IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [76], the ACR Guidance Document on MR Safe Practices [77], and the ACR Manual on Contrast Media [78].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [79,80].

V. SPECIFICATIONS OF THE EXAMINATION

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 ancillary studies that the patient may have undergone. The physician performing the MRI interpretation must have a clear understanding and knowledge of the anatomy and pathophysiology relevant to the MRI 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 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)

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 phone for consultation. Patients must be screened and interviewed by qualified personnel prior to the examination to exclude individuals who may be at risk by exposure to the MR environment.

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 [81]).

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 [82].

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 [3,5,83,84]. Regardless of magnet design, a local coil is mandatory to maximize signal-to-noise ratio. Typically, a cylindrical coil (often called an "extremity" or "knee" coil) surrounds the knee. Newer multichannel knee coils containing 8 or more coil elements will further increase signal-to-noise ratios and are required when using techniques like parallel imaging, which decrease the time of the scan [85]. 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 [86]. 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 signal-to-noise ratios 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 [87-89]. It may also be more difficult to achieve uniform chemical fat suppression on low-field-strength systems, necessitating the use of Dixon [90] or short-TI 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 [3]. For some indications like high-resolution imaging of articular cartilage, images obtained with a low-field system will be of lower quality compared to those acquired on a high-field system [84,90-94]. Detection of other conditions, such as cruciate ligament tears, is less dependent on magnet strength and design.

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, sagittal, and coronal imaging planes [95,96]. 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 [97,98]. 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 [99].

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 evaluate a detected or suspected abnormality completely, 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 decrease signal loss due to cross talk [100] but should be no more than 33% to 50% of the slice width and should not impair complete visualization of the intra-articular structures. The imaging matrix should balance intravoxel signal-to-noise ratio with desired in-plane spatial resolution and reduction of truncation artifacts but should be at least 196 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 [101-103].

Knee MRI uses a wide variety of pulse sequences [86]. Many practices tailor the specifics of each study to optimize the examination for specific clinical questions. The choice of sequences will vary due to local preferences and/or available equipment or software limitations. Spin-echo, fast (turbo) spin-echo, 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 TR, TE, and flip angle chosen will depend on the field strength of the magnet and the relative contrast weighting desired.

Fast (turbo) spin-echo images with a relatively short effective TE are most frequently used to examine the menisci. A short-echo train, short-interecho spacing, and/or tailored radiofrequency pulses can reduce potential blurring. Two-dimensional and 3-D gradient-recalled images can also demonstrate meniscal disorders [99,101,103]. To show ligament pathology, water-sensitive images obtained using conventional or fast (turbo) spin-echo long-TE sequences [110,111] or T2*-weighted gradient-recalled sequences [103] may be used. Including at least one plane of T1-weighted sequences is useful for characterizing marrow abnormalities [112], various stages of hemorrhage [113], and muscle pathology [35,36]. Additionally, T1-weighted images (often with fat suppression) are used after intravenous administration of gadolinium-based contrast agents to show tissue enhancement [114].

Imaging of articular cartilage disorders can be accomplished with a variety of pulse sequences [22,24], including fast spin-echo proton-density-weighted or T2-weighted sequences with or without fat suppression [21-23,115,116] or 3-D gradient-recalled sequences [103,117,118]. 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 [119-121] that selectively excite water protons [122,123] or that average 2 separate echoes to increase T2 weighting [124,125]. In skeletally immature children with remote history of knee trauma with transphyseal extension resulting in growth disturbance and limb-length discrepancy, physeal bar evaluation and mapping can be performed by using 3-D fat-suppressed spoiled gradient-recalled echo sequence [33,34]. Additional specialty sequences have been advocated for cartilage imaging and may require specialized equipment. In addition, MR arthrography may be useful for evaluating articular surfaces in the knee [73], especially following articular cartilage transplantation [126], or on low-field systems where many of the newer sequences are not available [127].

Suppressing the signal from fat may enhance the diagnostic yield of some pulse sequences [86]. Fat suppression techniques include spectral suppression of water protons, a phase-dependent method, such as the Dixon method or short-TI inversion recovery (STIR) [90,128-132]. The latter 2 techniques may be necessary on low-field systems. Methods also exist for generating separate water and lipid images [119-121], or for selectively exciting water protons, which essentially nulls the contribution of fat in the final images [122,123]. Fat suppression is useful for identifying marrow abnormalities [128,129] and may be a useful adjunct when performing MR arthrography [11,72], or when fast spin-echo sequences are used to examine the menisci, ligaments, and articular surfaces of the knee [21,115,131].

It may be possible to shorten the time required for a knee MR examination without compromising diagnostic yield. Multichannel local coils allow the use of parallel imaging techniques, which decrease acquisition times for individual pulse sequences [85,102,120]. Additionally, 3-D near-isotropic imaging is possible with newer gradient-recalled and fast spin-echo sequences [101,102,121]. Using these methods, a single volumetric acquisition obtained and reconstructed into multiple imaging planes will decrease the total number of pulse sequences needed.

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 [11,20,26,71-73,133]. In cases where 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 [134].

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 [135,136]. Truncation (Gibbs) artifacts may obscure or mimic meniscal tears; changing the phase-encoding direction or increasing the imaging matrix will reduce this artifact [135,137]. Ensuring patient comfort combined with gentle immobilization when necessary may reduce involuntary patient motion [86]. Presaturation pulses or the use of gradient moment nulling will reduce ghosting artifacts from flowing blood [135,138]. Chemical shift artifact is more severe at higher field strengths and may necessitate an increase in the receiver bandwidth [3,139]. 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 [135].

In knees containing large metallic implants, a combination of longer echo trains, increased receiver bandwidth, decreased FOV, 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 [71,74]. The term “metal artifact reduction sequences” (MARS) has been applied to such strategies.

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, such as the intra-articular injection of gadolinium chelates (direct MR arthrography) [140-142], 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 [143].

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.

VII. 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.

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 *Position Statement on QC & Improvement, Safety, Infection Control, and Patient Education* on the ACR website (http://www.acr.org/guidelines).

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 [79,80,144,145]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [79,80,144,145].

Equipment monitoring should be in accordance with the ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment [146].

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