

The American College of Radiology, with more than 30,000 members, is the principal organization of radiologists, radiation oncologists, and clinical medical physicists in the United States. The College is a nonprofit professional society whose primary purposes are to advance the science of radiology, improve radiologic services to the patient, study the socioeconomic aspects of the practice of radiology, and encourage continuing education for radiologists, radiation oncologists, medical physicists, and persons practicing in allied professional fields.

The American College of Radiology will periodically define new practice guidelines and technical standards for radiologic practice to help advance the science of radiology and to improve the quality of service to patients throughout the United States. Existing practice guidelines and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice guideline and technical standard, representing a policy statement by the College, has undergone a thorough consensus process in which it has been subjected to extensive review, requiring the approval of the Commission on Quality and Safety as well as the ACR Board of Chancellors, the ACR Council Steering Committee, and the ACR Council. The practice guidelines and technical standards recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice guideline and technical standard by those entities not providing these services is not authorized.

2005 (Res. 9)\*

## **PRACTICE GUIDELINE FOR THE PERFORMANCE AND INTERPRETATION OF MAGNETIC RESONANCE IMAGING (MRI) OF THE KNEE**

---

### **PREAMBLE**

These guidelines are an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. They are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care. For these reasons and those set forth below, the American College of Radiology cautions against the use of these guidelines 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 guidelines, 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 guidelines 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 guidelines. However, a practitioner who employs an approach substantially different from these guidelines 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 guidelines 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 these guidelines is to assist practitioners in achieving this objective.

### **I. INTRODUCTION**

This guideline was developed and written collaboratively by the American College of Radiology (ACR) and the Society of Skeletal Radiology (SSR).

Magnetic resonance imaging (MRI) is a proven and well-established 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, MRI of the knee should be performed only 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 frequently will be the first imaging test performed for suspected bone and soft tissue abnormalities in the knee and will often suffice to diagnose or exclude an abnormality or will direct further imaging work-up. Radionuclide bone scanning is often used when occult osseous 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 (e.g., a labeled white blood cell study for

suspected osteomyelitis). Computed tomography can show the detailed osseous anatomy, while sonography may be appropriate to examine relatively superficial soft tissue structures around the knee. 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.

While MRI is one of the most sensitive, noninvasive diagnostic tests for detecting anatomic abnormalities of the knee, its findings may be misleading if not closely correlated with the clinical history, clinical examination, and physiologic tests. Adherence to the following guidelines will enhance the probability of detecting such abnormalities.

## II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the [ACR Practice Guideline for Performing and Interpreting Magnetic Resonance Imaging \(MRI\)](#).

## III. 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, meniscal cysts † [1,2,3,4,5,6,7].
2. Ligament tears: cruciate, collateral, retinacular † [2,3,7,8,9,10,11,12].
3. Extensor mechanism abnormalities: quadriceps tendon, patellar tendon, patella [13,14,15,16,17].
4. Osteochondral and articular cartilage infractions: osteochondral fractures, osteochondritis dissecans, degenerative chondrosis, chondromalacia, chondral fissures, fractures, flaps, and separations † [18,19, 20,21,22,23,24].
5. Loose bodies: chondral, osteochondral, osseous † [25].
6. Synovial-based disorders: symptomatic plicae, synovitis (including pigmented villonodular synovitis), bursitis, and popliteal cysts \* [26,27,28,29].
7. Marrow abnormalities: avascular necrosis, marrow edema syndromes, and stress fractures \* [30,31].
8. Muscle and tendon disorders: strains, partial and complete tears, tendonitis, tendonopathy, infiltration [32,111,113-114].
9. Neoplasms of bone, joint, or soft tissue \* [33,34].
10. Infections of bone, joint, or soft tissue \* [35,36].
11. Congenital and developmental conditions: Blount disease, dysplasia, normal variants \* [37,38].

12. Vascular conditions: entrapment, aneurysm, stenosis, occlusion, cystic change \* [39].
13. Neurologic conditions: entrapment, compression, denervation, and peripheral neuritis \* [40].

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:

1. Arthritides: inflammatory, infectious, neuropathic, degenerative, crystal-induced, post-traumatic \* [41,42,43,44,45].
2. Primary and secondary bone and soft tissue tumors \* [33,34].
3. Fractures and dislocations [46,47,48].

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

1. Prolonged, refractory, or unexplained knee pain \* †.
2. Acute knee trauma [49].
3. Mechanical knee symptoms: catching, locking, snapping, crepitus † [50].
4. Tibiofemoral and/or patellofemoral instability: chronic, recurrent, subacute, acute dislocation and subluxation † [46,48,51].
5. Tibiofemoral and/or patellofemoral malalignment [52,53,54,55,56,57].
6. Limited or painful range of motion.
7. Swelling, enlargement, mass, or atrophy \*.
8. Iliotibial band friction syndrome [58,59].
9. Patients for whom diagnostic or therapeutic arthroscopy is planned † [60,61,62,63,64,65].
10. Patients with recurrent, residual, or new symptoms following knee surgery † [24, 66,67,68,69,70,71].

---

\* 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.

## IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the [ACR Practice Guideline for Performing and Interpreting Magnetic Resonance Imaging \(MRI\)](#) and the [ACR White Paper on Magnetic Resonance Safety](#)<sup>1</sup>.

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [72,74].

---

<sup>1</sup>In 2007 the following updated version was published: ACR Guidance Document for Safe MR Practices. AJR 2007;188:1-27.

## 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 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 employed 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 shall supervise patient selection and preparation, and be available in person or by phone for consultation. Patients shall be screened and interviewed 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 Practice Guideline for the Use of Intravascular Contrast Media](#).)

Patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of moderate sedation may be needed to achieve a successful examination. If moderate sedation is necessary, refer to the [ACR Practice Guideline for Adult Sedation/Analgesia](#) or the [ACR Practice Guideline for Pediatric Sedation/Analgesia](#).

### 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 can be performed using a variety of magnet designs (closed bore, whole body, open whole body, dedicated extremity) and field strengths [2,7,72,73]. Regardless of magnet design, a local coil is mandatory to maximize signal-to-noise. Typically, a cylindrical coil is used that completely surrounds the knee (often called an "extremity" or "knee" coil). Occasionally a slightly larger coil (posterior neck coil, for example) may be needed to accommodate a very large extremity, but every attempt should be made to ensure that the size of the coil closely matches that of the knee circumference [74]. The coil's placement should allow imaging of the major structures in and around the knee, or the coil and/or extremity should be repositioned during the examination to include any pertinent anatomy where an abnormality is suspected. For example, when a quadriceps tendon abnormality is clinically suspected or suggested by ancillary imaging findings in the knee, an additional set of images may be necessary above the knee after repositioning when using a dedicated extremity magnet.

Certain MR systems (e.g., low-field 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 [75,76,77]. It may also be more difficult to achieve uniform chemical fat suppression on low-field systems, necessitating the use of Dixon [78] or short-TI inversion recovery (STIR) techniques. Other systems may be more

prone to imaging artifacts (e.g., chemical shift artifact on high field magnets) again necessitating that imaging parameters, like readout bandwidth, should be modified to ensure that these artifacts do not detract from the diagnostic quality of the resultant images. For some indications, imaging on a low-field system may be disadvantageous compared to a high-field system. For example, high-resolution images of articular cartilage are more difficult to achieve with low-field systems, and may necessitate the inclusion of alternate methods of fat suppression and/or the performance of MR arthrography [73,78,79,80,81,82]. Detection of other conditions, like meniscal and anterior cruciate ligament tears, is probably less influenced by magnet strength and design.

Typically the patient is positioned supine with the affected knee completely or nearly completely extended. The coil is positioned to provide adequate anatomic coverage. Mild external rotation of the leg is often comfortable for the patient and may orient the anterior cruciate ligament into the sagittal plane to facilitate its evaluation. 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 the transverse, sagittal, and coronal imaging planes [84]. The sagittal and coronal images may be orthogonal to the magnet bore, or may be angled to better identify specific anatomic structures, such as the posterolateral corner ligaments [85,86]. 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 bursa should be included. The distal insertions of the patellar tendon and pes anserinus should be included inferiorly. Volumetric data acquired in one imaging plane may be electronically reformatted and displayed in other imaging planes. Radially acquired images of the menisci may be used in addition to sagittal and coronal images [87].

The field of view (FOV) should be tailored to the size of the patient 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 more fully 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 adequately 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 may be chosen to decrease signal loss due to cross talk [88], but should be no more than 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 with

desired in-plane spatial resolution and reduction of truncation artifacts, but should be at least 140 steps in the phase direction and 256 steps in the frequency direction for 2D imaging.

Knee MRI can be performed with a wide variety of pulse sequences [74]. The choice of sequences can be tailored to optimize the examination for specific clinical questions, and may vary due to local preferences. Spin-echo, fast (turbo) spin-echo, and gradient-recalled sequences have all been used successfully 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.

Short-TE images with either a relatively short TR (T1-weighted) or long TR (proton-density-weighted) are used most frequently to examine the menisci. Because of the image blurring inherent in fast spin-echo images made with a short effective TE, conventional spin-echo imaging may be preferred for the menisci [5,89,90,91]. However, some investigators have used properly optimized fast spin-echo imaging for this purpose [92,93]. 2D and 3D gradient-recalled images can also be used for meniscal disorders [87,94,95,96]. To demonstrate ligament pathology, T2-weighted imaging using conventional or fast (turbo) spin-echo sequences [97,98] or T2\*-weighted gradient-recalled sequences [94,95,96] are most frequently used. Imaging of articular cartilage disorders can be done with many different pulse sequences, including fast spin-echo proton-density-weighted or T2-weighted sequences with or without fat suppression [23, 22,99,100,101], or 3D gradient-recalled sequences [96,102,103,104]. In addition, MR arthrography can be done using T1-weighted spin-echo, fast spin-echo, or gradient-recalled sequences. Spin-echo long-TR images will show advanced abnormalities in the articular cartilage, but are relatively insensitive to lower stages of disease [107,108]. T1-weighted sequences have a role in characterizing marrow abnormalities [110], various stages of hemorrhage [111,112], and muscle pathology [113,114], and for showing enhancement when gadolinium-based contrast agents are used [115].

Suppressing the signal from fat may enhance the diagnostic yield of some pulse sequences [74]. Fat suppression can be performed using spectral suppression of water protons, a phase-dependent method such as the Dixon method, and short-T1 inversion recovery [78,116,117,118,119,120]. The latter two techniques may be necessary on low-field systems. Fat suppression is useful for identifying marrow abnormalities [116,117,119] and may be a useful adjunct when short effective TE (proton-density-weighted) fast spin-echo sequences are used to examine the menisci, ligaments, and articular surfaces of the knee.

Additional imaging techniques may have a role for specific knee disorders. Kinematic examinations performed with varying degrees of active or loaded knee flexion (i.e., movement against resistance) are beneficial for the evaluation of patellofemoral joint abnormalities [52,53,54,55,56,57]. Direct and indirect MR arthrography may be beneficial for various internal knee derangements and for imaging postoperative conditions [19,25,66,69,105,106,121,122].

Various techniques may be used to reduce artifacts that can reduce 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 [123,124]. Truncation (Gibbs) artifacts may obscure or mimic meniscal tears, and can be reduced by changing the phase-encoding direction, or by increasing the imaging matrix [124,125]. Involuntary patient motion is best controlled by ensuring patient comfort combined with gentle immobilization when necessary [74]. Flowing blood can produce ghosting artifacts, which can be reduced with presaturation pulses or the use of gradient moment nulling [124,126]. Chemical shift artifact is more severe at higher field strengths, and may necessitate an increase in the readout bandwidth [116,128]. Susceptibility artifacts, which originate from heterogeneity of the local field, 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 field of view will help reduce the magnitude of susceptibility artifacts [124,127].

For interpretation, the images can be printed on film or viewed on a workstation [129]. If hardcopy viewing is used, some practices may film the images of the menisci a second time, magnified and with narrow window settings, but this can be left to local preferences since there does not appear to be a demonstrable advantage to this practice [130].

It is the responsibility of the supervising physician to determine whether or not additional pulse sequences or unconventional pulse sequences and imaging techniques would confer added benefit for the diagnosis and management of the patient. Examinations that employ techniques not approved by the Food and Drug Administration – such as the intra-articular injection of gadolinium chelates (direct MR arthrography) [131,132,133] – can be considered when they are judged to be medically appropriate.

## V. DOCUMENTATION

Reporting should be in accordance with the [ACR Practice Guideline for Communication of Diagnostic Imaging Findings](#). The report should address the condition of the menisci, major ligaments, articular cartilage, bone marrow, and extensor mechanism. In selected cases, a description of findings in the neurovascular structures, muscles and tendons, synovium, and cortical bone would be appropriate.

## VI. EQUIPMENT SPECIFICATIONS

The MRI equipment specifications and performance shall 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.

## 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 elsewhere in the ACR Practice Guidelines and Technical Standards book.

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 [134,135,136,137]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [134,135,136,137].

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

## ACKNOWLEDGEMENTS

This guideline was developed according to the process described in the ACR Practice Guidelines and Technical Standards book by the Guidelines and Standards Committee of the Commission on Neuroradiology in collaboration with the Society of Skeletal Radiology.

Principal Drafter: David A. Rubin, MD

Society of Skeletal Radiology, Standards Committee

David A. Rubin, MD, Chair

James S. Jelinek, MD

Thomas L. Pope, Jr., MD

Jeffrey D. Towers, MD

ACR Guidelines and Standards Committee

Neuroradiology

Body MRI

Co-Chairs

Suresh K. Mukherji, MD

Jeffrey Brown, MD

John D. Barr, MD

David A. Bluemke, MD

John J. Connors, III, MD

Jerry W. Froelich, MD

John E. Jordan, MD

Michael L. Lipton, MD

Emanuel Kanal, MD

Colin S. Poon, MD, PhD

Stephen A. Kieffer, MD

Donald J. Schnapf, DO

Eric J. Russell, MD

Frank G. Shellock, PhD

Sanjay K. Shetty, MD

Cynthia S. Sherry, MD

Charles L. Truwit, MD

Barry Stein, MD

Patrick A. Turski, MD

Paul T. Weatherall, MD

Robert C. Wallace, MD

Wade H. Wong, DO

William G. Bradley, Jr., MD, Chair, Commission

**REFERENCES**

1. Crues JV III, Mink J, Levy TL, et al. Meniscal tears of the knee: accuracy of MR imaging. *Radiology* 1987;164:445-448.
2. Fischer SP, Fox JM, Del Pizzo W, et al. Accuracy of diagnoses from magnetic resonance imaging of the knee: a multi-center analysis of one thousand and fourteen patients. *J Bone Joint Surg Am* 1991;73:2-10.
3. Mackenzie R, Palmer CR, Lomas DJ, et al. Magnetic resonance imaging of the knee: diagnostic performance studies. *Clin Radiol* 1996;51:251-257.
4. Ryu KN, Kim IS, Kim EJ, et al. MR imaging of tears of discoid lateral menisci. *AJR* 1998;171:963-967.
5. Rubin DA, Paletta GA Jr. Current concepts and controversies in meniscal imaging. *Magn Reson Imaging Clin N Am* 2000;8:243-270.
6. Campbell SE, Sanders TG, Morrison WB. MR imaging of meniscal cysts: incidence, location, and clinical significance. *AJR* 2001;177:409-413.
7. Oei EH, Nikken JJ, Verstijnen AC, et al. MR imaging of the menisci and cruciate ligaments: a systematic review. *Radiology* 2003;226:837-848.
8. Brandser EA, Riley MA, Berbaum KS, et al. MR imaging of anterior cruciate ligament injury: independent value of primary and secondary signs. *AJR* 1996;167:121-126.
9. Spritzer CE, Courneya DL, Burk DL Jr, et al. Medial retinacular complex injury in acute patellar dislocation: MR findings and surgical implications. *AJR* 1997;168:117-122.
10. Ross G, Chapman AW, Newberg AR, et al. Magnetic resonance imaging for evaluation of acute posterolateral complex injuries of the knee. *Am J Sports Med* 1997;25:444-448.
11. Rubin DA, Kettering JM, Towers JD, et al. MR imaging of knees having isolated and combined ligament injuries. *AJR* 1998;170:1207-1213.
12. Lee K, Siegel MJ, Lau DM, et al. Anterior cruciate ligament tears: MR imaging-based diagnosis in a pediatric population. *Radiology* 1999;213:697-704.
13. Zeiss J, Saddemi SR, Ebraheim NA. MR imaging of the quadriceps tendon: normal layered configuration and its importance in cases of tendon rupture. *AJR* 1992;159:1031-1034.
14. Bates DG, Hresko MT, Jaramillo D. Patellar sleeve fracture: demonstration with MR imaging. *Radiology* 1994;193:825-827.
15. Yu JS, Popp JE, Kaeding CC, et al. Correlation of MR imaging and pathologic findings in athletes undergoing surgery for chronic patellar tendinitis. *AJR* 1995;165:115-118.
16. Khan KM, Bonar F, Desmond PM, et al. Patellar tendinosis (jumper's knee): findings at histopathologic examination, US, and MR imaging. *Radiology* 1996;200:821-827.
17. Shalaby M, Almekinders LC. Patellar tendinitis: the significance of magnetic resonance imaging findings. *Am J Sports Med* 1999;27:345-349.
18. Speer KP, Spritzer CE, Goldner JL, et al. Magnetic resonance imaging of traumatic knee articular cartilage injuries. *Am J Sports Med* 1991;19:396-402.
19. Kramer J, Stiglbauer R, Engel A, et al. MR contrast arthrography (MRA) in osteochondrosis dissecans. *J Comput Assist Tomogr* 1992;16:254-260.
20. De Smet AA, Ilahi OA, Graf BK. Reassessment of the MR criteria for stability of osteochondritis dissecans in the knee and ankle. *Skeletal Radiol* 1996;25:159-163.
21. Rubin DA. Magnetic resonance imaging of chondral and osteochondral injuries. *Top Magn Reson Imaging* 1998;9:348-359.
22. Potter HG, Linklater JM, Allen AA, et al. Magnetic resonance imaging of articular cartilage in the knee: an evaluation with use of fast-spin-echo imaging. *J Bone Joint Surg Am* 1998;80:1276-1284.
23. Bredella MA, Tirman PF, Peterfy CG, et al. Accuracy of T2-weighted fast spin-echo MR imaging with fat saturation in detecting cartilage defects in the knee: comparison with arthroscopy in 130 patients. *AJR* 1999;172:1073-1080.
24. Alparslan L, Winalski CS, Boutin RD, et al. Postoperative magnetic resonance imaging of articular cartilage repair. *Semin Musculoskelet Radiol* 2001;5:345-363.
25. Brossmann J, Preidler KW, Daenen B, et al. Imaging of osseous and cartilaginous intraarticular bodies in

- the knee: comparison of MR imaging and MR arthrography with CT and CT arthrography in cadavers. *Radiology* 1996;200:509-517.
26. Forbes JR, Helms CA, Janzen DL. Acute pes anserine bursitis: MR imaging. *Radiology* 1995;194:525-527.
  27. Miller TT, Staron RB, Koenigsberg T, et al. MR imaging of Baker cysts: association with internal derangement, effusion, and degenerative arthropathy. *Radiology* 1996;201:247-250.
  28. Rothstein CP, Laorr A, Helms CA, et al. Semimembranosus-tibial collateral ligament bursitis: MR imaging findings. *AJR* 1996;166:875-877.
  29. Boles CA, Martin DF. Synovial plicae in the knee. *AJR* 2001;177:221-227.
  30. Björkengren AG, AlRowaih A, Lindstrand A, et al. Spontaneous osteonecrosis of the knee: value of MR imaging in determining prognosis. *AJR* 1990;154:331-336.
  31. Lecouvet FE, van de Berg BC, Maldague BE, et al. Early irreversible osteonecrosis versus transient lesions of the femoral condyles: prognostic value of subchondral bone and marrow changes on MR imaging. *AJR* 1998;170:71-77.
  32. Helms CA, Fritz RC, Garvin GJ. Plantaris muscle injury: evaluation with MR imaging. *Radiology* 1995;195:201-203.
  33. Murphey MD, Gross TM, Rosenthal HG, et al. Magnetic resonance imaging of soft tissue and cystic masses about the knee. *Top Magn Reson Imaging* 1993;5:263-282.
  34. Nomikos GC, Murphey MD, Kransdorf MJ, et al. Primary bone tumors of the lower extremities. *Radiol Clin North Am* 2002;40:971-990.
  35. Struk DW, Munk PL, Lee MJ, et al. Imaging of soft tissue infections. *Radiol Clin North Am* 2001;39:277-303.
  36. Kothari NA, Pelchovitz DJ, Meyer JS. Imaging of musculoskeletal infections. *Radiol Clin North Am* 2001;39:653-671.
  37. Pfirrmann CW, Zanetti M, Romero J, et al. Femoral trochlear dysplasia: MR findings. *Radiology* 2000;216:858-864.
  38. Donnelly LF, Emery KH, Do TT. MR imaging of popliteal pterygium syndrome in pediatric patients. *AJR* 2002;178:1281-1284.
  39. Chernoff DM, Walker AT, Khorasani R, et al. Asymptomatic functional popliteal artery entrapment: demonstration at MR imaging. *Radiology* 1995;195:176-180.
  40. Leon J, Marano G. MRI of peroneal nerve entrapment due to a ganglion cyst. *Magn Reson Imaging* 1987;5:307-309.
  41. Björkengren AG, Geborek P, Rydholm U, et al. MR imaging of the knee in acute rheumatoid arthritis: synovial uptake of gadolinium-DOTA. *AJR* 1990;155:329-332.
  42. Kursunoglu-Brahme S, Riccio T, Weisman MH, et al. Rheumatoid knee: role of gadopentetate-enhanced MR imaging. *Radiology* 1990;176:831-835.
  43. Adam G, Dammer M, Bohndorf K, et al. Rheumatoid arthritis of the knee: value of gadopentetate dimeglumine-enhanced MR imaging. *AJR* 1991;156:125-129.
  44. Herve-Somma CM, Sebag GH, Prieur AM, et al. Juvenile rheumatoid arthritis of the knee: MR evaluation with Gd-DOTA. *Radiology* 1992;182:93-98.
  45. Gylys-Morin VM, Graham TB, Blebea JS, et al. Knee in early juvenile rheumatoid arthritis: MR imaging findings. *Radiology* 2001;220:696-706.
  46. Virolainen H, Visuri T, Kuusela T. Acute dislocation of the patella: MR findings. *Radiology* 1993;189:243-246.
  47. Kode L, Lieberman JM, Motta AO, et al. Evaluation of tibial plateau fractures: efficacy of MR imaging compared with CT. *AJR* 1994;163:141-147.
  48. Yu JS, Goodwin D, Salonen D, et al. Complete dislocation of the knee: spectrum of associated soft-tissue injuries depicted by MR imaging. *AJR* 1995;164:135-139.
  49. Maurer EJ, Kaplan PA, Dussault RG, et al. Acutely injured knee: effect of MR imaging on diagnostic and therapeutic decisions. *Radiology* 1997;204:799-805.
  50. McNally EG, Nasser KN, Dawson S, et al. Role of magnetic resonance imaging in the clinical management of the acutely locked knee. *Skeletal Radiol* 2002;31:570-573.
  51. Kirsch MD, Fitzgerald SW, Friedman H, et al. Transient lateral patellar dislocation: diagnosis with MR imaging. *AJR* 1993;161:109-113.
  52. Brossmann J, Muhle C, Schröder C, et al. Patellar tracking patterns during active and passive knee extension: evaluation with motion-triggered cine MR imaging. *Radiology* 1993;187:205-212.
  53. Shellock FG, Mink JH, Deutsch AL, et al. Patellofemoral joint: identification of abnormalities with active-movement, "unloaded" versus "loaded" kinematic MR imaging techniques. *Radiology* 1993;188:575-578.
  54. Brossmann J, Muhle C, Büll CC, et al. Evaluation of patellar tracking in patients with suspected patellar malalignment: cine MR imaging vs arthroscopy. *AJR* 1994;162:361-367.
  55. Shellock FG, Mink JH, Deutsch A, et al. Patellar tracking abnormalities: clinical experience with kinematic MR imaging in 130 patients. *Radiology* 1989;172:799-804.
  56. Shellock FG, Powers CM. *Kinematic MRI of the Joints: Functional Anatomy, Kinesiology, and Clinical Applications*. Boca Raton, Fla: CRC Press; 2001.
  57. Ward SR, Shellock FG, Terk MR, et al. Assessment of patellofemoral relationships using kinematic MRI:

- comparison between qualitative and quantitative methods. *J Magn Reson Imaging* 2002;16:69-74.
58. Ekman EF, Pope T, Martin DF, et al. Magnetic resonance imaging of iliotibial band syndrome. *Am J Sports Med* 1994;22:851-854.
  59. Muhle C, Ahn JM, Yeh L, et al. Iliotibial band friction syndrome: MR imaging findings in 16 patients and MR arthrographic study of six cadaveric knees. *Radiology* 1999;212:103-110.
  60. Ruwe PA, Wright J, Randall RL, et al. Can MR imaging effectively replace diagnostic arthroscopy? *Radiology* 1992;183:335-339.
  61. Spiers AS, Meagher T, Ostlere SJ, et al. Can MRI of the knee affect arthroscopic practice? A prospective study of 58 patients. *J Bone Joint Surg Br* 1993;75:49-52.
  62. Rangger C, Klestil T, Kathrein A, et al. Influence of magnetic resonance imaging on indications for arthroscopy of the knee. *Clin Orthop* 1996;330:133-142.
  63. Bui-Mansfield LT, Youngberg RA, Warme W, et al. Potential cost savings of MR imaging obtained before arthroscopy of the knee: evaluation of 50 consecutive patients. *AJR* 1997;168:913-918.
  64. Carmichael IW, MacLeod AM, Travlos J. MRI can prevent unnecessary arthroscopy. *J Bone Joint Surg Br* 1997;79:624-625.
  65. Vincken PW, ter Braak BP, van Erckel AR, et al. Effectiveness of MR imaging in selection of patients for arthroscopy of the knee. *Radiology* 2002;223:739-746.
  66. Applegate GR, Flannigan BD, Tolin BS, et al. MR diagnosis of recurrent tears in the knee: value of intraarticular contrast material. *AJR* 1993;161:821-825.
  67. Recht MP, Piraino DW, Applegate G, et al. Complications after anterior cruciate ligament reconstruction: radiographic and MR findings. *AJR* 1996;167:705-710.
  68. Lim PS, Schweitzer ME, Bhatia M, et al. Repeat tear of postoperative meniscus: potential MR imaging signs. *Radiology* 1999;210:183-188.
  69. Sciulli RL, Boutin RD, Brown RR, et al. Evaluation of the postoperative meniscus of the knee: a study comparing conventional arthrography, conventional MR imaging, MR arthrography with iodinated contrast material, and MR arthrography with gadolinium-based contrast material. *Skeletal Radiol* 1999;28:508-514.
  70. Bradley DM, Bergman AG, Dillingham MF. MR imaging of cyclops lesions. *AJR* 2000;174:719-726.
  71. Horton LK, Jacobson JA, Lin J, et al. MR imaging of anterior cruciate ligament reconstruction graft. *AJR* 2000;175:1091-1097.
  72. Barnett MJ. MR diagnosis of internal derangements of the knee: effect of field strength on efficacy. *AJR* 1993;161:115-118.
  73. Franklin PD, Lemon RA, Barden HS. Accuracy of imaging the menisci on an in-office, dedicated, magnetic resonance imaging extremity system. *Am J Sports Med* 1997;25:382-388.
  74. Rubin DA, Kneeland JB. MR imaging of the musculoskeletal system: technical considerations for enhancing image quality and diagnostic yield. *AJR* 1994;163:1155-1163.
  75. Rothschild PA, Domesek JM, Kaufman L, et al. MR imaging of the knee with a 0.064-T permanent magnet. *Radiology* 1990;175:775-778.
  76. Erickson SJ. High resolution imaging of the musculoskeletal system. *Radiology* 1997;205:593-618.
  77. Cotten A, Delfaut E, Demondion X, et al. MR imaging of the knee at 0.2 and 1.5 T: correlation with surgery. *AJR* 2000;174:1093-1097.
  78. Bredella MA, Losasso C, Moellenken SC, et al. Three-point Dixon chemical-shift imaging for evaluating articular cartilage defects in the knee joint on a low-field-strength open magnet. *AJR* 2001;177:1371-1375.
  79. Woertler K, Strothmann M, Tombach B, et al. Detection of articular cartilage lesions: experimental evaluation of low- and high-field-strength MR imaging at 0.18 and 1.0 T. *J Magn Reson Imaging* 2000;11:678-685.
  80. Rubenstein JD, Li JG, Majumdar S, et al. Image resolution and signal-to-noise ratio requirements for MR imaging of degenerative cartilage. *AJR* 1997;169:1089-1096.
  81. Kladny B, Gluckert K, Swoboda B, et al. Comparison of low-field (0.2 Tesla) and high-field (1.5 Tesla) magnetic resonance imaging of the knee joint. *Arch Orthop Trauma Surg* 1995;114:281-286.
  82. Kinnunen J, Bondestam S, Kivioja A, et al. Diagnostic performance of low field MRI in acute knee injuries. *Magn Reson Imaging* 1994;12:1155-1160.
  83. Vellet AD, Lee DH, Munk PL, et al. Anterior cruciate ligament tear: prospective evaluation of diagnostic accuracy of middle- and high-field-strength MR imaging at 1.5 and 0.5 T. *Radiology* 1995;197:826-830.
  84. Fitzgerald SW, Remer EM, Friedman H, et al. MR evaluation of the anterior cruciate ligament: value of supplementing sagittal images with coronal and axial images. *AJR* 1993;160:1233-1237.
  85. Buckwalter KA, Pennes DR. Anterior cruciate ligament: oblique sagittal MR imaging. *Radiology* 1990;175:276-277.
  86. Yu JS, Salonen DC, Hodler J, et al. Posterolateral aspect of the knee: improved MR imaging with a coronal oblique technique. *Radiology* 1996;198:199-204.
  87. Quinn SF, Brown TR, Szumowski J. Menisci of the knee: radial MR imaging correlated with arthroscopy in 259 patients. *Radiology* 1992;185:577-580.

88. Kneeland JB, Shimakawa A, Wehrli FW. Effect of intersection spacing on MR image contrast and study time. *Radiology* 1986;158:819-822.
89. Rubin DA, Kneeland JB, Listerud J, et al. MR diagnosis of meniscal tears of the knee: value of fast spin-echo vs conventional spin-echo pulse sequences. *AJR* 1994;162:1131-1135.
90. Anderson MW, Raghavan N, Seidenwurm DJ, et al. Evaluation of meniscal tears: fast spin-echo versus conventional spin-echo magnetic resonance imaging. *Acad Radiol* 1995;2:209-214.
91. White LM, Schweitzer ME, Johnson WJ, et al. The role of T2-weighted fast-spin-echo imaging in the diagnosis of meniscal tears. *J Magn Reson Imaging* 1996;6:874-877.
92. Escobedo EM, Hunter JC, Zink-Brody GC, et al. Usefulness of turbo spin-echo MR imaging in the evaluation of meniscal tears: comparison with a conventional spin-echo sequence. *AJR* 1996;167:1223-1227.
93. Cheung LP, Li KC, Hollett MD, et al. Meniscal tears of the knee: accuracy of detection with fast spin-echo MR imaging and arthroscopic correlation in 293 patients. *Radiology* 1997;203:508-512.
94. Tyrrell RL, Gluckert K, Pathria M, et al. Fast three-dimensional MR imaging of the knee: comparison with arthroscopy. *Radiology* 1988;166:865-872.
95. Reeder JD, Matz SO, Becker L, et al. MR imaging of the knee in the sagittal projection: comparison of three-dimensional gradient-echo and spin-echo sequences. *AJR* 1989;153:537-540.
96. Heron CW, Calvert PT. Three-dimensional gradient-echo MR imaging of the knee: comparison with arthroscopy in 100 patients. *Radiology* 1992;183:839-844.
97. Mink JH, Levy T, Crues JV 3rd. Tears of the anterior cruciate ligament and menisci of the knee: MR imaging evaluation. *Radiology* 1988;167:769-774.
98. Ha TP, Li KC, Beaulieu CF, et al. Anterior cruciate ligament injury: fast spin-echo MR imaging with arthroscopic correlation in 217 examinations. *AJR* 1998;170:1215-1219.
99. Broderick LS, Turner DA, Renfrew DL, et al. Severity of articular cartilage abnormality in patients with osteoarthritis: evaluation with fast spin-echo MR vs. arthroscopy. *AJR* 1994;162:99-103.
100. Kojima KY, Demlow TA, Szumowski J, et al. Coronal fat suppression fast spin echo images of the knee: evaluation of 202 patients with arthroscopic correlation. *Magn Reson Imaging* 1996;14:1017-1022.
101. Sonin AH, Pensy RA, Mulligan ME, et al. Grading articular cartilage of the knee using fast spin-echo proton density-weighted MR imaging without fat suppression. *AJR* 2002;179:1159-1166.
102. Recht MP, Kramer J, Marcelis S, et al. Abnormalities of articular cartilage in the knee: analysis of available MR techniques. *Radiology* 1993;187:473-478.
103. Recht MP, Piraino DW, Paletta GA, et al. Accuracy of fat-suppressed three-dimensional spoiled gradient-echo FLASH MR imaging in the detection of patellofemoral articular cartilage abnormalities. *Radiology* 1996;198:209-212.
104. Disler DG, McCauley TR, Kelman CG, et al. Fat-suppressed three-dimensional spoiled gradient-echo MR imaging of hyaline cartilage defects in the knee: comparison with standard MR imaging and arthroscopy. *AJR* 1996;167:127-132.
105. Gagliardi JA, Chung EM, Chandrani VP, et al. Detection and staging of chondromalacia patellae: relative efficacies of conventional MR imaging, MR arthrography, and CT arthrography. *AJR* 1994;163:629-636.
106. Kramer J, Recht MP, Imhof H, et al. Postcontrast MR arthrography in assessment of cartilage lesions. *J Comput Assist Tomogr* 1994;18:218-224.
107. McCauley TR, Kier R, Lynch KJ, et al. Chondromalacia patellae: diagnosis with MR imaging. *AJR* 1992;158:101-105.
108. Brown TR, Quinn AF. Evaluation of chondromalacia of the patellofemoral compartment with axial magnetic resonance imaging. *Skeletal Radiol* 1993;22:325-328.
109. Beltran J, Shankman S. Magnetic resonance imaging of bone marrow disorders of the knee. *Magn Reson Imaging Clin N Am* 1994;2:463-473.
110. Vande Berg BC, Malghem J, Lecouvet FE, et al. Classification and detection of bone marrow lesions with magnetic resonance imaging. *Skeletal Radiol* 1998;27:529-545.
111. De Smet AA, Fisher DR, Heiner JP, et al. Magnetic resonance imaging of muscle tears. *Skeletal Radiol* 1990;19:283-286.
112. Bush CH. The magnetic resonance imaging of musculoskeletal hemorrhage. *Skeletal Radiol* 2000;29:1-9.
113. De Smet AA. Magnetic resonance findings in skeletal muscle tears. *Skeletal Radiol* 1993;22:479-484.
114. Nguyen B, Brandser E, Rubin DA. Pains, strains, and fasciculations: lower extremity muscle disorders. *Magn Reson Imaging Clin N Am* 2000;8:391-408.
115. Wolf GL, Joseph PM, Goldstein EJ. Optimal pulsing sequences for MR contrast agents. *AJR* 1986;147:367-371.
116. Harned EM, Mitchell DG, Burk DL Jr, et al. Bone marrow findings on magnetic resonance images of the knee: accentuation by fat suppression. *Magn Reson Imaging* 1990;8:27-31.
117. Kapelov SR, Teresi LM, Bradley WG, et al. Bone contusions of the knee: increased lesion detection with fast spin-echo MR imaging with spectroscopic fat saturation. *Radiology* 1993;189:901-904.

118. Weinberger E, Shaw DW, White KS, et al. Nontraumatic pediatric musculoskeletal MR imaging: comparison of conventional and fast-spin-echo short inversion time inversion-recovery technique. *Radiology* 1995;194:721-726.
119. Arndt WF III, Truax AL, Barnett FM, et al. MR diagnosis of bone contusions of the knee: comparison of coronal T2-weighted fast spin-echo with fat saturation and fast spin-echo STIR images with conventional STIR images. *AJR* 1996;166:119-124.
120. Rybicki FJ, Chung T, Reid J, et al. Fast three-point Dixon MR imaging using low-resolution images for phase correction: a comparison with chemical shift selective fat suppression for pediatric musculoskeletal imaging. *AJR* 2001;177:1019-1023.
121. Vahlensieck M, Peterfy CG, Wischer T, et al. Indirect MR arthrography: optimization and clinical applications. *Radiology* 1996;200:249-254.
122. Winalski CS, Aliabadi P, Wright RJ, et al. Enhancement of joint fluid with intravenously administered gadopentetate dimeglumine: technique, rationale, and implications. *Radiology* 1993;187:179-185.
123. Van Hecke PE, Marchal GJ, Baert AL. Use of shielding to prevent folding in MR imaging. *Radiology* 1988;167:557-558.
124. Peh WC, Chan JH. Artifacts in musculoskeletal magnetic resonance imaging: identification and correction. *Skeletal Radiol* 2001;30:179-191.
125. Turner DA, Rapoport MI, Erwin WD, et al. Truncation artifact: a potential pitfall in MR imaging of the menisci of the knee. *Radiology* 1991;179:629-633.
126. Haacke EM, Lenz GW. Improving MR image quality in the presence of motion by using rephrasing gradients. *AJR* 1987;148:1251-1258.
127. Mirowitz SA. Fast scanning and fat-suppression MR imaging of musculoskeletal disorders. *AJR* 1993;161:1147-1157.
128. Runge VM. Safety of MR contrast agents. In: Shellock, FG, ed. *Magnetic Resonance Procedures: Health Effects and Safety*. Boca Raton, Fla: CRC Press; 2001.
129. Brown JJ, Malchow SC, Totty WG, et al. MR examination of the knee: interpretation with multiscreen digital workstation vs. hardcopy format. *AJR* 1991;157:81-85.
130. Buckwalter KA, Braunstein EM, Janizek DB, et al. MR imaging of meniscal tears: narrow versus conventional window width photography. *Radiology* 1993;187:827-830.
131. Magee T, Shapiro M, Rodriguez J, et al. MR arthrography of postoperative knee: for which patients is it useful? *Radiology* 2003;229:159-163.
132. Schulte-Altendorneburg G, Gebhard M, Wohlgemuth WA, et al. MR arthrography: pharmacology, efficacy, and safety in clinical trials. *Skeletal Radiol* 2003;32:1-12.
133. Haims AH, Katz LD, Ruwe PA. MR arthrography of the knee. *Semin Musculoskelet Radiol* 1998;2:385-396.
134. Shellock FG, Crues JV. MR procedures: biologic effects, safety, and patient care. *Radiology* 2004;232:635-652.
135. Shellock FG. *Guide to MR Procedures and Metallic Objects: Update 2001*. 7th edition. Philadelphia, Pa: Lippincott Williams and Wilkins; 2001.
136. Shellock FG. *Reference Manual for Magnetic Resonance Safety, Implants, and Devices*. 2005 edition. Los Angeles, Calif: Biomedical Research Publishing Group; 2005.
137. Sawyer-Glover AM, Shellock FG. Pre-MRI procedure screening: recommendations and safety considerations for biomedical implants and devices. *J Magn Reson Imaging* 2000;12:92-106.

---

\*Guidelines and 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 guidelines and standards published before 1999, the effective date was January 1 following the year in which the guideline or standard was amended, revised, or approved by the ACR Council.

Development Chronology for this Guideline

2005 (Resolution 9)

Amended 2006 (Resolution 35)