

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

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## 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<sup>1</sup>. 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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<sup>1</sup> *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 with radiographs. With multiplanar reformatting capabilities, CT can be helpful to demonstrate radiographically occult fracture or osseous intra-articular bodies within the joint [1]. Dual-energy CT techniques have been used in evaluation for crystalline arthropathy, such as gout [2]. CT arthrography can be used to diagnose an internal derangement in patients who cannot undergo MRI. Ultrasound can evaluate the extra-articular soft tissues around the knee, including tendons and bursae, assess for joint effusion, and diagnose synovitis [1].

In children, who often have an abundance of unossified growth cartilage and periarticular soft tissues that can limit clinical assessment, ultrasound is helpful to confirm or exclude a 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 examinations have a role for specific clinical scenarios (eg, a labeled white blood cell study or Positron Emission Tomography (PET)/CT for suspected osteomyelitis).

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: intrameniscal signal alterations, meniscal and meniscal root tears, discoid menisci, meniscocapsular tears, meniscal cysts, and evaluation of the postoperative meniscus<sup>3</sup> [3-11]
2. Ligament abnormalities: cruciate and collateral sprains and tears; ligament evaluation following ligament repair or reconstruction<sup>3</sup> [12-17]
3. Extensor mechanism abnormalities: quadriceps and patellar tendon degeneration, partial and complete tears; patellar and tibial tubercle stress injuries and fractures; and retinacular sprains and tears [18-22]
4. Osteochondral abnormalities: osteochondral fractures, osteochondral lesions, and treated osteochondral defects<sup>3</sup> [23-25]
5. Articular cartilage abnormalities: cartilage fissures, partial and full thickness cartilage loss, cartilage delamination, chondral flaps, and separations; post-operative evaluation of cartilage procedures<sup>3</sup> [26-33]
6. Abnormalities of intra-articular fat pads: Hoffa syndrome, patellar and quadriceps impingement, prefemoral fat pad [34].
7. Synovial-based and joint-based disorders: synovitis, bursitis, symptomatic plicae<sup>†</sup>, intra-articular bodies, and popliteal cysts<sup>2</sup> [35-38]
8. Osseous abnormalities: osteonecrosis, marrow edema patterns or lesions, stress fractures, radiographically occult fractures, physeal and transphyseal injuries, and transphyseal osseous and nonosseous tethering<sup>2</sup> [39-42]
9. Muscle and tendon disorders: strains, partial and complete tears, tendonitis, tendinopathy, inflammation, and ischemia [43, 44]. Iliotibial band friction syndrome [35, 45]
10. Iliotibial band friction syndrome Infections of bone, cartilage, joint, or soft tissue<sup>2</sup> [46, 47]
11. Congenital and developmental conditions: Blount disease, dysplasia, normal variants<sup>2</sup>
12. Vascular conditions: popliteal artery entrapment, aneurysm, stenosis, occlusion, cystic adventitial disease<sup>2</sup>
13. Neurologic conditions: common peroneal or tibial nerve traumatic injury, entrapment, compression injury, denervation, and peripheral neuropathy<sup>2</sup> [48]

14. Evaluation of knee following arthroscopy: Meniscal repair, Partial meniscectomy, ligament reconstruction/repair
15. Patients with selected complications following knee arthroplasty [49, 50] using appropriate metal artifact reduction strategies [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, posttraumatic<sup>2</sup> [51-55]
2. Primary and secondary bone and soft-tissue tumors<sup>2</sup> [56, 57]
3. Fractures and dislocations [58-60]

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 [61]
2. Acute knee trauma [62]
3. Mechanical knee symptoms: catching, differentiating a stiff versus a locked knee (fixed extension block), painful range of motion, snapping, crepitus<sup>3</sup> [63, 64]
4. Patellofemoral instability (acute, subacute, chronic, or recurrent subluxations and/or dislocations): malalignment or maltracking [59, 60, 65-67]
5. Tibiofemoral instability or malalignment [68-70]
6. Swelling, palpable enlargement, mass, or atrophy<sup>2</sup>
7. Patients for whom diagnostic or therapeutic arthroscopy is planned<sup>3</sup> [61, 71-76]
8. Patients with recurrent, residual, or new symptoms following knee surgery<sup>3</sup> [10, 13, 14, 27, 77-81]

<sup>2</sup> Conditions in which intravenous (IV) contrast may be useful.

<sup>3</sup> Conditions in which intra-articular contrast (performed by direct intra-articular injection or indirect joint opacification following IV administration) may be useful.

### III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the [ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging \(MRI\)](#) [82].

### 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 adequate 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.

#### **IV. SPECIFICATIONS OF THE EXAMINATION**

##### **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 before the examination to exclude individuals who may have contraindication to MRI, in which the risks may outweigh the benefits.

Certain indications require administration of 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](#) [83]).

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 Minimal and/or Moderate Sedation/Analgesia](#) [84].

#### **IV. SPECIFICATIONS OF THE EXAMINATION**

##### **B. Facility Requirements**

Appropriate emergency equipment and medications must be immediately available to treat adverse reactions associated with administered medications. The equipment and medications should be 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.

#### **IV. SPECIFICATIONS OF THE EXAMINATION**

##### **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, 85, 86]. Regardless of magnet design, a local coil surrounding the knee is mandatory to maximize signal-to-noise ratio (SNR). Multichannel knee coils or flexible surface coils containing 8 or more coil elements are required when using techniques like parallel imaging, which can be used to increase spatial resolution and/or decrease the time of the scan [87]. Occasionally, a very large extremity may require a slightly larger coil, but every attempt should be made to ensure that the size of the coil closely matches that of the knee circumference [88]. 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, number of acquisitions, or postprocessing algorithms, may be needed to ensure adequate spatial and contrast resolution for confident diagnoses. [89-91]. It may also be more difficult to achieve uniform chemical fat suppression on low-field-strength systems, necessitating the use of Dixon [92] 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 may be of lower quality compared with those acquired on a high-field system [86, 92-96].

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 [97, 98]. 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 or anterior cruciate ligament [99, 100]. The coverage should include all the anterior, posterior, medial, and lateral supporting structures of the knee, although 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 and distal insertion of the medial collateral ligament should be included inferiorly [101].

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. Three-dimensional sequences with near isotropic voxels allow for multiplanar reconstructions from a single acquisition [102-104].

Knee MRI uses a wide variety of pulse sequences [88]. 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. Two-dimensional and 3-D gradient-recalled images can also demonstrate meniscal disorders [101, 102, 104]. To show ligament pathology, water-sensitive images obtained using conventional or FSE long-TE sequences [105, 106] or T2\*-weighted gradient-recalled sequences [104] may be used. Including at least one plane of T1-weighted sequences is useful for characterizing marrow abnormalities [107], various stages of hemorrhage [108], bone and soft tissue tumors, and muscle pathology [43, 44]. Additionally, T1-weighted images (often with fat suppression) are used after IV administration of gadolinium-based contrast agents to show tissue enhancement [109].

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, 110, 111], 3-D gradient-recalled sequences, or 3-D FSE sequences [104, 112-114]. 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 [115-117] that selectively excite water protons [118, 119] or that average 2 separate echoes to increase T2 weighting [120, 121]. In contrast with 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 before irreversible damage [32, 33].

In skeletally immature children, especially with a history of knee trauma that involved the physis, physal imaging should be performed. This can be done with a 3-D fat-suppressed spoiled gradient-recalled echo sequence [41, 42]. 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 [122], especially following articular cartilage transplantation [119], or on low-field systems where many of the newer sequences are not available [123]. IV contrast-enhanced MRI is typically recommended

for the diagnosis of isolated cartilaginous infection in infants and young children. This is because the focus of infection (*Staphylococcus aureus*) and the surrounding cartilage often have similar signal intensity, which can hinder its detection on unenhanced MRI sequences [113].

Suppressing the signal from fat may enhance the diagnostic yield of some pulse sequences [88]. Fat suppression techniques include spectral suppression of water protons, a phase-dependent method, such as the Dixon method or STIR [92, 124-128]. The latter 2 techniques may be necessary on low-field systems. Methods also exist for generating separate water and lipid images [115-117] or for selectively exciting water protons, which essentially nulls the contribution of fat in the final images [118, 119]. Fat suppression is useful for identifying marrow abnormalities [124, 125] and may be a useful adjunct when performing MR arthrography [14, 79] or when FSE sequences are used to examine the menisci, ligaments, and articular surfaces of the knee [26, 110, 127].

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 [129]. Reduced sampling of k-space using parallel imaging, compressed sensing, and machine-learning acceleration techniques can decrease acquisition times for individual pulse sequences [87, 103, 116, 130, 131]. 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 [102, 103, 117]. 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 [132].

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, 78, 79, 122, 133]. 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 [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 [88]. 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 [5, 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, 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 [78, 140, 141]. Vendor specific pulse sequences have been developed which can further reduce metal artifacts [142-144]. The term "metal artifact reduction sequences" 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 techniques should be avoided [141, 145].

It is the responsibility of the supervising physician to determine whether additional or specialized 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 FDA, such as the intra-articular injection of gadolinium chelates (direct MR arthrography) [146-148], 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](#) [149].

The report should address the condition of the menisci, major ligaments, articular cartilage, osseous structures, extensor mechanism, neurovascular structures, muscles, tendons, synovium, and bones.

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 [150-153]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [150-153].

For additional recommendations on safety, see the [ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging \(MRI\)](#) [82], the [ACR Manual on MR Safety](#) [154], and the [ACR Manual on Contrast Media](#) [155].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [151, 152].

## VI. EQUIPMENT SPECIFICATIONS

Equipment monitoring should be in accordance with the [ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging \(MR\) Imaging Equipment](#) [132].

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.

## 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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### **REFERENCES**

1. Terslev L, Naredo E, Aegerter P, et al. Scoring ultrasound synovitis in rheumatoid arthritis: a EULAR-OMERACT ultrasound taskforce-Part 2: reliability and application to multiple joints of a standardised consensus-based

scoring system. *RMD Open*. 2017;3(1):e000427.

2. Nicolaou S, Liang T, Murphy DT, Korzan JR, Ouellette H, Munk P. Dual-energy CT: a promising new technique for assessment of the musculoskeletal system. *AJR Am J Roentgenol*. 199(5 Suppl):S78-86, 2012 Nov.
3. Campbell SE, Sanders TG, Morrison WB. MR imaging of meniscal cysts: incidence, location, and clinical significance. *AJR Am J Roentgenol*. 2001 Aug;177(2):409-13.
4. Lim PS, Schweitzer ME, Bhatia M, et al. Repeat tear of postoperative meniscus: potential MR imaging signs. *Radiology*. 1999 Jan;210(1):183-8.
5. Magee T, Williams D. 3.0-T MRI of meniscal tears. *AJR Am J Roentgenol*. 2006;187(2):371-375.
6. Oei EH, Nikken JJ, Verstijnen AC, Ginai AZ, Myriam Hunink MG. MR imaging of the menisci and cruciate ligaments: a systematic review. *Radiology*. 2003 Mar;226(3):837-48.
7. Ramnath RR, Magee T, Wasudev N, Murrar R. Accuracy of 3-T MRI using fast spin-echo technique to detect meniscal tears of the knee. *AJR Am J Roentgenol*. 2006 Jul;187(1):221-5.
8. Rubin DA, Paletta GA. Current concepts and controversies in meniscal imaging. *Magn Reson Imaging Clin N Am*. 2000 May;8(2):243-70.
9. Ryu KN, Kim IS, Kim EJ, et al. MR imaging of tears of discoid lateral menisci. *AJR Am J Roentgenol*. 1998 Oct;171(4):963-7.
10. 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 Sep;28(9):508-14.
11. Faruch-Bilfeld M, Lapegue F, Chiavassa H, Sans N. Imaging of meniscus and ligament injuries of the knee. *Diagn Interv Imaging*. 2016;97(7-8):S2211-5684(16)30152-8.
12. Brandser EA, Riley MA, Berbaum KS, el-Khoury GY, Bennett DL. MR imaging of anterior cruciate ligament injury: independent value of primary and secondary signs. *AJR Am J Roentgenol*. 1996 Jul;167(1):121-6.
13. Horton LK, Jacobson JA, Lin J, Hayes CW. MR imaging of anterior cruciate ligament reconstruction graft. *AJR Am J Roentgenol*. 2000 Oct;175(4):1091-7.
14. McCauley TR, Elfar A, Moore A, et al. MR arthrography of anterior cruciate ligament reconstruction grafts. *AJR Am J Roentgenol*. 2003 Nov;181(5):1217-23.
15. Ross G, Chapman AW, Newberg AR, Scheller AD. Magnetic resonance imaging for the evaluation of acute posterolateral complex injuries of the knee. *Am J Sports Med*. 1997;25(4):444-8.
16. Rubin DA, Kettering JM, Towers JD, Britton CA. MR imaging of knees having isolated and combined ligament injuries. *AJR Am J Roentgenol*. 1998 May;170(5):1207-13.
17. Lee JE, Park HJ, Lee SY, Ahn JH, Park JH, Park JY. Evaluation of Selective Bundle Injury to the Anterior Cruciate Ligament: T2-Weighted Fast Spin-Echo 3-T MRI With Reformatted 3D Oblique Isotropic (VISTA) Versus 2D Technique. *AJR. American Journal of Roentgenology*. 209(5):W308-W316, 2017 Nov.
18. Bates DG, Hresko MT, Jaramillo D. Patellar sleeve fracture: demonstration with MR imaging. *Radiology*. 1994 Dec;193(3):825-7.
19. Khan KM, Bonar F, Desmond PM, et al. Patellar tendinosis (jumper's knee): findings at histopathologic examination, US, and MR imaging. *Victorian Institute of Sport Tendon Study Group. Radiology*. 1996 Sep;200(3):821-7.
20. Shalaby M, Almekinders LC. Patellar tendinitis: the significance of magnetic resonance imaging findings. *Am J Sports Med*. 1999;27(3):345-9.
21. Spritzer CE, Courneya DL, Burk DL, Garrett WE, Strong JA. Medial retinacular complex injury in acute patellar dislocation: MR findings and surgical implications. *AJR Am J Roentgenol*. 1997 Jan;168(1):117-22.
22. Zeiss J, Saddemi SR, Ebraheim NA. MR imaging of the quadriceps tendon: normal layered configuration and its importance in cases of tendon rupture. *AJR Am J Roentgenol*. 1992 Nov;159(5):1031-4.
23. 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(2):159-163.
24. Kramer J, Stiglbauer R, Engel A, Prayer L, Imhof H. MR contrast arthrography (MRA) in osteochondrosis dissecans. *J Comput Assist Tomogr*. 1992;16(2):254-60.
25. Nizak R, Bekkers J, de Jong PA, Witkamp T, Luijckx T, Saris D. Osteochondral lesion depth on MRI can help predict the need for a sandwich procedure. *Eur J Radiol*. 2017 May;90():S0720-048X(17)30107-9.
26. 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 Am J Roentgenol*. 1999 Apr;172(4):1073-80.
27. Potter HG, Foo LF. Magnetic resonance imaging of articular cartilage: trauma, degeneration, and repair. *Am J Sports Med*. 2006 Apr;34(4):661-77.

- 28.** Potter HG, Linklater JM, Allen AA, Hannafin JA, Haas SB. Magnetic resonance imaging of articular cartilage in the knee. An evaluation with use of fast-spin-echo imaging. *J Bone Joint Surg Am.* 1998 Sep;80(9):1276-84.
- 29.** Recht MP, Goodwin DW, Winalski CS, White LM. MRI of articular cartilage: revisiting current status and future directions. *AJR Am J Roentgenol.* 2005 Oct;185(4):899-914.
- 30.** Rubin DA. Magnetic resonance imaging of chondral and osteochondral injuries. *Top Magn Reson Imaging.* 1998 Dec;9(6):348-59.
- 31.** Lee YH, Hahn S, Lim D, Suh JS. Articular cartilage grading of the knee: diagnostic performance of fat-suppressed 3D volume isotropic turbo spin-echo acquisition (VISTA) compared with 3D T1 high-resolution isovolumetric examination (THRIVE). *Acta Radiol.* 2017 Feb;58(2):190-196.
- 32.** Tadenuma T, Uchio Y, Kumahashi N, et al. Delayed gadolinium-enhanced MRI of cartilage and T2 mapping for evaluation of reparative cartilage-like tissue after autologous chondrocyte implantation associated with Atelocollagen-based scaffold in the knee. *Skeletal Radiol.* 2016 Oct;45(10):1357-63.
- 33.** van Tiel J, Kotek G, Reijman M, et al. Is T1rho Mapping an Alternative to Delayed Gadolinium-enhanced MR Imaging of Cartilage in the Assessment of Sulphated Glycosaminoglycan Content in Human Osteoarthritic Knees? An in Vivo Validation Study. *Radiology.* 279(2):523-31, 2016 May.
- 34.** 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.* 200(2):509-17, 1996 Aug.
- 35.** Boles CA, Martin DF. Synovial plicae in the knee. *AJR Am J Roentgenol.* 2001 Jul;177(1):221-7.
- 36.** Forbes JR, Helms CA, Janzen DL. Acute pes anserine bursitis: MR imaging. *Radiology.* 1995 Feb;194(2):525-7.
- 37.** Miller TT, Staron RB, Koenigsberg T, Levin TL, Feldman F. MR imaging of Baker cysts: association with internal derangement, effusion, and degenerative arthropathy. *Radiology.* 1996 Oct;201(1):247-50.
- 38.** Rothstein CP, Laorr A, Helms CA, Tirman PF. Semimembranosus-tibial collateral ligament bursitis: MR imaging findings. *AJR Am J Roentgenol.* 1996 Apr;166(4):875-7.
- 39.** Björkengren AG, AlRowaih A, Lindstrand A, Wingstrand H, Thorngren KG, Pettersson H. Spontaneous osteonecrosis of the knee: value of MR imaging in determining prognosis. *AJR Am J Roentgenol.* 1990 Feb;154(2):331-6.
- 40.** 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 Am J Roentgenol.* 1998 Jan;170(1):71-7.
- 41.** Ecklund K, Jaramillo D. Patterns of premature physal arrest: MR imaging of 111 children. *AJR Am J Roentgenol.* 2002 Apr;178(4):967-72.
- 42.** Shailam R, Jaramillo D, Kan JH. Growth arrest and leg-length discrepancy. [Review]. *Pediatric Radiology.* 43 Suppl 1:S155-65, 2013 Mar.
- 43.** De Smet AA. Magnetic resonance findings in skeletal muscle tears. *Skeletal Radiol.* 1993 Oct;22(7):479-84.
- 44.** Nguyen B, Brandser E, Rubin DA. Pains, strains, and fasciculations: lower extremity muscle disorders. *Magn Reson Imaging Clin N Am.* 2000 May;8(2):391-408.
- 45.** Subhawong TK, Eng J, Carrino JA, Chhabra A. Superolateral Hoffa's fat pad edema: association with patellofemoral maltracking and impingement. *AJR Am J Roentgenol.* 2010 Dec;195(6):1367-73.
- 46.** Kothari NA, Pelchovitz DJ, Meyer JS. Imaging of musculoskeletal infections. *Radiol Clin North Am.* 2001 Jul;39(4):653-71.
- 47.** Struk DW, Munk PL, Lee MJ, Ho SG, Worsley DF. Imaging of soft tissue infections. *Radiol Clin North Am.* 2001 Mar;39(2):277-303.
- 48.** Leon J, Marano G. MRI of peroneal nerve entrapment due to a ganglion cyst. *Magn Reson Imaging.* 1987;5(4):307-9.
- 49.** Hai Z, Guangrui S, Yuan Z, et al. CT angiography and MRI in patients with popliteal artery entrapment syndrome. *AJR Am J Roentgenol.* 2008 Dec;191(6):1760-6.
- 50.** Kim HK, Shin MJ, Kim SM, Lee SH, Hong HJ. Popliteal artery entrapment syndrome: morphological classification utilizing MR imaging. *Skeletal Radiol.* 2006 Sep;35(9):648-58.
- 51.** Adam G, Dammer M, Bohndorf K, Christoph R, Fenke F, Günther RW. Rheumatoid arthritis of the knee: value of gadopentetate dimeglumine-enhanced MR imaging. *AJR Am J Roentgenol.* 1991 Jan;156(1):125-9.
- 52.** Björkengren AG, Geborek P, Rydholm U, Holtås S, Petterson H. MR imaging of the knee in acute rheumatoid arthritis: synovial uptake of gadolinium-DOTA. *AJR Am J Roentgenol.* 1990 Aug;155(2):329-32.
- 53.** Gylys-Morin VM, Graham TB, Blebea JS, et al. Knee in early juvenile rheumatoid arthritis: MR imaging findings. *Radiology.* 2001 Sep;220(3):696-706.
- 54.** Hervé-Somma CM, Sebag GH, Prieur AM, Bonnerot V, Lallemand DP. Juvenile rheumatoid arthritis of the knee:

MR evaluation with Gd-DOTA. *Radiology*. 1992 Jan;182(1):93-8.

55. Kursunoglu-Brahme S, Riccio T, Weisman MH, et al. Rheumatoid knee: role of gadopentetate-enhanced MR imaging. *Radiology*. 1990;176(3):831-835.
56. Murphey MD, Gross TM, Rosenthal HG, Neff JR. Magnetic resonance imaging of soft tissue and cystic masses about the knee. *Top Magn Reson Imaging*. 1993;5(4):263-82.
57. Nomikos GC, Murphey MD, Kransdorf MJ, Bancroft LW, Peterson JJ. Primary bone tumors of the lower extremities. *Radiol Clin North Am*. 2002 Sep;40(5):971-90.
58. Kode L, Lieberman JM, Motta AO, Wilber JH, Vasen A, Yagan R. Evaluation of tibial plateau fractures: efficacy of MR imaging compared with CT. *AJR Am J Roentgenol*. 1994 Jul;163(1):141-7.
59. Virolainen H, Visuri T, Kuusela T. Acute dislocation of the patella: MR findings. *Radiology*. 1993 Oct;189(1):243-6.
60. Yu JS, Goodwin D, Salonen D, et al. Complete dislocation of the knee: spectrum of associated soft-tissue injuries depicted by MR imaging. *AJR Am J Roentgenol*. 1995 Jan;164(1):135-9.
61. Vincken PW, ter Braak AP, van Erkel AR, et al. MR imaging: effectiveness and costs at triage of patients with nonacute knee symptoms. *Radiology*. 2007; 242(1):85-93.
62. Maurer EJ, Kaplan PA, Dussault RG, et al. Acutely injured knee: effect of MR imaging on diagnostic and therapeutic decisions. *Radiology*. 1997 Sep;204(3):799-805.
63. McNally EG, Nasser KN, Dawson S, Goh LA. Role of magnetic resonance imaging in the clinical management of the acutely locked knee. *Skeletal Radiol*. 2002 Oct;31(10):570-3.
64. Helmark IC, Neergaard K, Krogsgaard MR. Traumatic knee extension deficit (the locked knee): can MRI reduce the need for arthroscopy? *Knee Surg Sports Traumatol Arthrosc*. 2007;15(7):863-868.
65. Kirsch MD, Fitzgerald SW, Friedman H, Rogers LF. Transient lateral patellar dislocation: diagnosis with MR imaging. *AJR Am J Roentgenol*. 1993;161(1):109-113.
66. Walker RE, McDougall D, Patel S, Grant JA, Longino PD, Mohtadi NG. Radiologic review of knee dislocation: from diagnosis to repair. *AJR Am J Roentgenol*. 2013 Sep;201(3):483-95.
67. Diederichs G, Issever AS, Scheffler S. MR imaging of patellar instability: injury patterns and assessment of risk factors. *Radiographics*. 2010;30(4):961-81.
68. Brossmann J, Muhle C, Büll CC, et al. Evaluation of patellar tracking in patients with suspected patellar malalignment: cine MR imaging vs arthroscopy. *AJR Am J Roentgenol*. 1994 Feb;162(2):361-7.
69. Shellock FG, Mink JH, Deutsch AL, Fox JM. Patellar tracking abnormalities: clinical experience with kinematic MR imaging in 130 patients. *Radiology*. 1989 Sep;172(3):799-804.
70. Ward SR, Shellock FG, Terk MR, Salsich GB, Powers CM. Assessment of patellofemoral relationships using kinematic MRI: comparison between qualitative and quantitative methods. *J Magn Reson Imaging*. 2002 Jul;16(1):69-74.
71. Bui-Mansfield LT, Youngberg RA, Warme W, Pitcher JD, Nguyen PL. Potential cost savings of MR imaging obtained before arthroscopy of the knee: evaluation of 50 consecutive patients. *AJR Am J Roentgenol*. 1997 Apr;168(4):913-8.
72. Carmichael IW, MacLeod AM, Travlos J. MRI can prevent unnecessary arthroscopy. *J Bone Joint Surg Br*. 1997 Jul;79(4):624-5.
73. Rangger C, Klestil T, Kathrein A, Inderster A, Hamid L. Influence of magnetic resonance imaging on indications for arthroscopy of the knee. *Clin Orthop Relat Res*. 1996 Sep;(330):133-42.
74. Ruwe PA, Wright J, Randall RL, Lynch JK, Jokl P, McCarthy S. Can MR imaging effectively replace diagnostic arthroscopy?. *Radiology*. 1992 May;183(2):335-9.
75. Spiers AS, Meagher T, Ostlere SJ, Wilson DJ, Dodd CA. Can MRI of the knee affect arthroscopic practice? A prospective study of 58 patients. *J Bone Joint Surg Br*. 1993 Jan;75(1):49-52.
76. Vincken PW, ter Braak BP, van Erkel AR, et al. Effectiveness of MR imaging in selection of patients for arthroscopy of the knee. *Radiology*. 2002 Jun;223(3):739-46.
77. Alparslan L, Winalski CS, Boutin RD, Minas T. Postoperative magnetic resonance imaging of articular cartilage repair. *Semin Musculoskelet Radiol*. 2001 Dec;5(4):345-63.
78. McCauley TR. MR imaging evaluation of the postoperative knee. *Radiology*. 2005 Jan;234(1):53-61.
79. Vives MJ, Homesley D, Ciccotti MG, Schweitzer ME. Evaluation of recurring meniscal tears with gadolinium-enhanced magnetic resonance imaging: a randomized, prospective study. *Am J Sports Med*. 31(6):868-73, 2003 Nov-Dec.
80. Monu UD, Jordan CD, Samuelson BL, Hargreaves BA, Gold GE, McWalter EJ. Cluster analysis of quantitative MRI T2 and T1 $\rho$  relaxation times of cartilage identifies differences between healthy and ACL-injured individuals at 3T. *Osteoarthritis & Cartilage*. 25(4):513-520, 2017 Apr.

- 81.** Lee SM, Yoon KH, Lee SH, Hur D. The Relationship Between ACL Femoral Tunnel Position and Postoperative MRI Signal Intensity. *Journal of Bone & Joint Surgery - American Volume*. 99(5):379-387, 2017 Mar 01.
- 82.** American College of Radiology. ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI). Available at: <https://gravitas.acr.org/PPTS/GetDocumentView?docId=146+&releaseId=2>
- 83.** American College of Radiology. ACR-SPR Practice Parameter for the use of Intravascular Contrast Media. Available at <https://gravitas.acr.org/PPTS/GetDocumentView?docId=142+&releaseId=2>
- 84.** American College of Radiology. ACR-SIR Practice Parameter For Minimal and/or Moderate Sedation/Analgesia. Available at <https://gravitas.acr.org/PPTS/GetDocumentView?docId=95+&releaseId=2>
- 85.** Barnett MJ. MR diagnosis of internal derangements of the knee: effect of field strength on efficacy. *AJR Am J Roentgenol*. 1993 Jul;161(1):115-8.
- 86.** 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(3):382-8.
- 87.** Magee T, Shapiro M, Williams D. Usefulness of simultaneous acquisition of spatial harmonics technique for MRI of the knee. *AJR Am J Roentgenol*. 2004 Jun;182(6):1411-5.
- 88.** Rubin DA, Kneeland JB. MR imaging of the musculoskeletal system: technical considerations for enhancing image quality and diagnostic yield. *AJR Am J Roentgenol*. 1994 Nov;163(5):1155-63.
- 89.** Cotten A, Delfaut E, Demondion X, et al. MR imaging of the knee at 0.2 and 1.5 T: correlation with surgery. *AJR Am J Roentgenol*. 2000 Apr;174(4):1093-7.
- 90.** Erickson SJ. High-resolution imaging of the musculoskeletal system. *Radiology*. 1997 Dec;205(3):593-618.
- 91.** Rothschild PA, Domesek JM, Kaufman L, et al. MR imaging of the knee with a 0.064-T permanent magnet. *Radiology*. 1990 Jun;175(3):775-8.
- 92.** Bredella MA, Losasso C, Moelleken SC, Huegeli RW, Genant HK, Tirman PF. Three-point Dixon chemical-shift imaging for evaluating articular cartilage defects in the knee joint on a low-field-strength open magnet. *AJR Am J Roentgenol*. 2001 Dec;177(6):1371-5.
- 93.** Kinnunen J, Bondestam S, Kivioja A, et al. Diagnostic performance of low field MRI in acute knee injuries. *Magn Reson Imaging*. 1994;12(8):1155-60.
- 94.** Kladny B, Glückert K, Swoboda B, Beyer W, Weseloh G. 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(5):281-6.
- 95.** Rubenstein JD, Li JG, Majumdar S, Henkelman RM. Image resolution and signal-to-noise ratio requirements for MR imaging of degenerative cartilage. *AJR Am J Roentgenol*. 1997 Oct;169(4):1089-96.
- 96.** Woertler K, Strothmann M, Tombach B, Reimer P. 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 Jun;11(6):678-85.
- 97.** Fitzgerald SW, Remer EM, Friedman H, Rogers LF, Hendrix RW, Schafer MF. MR evaluation of the anterior cruciate ligament: value of supplementing sagittal images with coronal and axial images. *AJR Am J Roentgenol*. 1993 Jun;160(6):1233-7.
- 98.** Magee T, Williams D. Detection of meniscal tears and marrow lesions using coronal MRI. *AJR Am J Roentgenol*. 2004 Nov;183(5):1469-73.
- 99.** Buckwalter KA, Pennes DR. Anterior cruciate ligament: oblique sagittal MR imaging. *Radiology*. 1990 Apr;175(1):276-7.
- 100.** Yu JS, Salonen DC, Hodler J, Haghighi P, Trudell D, Resnick D. Posterolateral aspect of the knee: improved MR imaging with a coronal oblique technique. *Radiology*. 1996 Jan;198(1):199-204.
- 101.** Quinn SF, Brown TR, Szumowski J. Menisci of the knee: radial MR imaging correlated with arthroscopy in 259 patients. *Radiology*. 1992 Nov;185(2):577-80.
- 102.** Duc SR, Pfirrmann CW, Koch PP, Zanetti M, Hodler J. Internal knee derangement assessed with 3-minute three-dimensional isovoxel true FISP MR sequence: preliminary study. *Radiology*. 2008 Feb;246(2):526-35.
- 103.** Gold GE, Busse RF, Beehler C, et al. Isotropic MRI of the knee with 3D fast spin-echo extended echo-train acquisition (XETA): initial experience. *AJR Am J Roentgenol*. 2007 May;188(5):1287-93.
- 104.** Heron CW, Calvert PT. Three-dimensional gradient-echo MR imaging of the knee: comparison with arthroscopy in 100 patients. *Radiology*. 1992 Jun;183(3):839-44.
- 105.** Ha TP, Li KC, Beaulieu CF, et al. Anterior cruciate ligament injury: fast spin-echo MR imaging with arthroscopic correlation in 217 examinations. *AJR Am J Roentgenol*. 1998 May;170(5):1215-9.
- 106.** Mink JH, Levy T, Crues JV. Tears of the anterior cruciate ligament and menisci of the knee: MR imaging evaluation. *Radiology*. 1988 Jun;167(3):769-74.
- 107.** Vande Berg BC, Malghem J, Lecouvet FE, Maldague B. Classification and detection of bone marrow lesions with magnetic resonance imaging. *Skeletal Radiol*. 1998 Oct;27(10):529-45.

- 108.** Bush CH. The magnetic resonance imaging of musculoskeletal hemorrhage. *Skeletal Radiol.* 2000 Jan;29(1):1-9.
- 109.** Wolf GL, Joseph PM, Goldstein EJ. Optimal pulsing sequences for MR contrast agents. *AJR Am J Roentgenol.* 1986 Aug;147(2):367-71.
- 110.** Mohr A. The value of water-excitation 3D FLASH and fat-saturated PDw TSE MR imaging for detecting and grading articular cartilage lesions of the knee. *Skeletal Radiol.* 2003 Jul;32(7):396-402.
- 111.** Sonin AH, Pensy RA, Mulligan ME, Hatem S. Grading articular cartilage of the knee using fast spin-echo proton density-weighted MR imaging without fat suppression. *AJR Am J Roentgenol.* 2002 Nov;179(5):1159-66.
- 112.** 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 Am J Roentgenol.* 1996 Jul;167(1):127-32.
- 113.** Recht MP, Piraino DW, Paletta GA, Schils JP, Belhobek GH. Accuracy of fat-suppressed three-dimensional spoiled gradient-echo FLASH MR imaging in the detection of patellofemoral articular cartilage abnormalities. *Radiology.* 1996 Jan;198(1):209-12.
- 114.** Browne LP, Guillerman RP, Orth RC, Patel J, Mason EO, Kaplan SL. Community-acquired staphylococcal musculoskeletal infection in infants and young children: necessity of contrast-enhanced MRI for the diagnosis of growth cartilage involvement. *AJR Am J Roentgenol.* 198(1):194-9, 2012 Jan.
- 115.** Gold GE, Hargreaves BA, Vasawala SS, et al. Articular cartilage of the knee: evaluation with fluctuating equilibrium MR imaging--initial experience in healthy volunteers. *Radiology.* 2006 Feb;238(2):712-8.
- 116.** Siepmann DB, McGovern J, Brittain JH, Reeder SB. High-resolution 3D cartilage imaging with IDEAL SPGR at 3 T. *AJR Am J Roentgenol.* 2007 Dec;189(6):1510-5.
- 117.** Vasawala SS, Hargreaves BA, Pauly JM, Nishimura DG, Beaulieu CF, Gold GE. Rapid musculoskeletal MRI with phase-sensitive steady-state free precession: comparison with routine knee MRI. *AJR Am J Roentgenol.* 2005 May;184(5):1450-5.
- 118.** Duc SR, Koch P, Schmid MR, Horger W, Hodler J, Pfirrmann CW. Diagnosis of articular cartilage abnormalities of the knee: prospective clinical evaluation of a 3D water-excitation true FISP sequence. *Radiology.* 2007 May;243(2):475-82.
- 119.** Duc SR, Pfirrmann CW, Schmid MR, et al. Articular cartilage defects detected with 3D water-excitation true FISP: prospective comparison with sequences commonly used for knee imaging. *Radiology.* 2007 Oct;245(1):216-23.
- 120.** Hardy PA, Recht MP, Piraino D, Thomasson D. Optimization of a dual echo in the steady state (DESS) free-precession sequence for imaging cartilage. *J Magn Reson Imaging.* 1996;6(2):329-35.
- 121.** Ruehm S, Zanetti M, Romero J, Hodler J. MRI of patellar articular cartilage: evaluation of an optimized gradient echo sequence (3D-DESS). *J Magn Reson Imaging.* 1998;8(6):1246-51.
- 122.** Kramer J, Recht MP, Imhof H, Stiglbauer R, Engel A. Postcontrast MR arthrography in assessment of cartilage lesions. *J Comput Assist Tomogr.* 1994;18(2):218-24.
- 123.** Harman M, Ipeksoy U, Dogan A, Arslan H, Etlik O. MR arthrography in chondromalacia patellae diagnosis on a low-field open magnet system. *Clin Imaging.* 2003;27(3):194-9.
- 124.** Arndt WF, Truax AL, Barnett FM, Simmons GE, Brown DC. 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 Am J Roentgenol.* 1996 Jan;166(1):119-24.
- 125.** 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 Dec;189(3):901-4.
- 126.** Rybicki FJ, Chung T, Reid J, Jaramillo D, Mulkern RV, Ma J. 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 Am J Roentgenol.* 2001 Nov;177(5):1019-23.
- 127.** Totterman S, Weiss SL, Szumowski J, et al. MR fat suppression technique in the evaluation of normal structures of the knee. *J Comput Assist Tomogr.* 1989;13(3):473-9.
- 128.** 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 Mar;194(3):721-6.
- 129.** Alaia EF, Benedick A, Obuchowski NA, et al. Comparison of a fast 5-min knee MRI protocol with a standard knee MRI protocol: a multi-institutional multi-reader study. *Skeletal Radiology.* 47(1):107-116, 2018 Jan.
- 130.** Benali S, Johnston PR, Gholipour A, et al. Simultaneous multi-slice accelerated turbo spin echo of the knee in pediatric patients. *Skeletal Radiol.* 2018 Jun;47(6):821-831.
- 131.** Altahawi FF, Blount KJ, Morley NP, Raithel E, Omar IM. Comparing an accelerated 3D fast spin-echo sequence

- (CS-SPACE) for knee 3-T magnetic resonance imaging with traditional 3D fast spin-echo (SPACE) and routine 2D sequences. *Skeletal Radiol.* 2017 Jan;46(1):7-15.
- 132.** Park S, Kwack KS, Lee YJ, Gho SM, Lee HY. Initial experience with synthetic MRI of the knee at 3T: comparison with conventional T1 weighted imaging and T2 mapping. *Br J Radiol.* 2017 Dec;90(1080):20170350.
- 133.** Vahlensieck M, Peterfy CG, Wischer T, et al. Indirect MR arthrography: optimization and clinical applications. *Radiology.* 1996;200(1):249-254.
- 134.** Disler DG, McCauley TR, Ratner LM, Kesack CD, Cooper JA. In-phase and out-of-phase MR imaging of bone marrow: prediction of neoplasia based on the detection of coexistent fat and water. *AJR Am J Roentgenol.* 1997 Nov;169(5):1439-47.
- 135.** Peh WC, Chan JH. Artifacts in musculoskeletal magnetic resonance imaging: identification and correction. *Skeletal Radiol.* 2001 Apr;30(4):179-91.
- 136.** Van Hecke PE, Marchal GJ, Baert AL. Use of shielding to prevent folding in MR imaging. *Radiology.* 1988 May;167(2):557-8.
- 137.** Turner DA, Rapoport MI, Erwin WD, McGould M, Silvers RI. Truncation artifact: a potential pitfall in MR imaging of the menisci of the knee. *Radiology.* 1991 Jun;179(3):629-33.
- 138.** Haacke EM, Lenz GW. Improving MR image quality in the presence of motion by using rephasing gradients. *AJR Am J Roentgenol.* 1987 Jun;148(6):1251-8.
- 139.** Shellock FG. *Magnetic Resonance Procedures: Health Effects and Safety.* Boca Raton, Fla.: CRC Press; 2001.
- 140.** Raphael B, Haims AH, Wu JS, Katz LD, White LM, Lynch K. MRI comparison of periprosthetic structures around zirconium knee prostheses and cobalt chrome prostheses. *AJR Am J Roentgenol.* 2006 Jun;186(6):1771-7.
- 141.** Harris CA, White LM. Metal artifact reduction in musculoskeletal magnetic resonance imaging. *Orthop Clin North Am.* 2006 Jul;37(3):349-59, vi.
- 142.** Liebl H, Heilmeyer U, Lee S, et al. In vitro assessment of knee MRI in the presence of metal implants comparing MAVRIC-SL and conventional fast spin echo sequences at 1.5 and 3 T field strength. *J Magn Reson Imaging.* 2015 May;41(5):1291-9.
- 143.** Fritz J, Fritz B, Thawait GG, Meyer H, Gilson WD, Raithel E. Three-Dimensional CAIPRINHA SPACE TSE for 5-Minute High-Resolution MRI of the Knee. *Invest Radiol.* 2016 Oct;51(10):609-17.
- 144.** Jawhar A, Reichert M, Kostrzewa M, et al. Usefulness of slice encoding for metal artifact correction (SEMAC) technique for reducing metal artifacts after total knee arthroplasty. *Eur. j. orthop. surg. traumatol.* 29(3):659-666, 2019 Apr.
- 145.** Sutter R, Hodek R, Fucentese SF, Nittka M, Pfirrmann CW. Total knee arthroplasty MRI featuring slice-encoding for metal artifact correction: reduction of artifacts for STIR and proton density-weighted sequences. *AJR Am J Roentgenol.* 2013;201(6):1315-1324.
- 146.** Haims AH, Katz LD, Ruwe PA. MR Arthrography of the Knee. *Semin Musculoskelet Radiol.* 1998;2(4):385-396.
- 147.** Magee T, Shapiro M, Rodriguez J, Williams D. MR arthrography of postoperative knee: for which patients is it useful?. *Radiology.* 2003 Oct;229(1):159-63.
- 148.** Schulte-Altdorneburg G, Gebhard M, Wohlgemuth WA, et al. MR arthrography: pharmacology, efficacy and safety in clinical trials. *Skeletal Radiol.* 2003 Jan;32(1):1-12.
- 149.** American College of Radiology. ACR Practice Parameter for Communication of Diagnostic Imaging Findings. Available at <https://gravitas.acr.org/PPTS/GetDocumentView?docId=74+&releaseId=2>
- 150.** Shellock FG. *Guide to MR Procedures and Metallic Objects: Update 2001.* 7th ed. Philadelphia, Pa: Lippincott Williams & Wilkins; 2001.
- 151.** Shellock FG. *Reference Manual for Magnetic Resonance Safety, Implants, and Devices.* Playa Del Rey, CA Biomedical Research Publishing Group; 2013.
- 152.** Shellock FG, Crues JV. MR procedures: biologic effects, safety, and patient care. *Radiology.* 2004 Sep;232(3):635-52.
- 153.** Shellock FG, Spinazzi A. MRI safety update 2008: part 2, screening patients for MRI. *AJR Am J Roentgenol.* 2008 Oct;191(4):1140-9.
- 154.** American College of Radiology. ACR Committee on MR Safety. 2026 ACR Manual on MR Safety. Available at: <https://edge.sitecorecloud.io/americancoldf5f-acrorgf92a-productioncb02-3650/media/ACR/Files/Clinical/Radiology-Safety/Manual-on-MR-Safety.pdf>.
- 155.** American College of Radiology. ACR Committee on Drugs and Contrast Media. *Manual on Contrast Media.* Available at: <https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Contrast-Manual>.
- \*Practice parameters and technical standards are published annually with an effective date of October 1 in the year in which amended, revised, or approved by the ACR Council. For practice parameters and technical

standards published before 1999, the effective date was January 1 following the year in which the practice parameter or technical standard was amended, revised, or approved by the ACR Council.

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