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ACR–SPR–SSR PRACTICE PARAMETER FOR THE PERFORMANCE AND INTERPRETATION OF MAGNETIC RESONANCE IMAGING (MRI) OF THE HIP AND PELVIS FOR MUSCULOSKELETAL DISORDERS

PREAMBLE

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care[1]. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the practitioner considering all the circumstances presented. Thus, an approach that differs from the guidance in this document, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in this document when, in the reasonable judgment of the practitioner, such course of action is indicated by variables such as the condition of the patient, limitations of available resources, or advances in knowledge or technology after publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document may consider documenting in the patient record information sufficient to explain the approach taken.

The practice of medicine involves the science, and the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment. Therefore, it should be recognized that adherence to the guidance in this document will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The purpose of this document is to assist practitioners in achieving this objective.

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[1] Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing 831 N.W.2d 826 (Iowa 2013) Iowa Supreme Court refuses to find that the *ACR Technical Standard for Management of the Use of Radiation in Fluoroscopic Procedures* (Revised 2008) sets a national standard for who may perform fluoroscopic procedures in light of the standard's stated purpose that ACR standards are educational tools and not intended to establish a legal standard of care. See also, Stanley v. McCarver, 63 P.3d 1076 (Ariz. App. 2003) where in a concurring opinion the Court stated that "published standards or guidelines of specialty medical organizations are useful in determining the duty owed or the standard of care applicable in a given situation" even though ACR standards themselves do not establish the standard of care.

I. INTRODUCTION

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

This parameter addresses magnetic resonance imaging (MRI) performed to evaluate musculoskeletal disorders of the pelvis and hips and to investigate symptoms that are believed to originate in the musculoskeletal system. Guidelines for pelvic MRI examinations performed to evaluate the male and female genitourinary tracts, bowel, and vasculature are not included herein (see the ACR–SAR–SPR Practice Parameter for the Performance of Magnetic Resonance Imaging (MRI) of the Soft-Tissue Components of the Pelvis [1]).

MRI is a proven, established imaging method for the detection, evaluation, staging, and follow-up of musculoskeletal conditions of the hip and pelvis. Properly performed and interpreted, MRI not only contributes to diagnosis but also serves as an important guide to treatment planning and prognostication [2-11]. However, MRI should be performed only for a valid medical reason and only after careful consideration of alternative imaging methods. The strengths of MRI and other imaging techniques should be weighed as to their suitability in particular patients and clinical conditions.

Radiographs should be the initial imaging study for most suspected abnormalities of the hip and pelvis [12]. Sequential radiographs are a key component in the postoperative evaluation of hip arthroplasty and other orthopedic procedures [13]. Bone scintigraphy is used to screen the entire skeleton for conditions such as metastases. Additionally, with some limitations [14], bone scans can also detect radiographically occult osteonecrosis, fractures [15], and stress fractures [16] in the hips and pelvis. Bone scintigraphy and labeled leukocyte scintigraphy may also have a role in the evaluation of symptomatic hip arthroplasties [20,21]. Because of its superior sensitivity and specificity, however, MRI has largely replaced scintigraphy for these indications [12,17-19]. Ultrasound may be used to detect tendon disorders in the proximal thighs [22-24], bursitis, synovitis, and joint effusion [25-27]. Ultrasound is useful in the assessment of the snapping hip due to external and internal causes [28,29]. Ultrasound is a useful tool for guiding hip and pelvis injections and aspirations. In children, sonography can be used to diagnose developmental dysplasia of the hip, hip effusions, and pelvic apophyseal avulsions [30]. Ultrasound can be used to evaluate developmental hip dysplasia in infants and young children [31]. In adults, the clinical response to intra-articular anesthetic injection in the hip helps predict intra-articular pathology [32,33]. Therapeutic injection of the pubic symphysis cleft may help diagnose the cause of groin pain in athletes [34,35]. Hip arthroscopy, an invasive procedure, provides a detailed examination of the internal structures of the hip joint, allowing the surgeon to treat as well as diagnose many internal derangements [36,37].

Computed tomography (CT), especially with multidetector helical scanners using thin collimation, is often preferred to MRI for detailed evaluation of bony alignment, morphology, and cortical pathology. Multiplanar 2-D reformatting and 3-D volume rendering increase the utility of CT for orthopedic purposes. Typical applications include evaluation of the acetabulum and hip joint after fractures or dislocations [38-40], preoperative planning for complex pelvic osteotomies and arthroplasties [39,41], preoperative planning of complex osteotomies in femoroacetabular impingement and surgical navigation [42,43], and evaluation of osteolysis around hip arthroplasty components [44-46]. MRI has largely replaced CT for detecting femoral head osteonecrosis [47], but CT is still valuable for detecting subchondral fractures in necrotic femoral heads [48]. CT can detect radiographically occult hip fractures, but MRI is more sensitive [49,50]. CT is a reasonable secondary imaging method (after MRI) for soft-tissue disorders such as sports hernias [51] and monoarticular proliferative arthropathies [12]. CT can detect erosions in patients with suspected sacroiliitis, and normal radiographs [52]. Multidetector CT arthrography can detect cartilage and labral lesions [53] in patients with contraindications to MR imaging. Radially oriented multiplanar reformation may be a useful adjunct in the assessment of bone morphology, acetabular cartilage, and labrum [53-55].

Although MRI is often the most sensitive noninvasive diagnostic test for detecting anatomic abnormalities of the hip and pelvis, its findings may be misleading if not closely correlated with the clinical history, physical examination, physiologic tests such as nerve conduction analysis and electromyography, and other imaging studies. Adherence to the following parameters will enhance the probability of detecting such abnormalities.

II. INDICATIONS

A. Primary indications for MRI of the hip and pelvis include, but are not limited to, screening, diagnosis, exclusion, grading, and/or prognostication of suspected:

1. Osteonecrosis of the femoral head(s), including staging of osteonecrosis and screening of asymptomatic hips contralateral to a hip with osteonecrosis [2,6,47,56-69]
2. Other marrow abnormalities of the femoral head(s), including transient and migratory osteoporosis of the hip, transient bone marrow edema syndrome, and subchondral insufficiency fractures[2] [66,68,70-74]
3. Radiographically occult traumatic fractures of the proximal femur and pelvis [11,17,18,50,75-82]
4. Stress fractures (fatigue and insufficiency types) of the proximal femur, pelvis, and sacrum, atypical fractures in the setting of osteoporosis therapy [16,19,49,83-92]
5. Childhood hip disorders and their adult sequelae: Legg-Calvé-Perthes disease, slipped capital femoral epiphysis, idiopathic chondrolysis, coxa vara, proximal femoral focal deficiency, and developmental dysplasia of the hip (DDH)[2,3] [3,7,41,93-98]
6. Femoroacetabular impingement (cam, pincer, and mixed types), including evaluation of labral, articular cartilage, and bone morphologic abnormalities[3] [5,97,99-110]
7. Acetabular labral tears, traumatic and/or degenerative[3] [97,99,111-120]
8. Abductor (gluteus medius and minimus) musculotendinous disorders and greater trochanteric bursitis[2] [121-128]
9. Proximal hamstring musculotendinous disorders and ischial bursitis[2] [22,129-131]
10. Hip rotator and flexor musculotendinous disorders and iliopsoas bursitis (including quadratus femoris, iliopsoas, rectus femoris) [27,132-137]
11. Athletic pubalgia, including adductor/rectus abdominus musculotendinous disorders and pubic bone, osteitis pubis, and other disorders presenting as "sports hernia" [3] [10,19,34,35,51,88,138-147]
12. Proximal iliotibial band syndrome [148]
13. Osteochondral and chondral abnormalities in the hip joint, including chondral delamination[3] [98,102,104,105,111,112,149-152]
14. Ligamentum teres injury (rupture)[3] [153,154]
15. Bursitis in and around the pelvis[2] [27,88,111,122,134,155,156]
16. Sacral plexus abnormalities, nerve entrapment, and piriformis syndrome [91,157,158]
17. Pelvic impingement syndromes, including ischiofemoral and subspine impingement [125] [136,170,171]
18. Osteomyelitis, septic arthritis, and soft-tissue infection of the hip and pelvis[2] [9,159-164]

B. MRI of the hip and pelvis may be indicated to further clarify and stage conditions diagnosed clinically and/or suggested by other imaging modalities, including, but not limited to:

1. Hip arthritis and synovitis of unclear etiology: inflammatory, infectious, degenerative, crystal-induced, posttraumatic, proliferative[2] [160,165-174]
2. Hip joint effusions [27,60,175]
3. Hip joint bodies[3] [176]
4. Sacroiliitis[2] [4,165,177]
5. Primary and secondary bone and soft-tissue tumors of the pelvis, proximal femur, and thigh[2] [157,178-181] (see also the ACR–SPR–SSR Practice Parameter for the Performance and Interpretation of Magnetic Resonance Imaging (MRI) of Bone and Soft-Tissue Tumors [182])
6. Fractures and dislocations of the hip and pelvis[2] [30,183,184]

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

1. Prolonged, refractory, or unexplained hip, trochanteric, pubic, or pelvic pain[3] [88,122,124,126,128,142,147,158,185]

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[2] Conditions in which intravenous contrast may be useful

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

2. Pelvic, proximal thigh, or groin pain in athletes[3] [19,22,34,35,88,111,138-142,144-147,151,186]
3. Acute or chronic hip and pelvis trauma with associated soft-tissue injuries[2] [40,77,187]
4. Pelvic pain after radiation therapy [84,85,87]
5. Mechanical symptoms in the hip, including snapping and clicking[3] [8,24,37,112,114]
6. Following reduction of congenital or acquired hip dislocation in infants and children[2,3] [67,188-193]
7. Symptomatic adults with developmental dysplasia of the hip[3] [3,7,41,53,97]
8. Patients for whom diagnostic or therapeutic hip arthroscopy is planned[3] [33,112,116]
9. Hip arthroplasties with suspected soft-tissue or periprosthetic abnormalities[2,4] [13,127,128,194-199]
10. Pelvimetry in women with obstructed labor [200,201]

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [202].

IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [202] and the ACR Guidance Document on MR Safe Practices 2020 [203].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [204,205].

V. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for MRI of the hip and pelvis for musculoskeletal disorders should provide sufficient information to demonstrate the medical necessity of the examination and allow for its proper performance and interpretation.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). Additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient's clinical problem or question and consistent with the state's scope of practice requirements. (ACR Resolution 35 adopted in 2006 – revised in 2016, Resolution 12-b)

The supervising physician must have adequate understanding of the indications, risks, and benefits of the imaging examination as well as alternative imaging procedures. The physician must be familiar with potential hazards associated with MRI, including potential adverse reactions to contrast media. The physician should be familiar with relevant ancillary studies that the patient may have undergone. The physician performing MRI interpretation must have a clear understanding and knowledge of the anatomy and pathophysiology relevant to the MRI examination.

The supervising physician must also understand the pulse sequences to be used and their effect on the appearance of the images, including the potential generation of image artifacts. Standard imaging protocols may be established and varied on a case-by-case basis when necessary. These protocols should be reviewed and updated periodically.

A. Patient Selection

The physician responsible for the examination should supervise patient selection and preparation and be available in person or by telephone for consultation. Patients must be screened and interviewed prior to the examination to exclude individuals who may be at risk by exposure to the MR environment.

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[4] Conditions in which use of metal artifact reduction pulse sequences (MARS) may be useful

Certain indications may 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 use (see the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [206]).

Pediatric patients or patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of moderate sedation or general anesthesia may be needed to achieve a successful examination, particularly in young children. If moderate sedation is necessary, refer to the ACR–SIR Practice Parameter for Minimal and/or Moderate Sedation/Analgesia [207].

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 hip and pelvis MRI can be performed with low-, medium-, or high-field systems of either closed-bore or open design. High-field magnets (1.5T and higher) have inherently better signal-to-noise ratios (SNRs) than lower-field systems, providing greater flexibility to obtain high-resolution images in a reasonable amount of time. However, there are circumstances in which lower field strength may be advantageous. These situations include imaging around metallic implants like prostheses and screws [13,208] and imaging in pregnant patients to reduce energy deposition in the fetus [201] (for more information, refer to the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [202] and the ACR Guidance Document on MR Safe Practices 2020 [203]). Three-tesla (3T) MRI systems have higher SNRs and may offer improvements in assessment of cartilage and functional imaging [209-212].

Although an initial screen for abnormalities may use a body coil [39,62,213,214], high-resolution images require the use of a local coil. Multicoil arrays work best when imaging the entire pelvis and both hips [215,216]. When detailed images of a single hip or proximal femur are needed, several coil choices are available, ranging in configuration from flexible single coils [78,217] to paired loop-gap designs to commercially available or custom-built phased arrays [77,194,218-220].

Patients are typically positioned supine. The feet may be internally rotated and gently immobilized with tape, if necessary. Slight flexion at the knees achieved with padding may be more comfortable for some patients.

Coronal images are a mainstay of pelvic and hip MRI, and coronal T1-weighted and short-tau inversion recovery (STIR) images alone can rapidly screen for fractures [11,78,80] or femoral head osteonecrosis [62], but a complete examination should also include images in at least 1 additional imaging plane. Coronal and transverse images constitute a minimum examination for most indications [89,142,147,221]. The addition of sagittal plane images is useful for quantifying the extent of femoral head osteonecrosis [58,63,222], evaluating the hip joint cartilage and acetabular roof [85,223], investigating abnormalities of the proximal hamstring muscles and tendons [129,130], and assessing anterosuperior labral tears [200,201]. Sagittal images are essential and constitute the most important imaging plane to evaluate labrum and chondrolabral separation in the setting of common conditions of femoroacetabular impingement and hip dysplasia. Additionally, the standard imaging planes may be altered for specific indications. Sensitivity for detection of labral tears with large field of view (FOV) is poor, and small FOV images and arthrography should be performed for evaluation of labrum [118].

Oblique coronal and transverse images angled parallel to the upper sacrum are useful to evaluate the sacroiliac joints [165,177], whereas images in either direct or oblique coronal and transverse planes can image the sacral plexus [157,224]. Selective use of oblique images along one femoral neck may assist in the diagnosis of subtle fractures [214,217,225] and labral tears [119,226] and in the evaluation of the femoral head-neck junction in femoroacetabular impingement syndrome [101]. Axial oblique images obtained parallel to the arcuate line of the pelvic inlet using a sagittal localizer can provide improved delineation of symphysis pubis anatomy in cases of groin pain or pubalgia [146]. In some practices, radial images acquired either directly [227,228] or via multiplanar reformatting of a volumetric data set [103,116,229,230] may assist the diagnosis of labral and cartilage pathology and potentially provide a more sensitive assessment of femoral head asphericity in cam-type femoroacetabular impingement [103,229], but whether the accuracy for diagnosing labral tears in such patients is improved compared with conventional imaging planes has not been determined [227]. Typically, 3 imaging planes are used for MR arthrography of the hip [114]. These may be oriented orthogonal to the pelvis or parallel to the femoral neck and perpendicular to the acetabular face for evaluating the acetabular labrum and hip joint capsule [231]. 3-D imaging may be useful for delineation and follow-up of femoral head and acetabular cartilage abnormalities [232-234]. 3-D imaging is best performed using isotropic spin-echo technique with prudent use of parallel imaging, and it allows radial reconstructions of hip and labral-cartilage assessment in multiple planes [235]. The pain response to the anesthetic in the arthrogram should be recorded and can provide valuable additional information to the orthopedic surgeon in addition to the MR arthrography findings, with respect to intra- or extra-articular origin of hip pain [236].

The FOV should be tailored to the size of the patient and the structures being examined. To screen the entire pelvis, a 35- to 45-cm FOV is typical, and the images should include enough tissue laterally to encompass the gluteal insertions and trochanteric bursae [123]. Images that include the entire pelvis are useful for making side-to-side comparisons [214]. Even when symptoms are unilateral, it may be advantageous to include at least 1 sequence with a large enough FOV to detect contralateral disease, which is frequently present [86]. Hip or groin pain may originate from several different anatomic structures, and a larger FOV may be required for evaluating the source of pain [146]. Larger FOV images can also frequently detect clinically occult pathology in patients with suspected proximal femur fractures [11]. For screening purposes, 6- to 8-mm-thick sections are adequate. However, higher imaging resolution is necessary to distinguish femoral head osteonecrosis from transient marrow conditions [66], to demonstrate subtle fracture lines, and to quantify the extent of osteonecrosis [58]. High-resolution imaging can be accomplished with a relatively large FOV if thin slices and a high imaging matrix are used (for example, 3- to 4-mm slice thickness and a 512 × 512 matrix) [58], or it can be accomplished by reducing the FOV to 16 to 20 cm and imaging each hip separately [77,237]. MR arthrography for labral or articular cartilage disease often requires even higher spatial resolution, with a small FOV to cover just 1 hip (typically 15 to 22 cm), thin sections (1.5 to 3 mm), and a relatively high matrix (256 phase steps or more) [149,231]. There is generally a trade-off between spatial resolution and imaging time [215]. Parallel imaging, which is available on some MR systems, allows faster image acquisition without substantial loss in image quality [238]. Parallel imaging can also mitigate undesired energy deposition on higher-field MRI systems like 3T scanners [239]. An interslice gap can increase coverage [240] but should be as small as feasible in order not to impair visualization of the imaged structures.

A wide variety of pulse sequences are available to image the pelvis and hips [241]. The choice of sequences, like other aspects of the imaging protocol, can be tailored to optimize the examination to answer specific clinical questions [39] and may vary because of local preferences. Short transition time/echo time (TR/TE) (T1-weighted) images are typically obtained using conventional spin-echo (SE) or fast (turbo) spin-echo (FSE) sequences. Long TR/TE (T2-weighted) and STIR images are frequently obtained using FSE techniques for more rapid image acquisition than SE technique allows [64]. A common higher-resolution 2-D imaging protocol for evaluation of internal derangements includes multiplanar intermediate-weighted fat-suppressed and nonfat-suppressed imaging, whereas T1W imaging is reserved specifically for infection and tumor protocols. Dixon imaging is another option that can be used to obtain multiple contrasts, including in-phase, opposed phase, and fat and water maps, which allow combined assessment of internal derangement and marrow assessment in the same setting [242]. Gradient-recalled sequences tend to produce larger artifacts and result in lower soft-tissue contrast [214] but may be advantageous at lower field strengths [243] and for selected applications, such as demonstration of hemosiderin in hips affected by pigmented villonodular synovitis [167] or evaluation of articular cartilage [150,228]. Gradient-echo and modified fast (turbo) SE sequences can also be acquired as a 3-D volume, which is partitioned into contiguous thin sections or nonorthogonal imaging planes. Gradient-echo imaging results in suboptimal contrast and resolution as compared with FSE sequences. With current scanners, SE sequence with isotropic resolution can be obtained in 6-7 minutes of scanning time.

An imaging protocol will be composed of 1 or more pulse sequence types. For each sequence, the exact TR, TE, TI (inversion time), and flip angle chosen will depend on the field strength of the magnet and the desired contrast weighting. A typical minimal MRI examination of the pelvis and hips might consist of coronal SE or FSE T1-weighted and fat-suppressed, FSE T2-weighted or STIR images, and transverse T1-weighted and T2-weighted sequences [147,214,221]. The T1-weighted images optimally show anatomic details such as fracture lines and bone marrow assessment [58,78,85,87], whereas T2-weighted or STIR images demonstrate fluid collections and edema within the soft tissue and bone marrow [85,175,213]; the combination is an effective screen for a variety of hip and pelvic pathologies [83,142,221]. T1-weighted sequences also have a role in characterizing various stages of hemorrhage [244,245] and muscle pathology [246,247] and in showing enhancement when gadolinium-based IV contrast agents are used [248]. T1-weighted images with fat suppression—either 2-D SE or FSE [114,149] or 3-D spoiled gradient-echo [230,231]—are also used when MR arthrography is performed with a gadolinium-based contrast agent. At least 1 T2-weighted sequence should also be performed with MR arthrograms to show additional abnormalities affecting the hip (eg, stress fractures, tendon/muscle injuries, bursitis, and cystic structures that do not communicate with the joint). Additionally, at least 1 T1-weighted sequence without fat suppression is useful for evaluating bone marrow and characterizing soft-tissue lesions.

Suppressing the signal from fat may enhance the diagnostic yield of some pulse sequences [241]. Fat suppression can use spectral suppression of water protons, a phase-dependent method such as the Dixon technique, or a STIR sequence [249,250]. The latter 2 methods may be necessary on low-field systems [251]. Fat suppression increases the conspicuity of marrow abnormalities and soft-tissue edema on fluid-sensitive sequences [4,214] and is useful with a T1-weighted sequence when using gadolinium-based contrast agents such as in MR arthrographic evaluation of hip cartilage or labral tears [104,119]. Selective excitation of water protons is an alternative to fat suppression and has been investigated for evaluating the hip articular cartilage [223].

For specific hip and pelvis disorders, IV contrast may be useful. Contrast enhancement, especially on dynamic contrast-enhanced imaging, suggests femoral head viability in Legg-Calvé-Perthes disease [252] and femoral neck fractures [183,184], and may detect early ischemia [253] and predict future risk of osteonecrosis after closed reduction of developmental hip dysplasia [67]. IV contrast can also aid in the diagnosis of hip joint synovitis [160,164,165], pelvic infections [159], tendon degeneration [145], and tumors, and it may play a role in the evaluation of the interface surrounding hip prosthesis components [13]. MR arthrography is beneficial for evaluating internal hip derangements [33,37] and sports injury [88]. The MR diagnosis of labral, articular cartilage, and joint capsule abnormalities in the hip is enhanced by the addition of intra-articular contrast [97,112,231,254]. Conventional 3T MRI is equivalent or superior to 1.5T MR arthrography for labral tears and cartilage defects. Sensitivity of labral tears with 3T MRI is similar to 3T MR arthrography [255]. For the hip joint, MR arthrography is usually performed following direct imaging-guided, intra-articular injection of dilute gadolinium-based contrast or saline. Adding leg traction has been reported to improve delineation of the cartilage surfaces [150,256] and acetabular labrum [254] during MR arthrography but is not commonly used in clinical practice because of logistical issues.

Although indirect MR arthrography is also possible for hip imaging, because of the size of the joint, a delay after IV contrast administration is necessary to allow adequate contrast diffusion into the joint [254]. Indirect MR arthrography may be more sensitive for labral tears but may not improve diagnosis of chondral abnormalities compared with nonarthrographic MRI [120].

Delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) is a technique for assessing cartilage integrity in osteoarthritis and other hip diseases that result in cartilage damage. It requires the use of an anionically charged gadolinium contrast agent, typically administered intravenously [5,109,110,257], but can also be performed after intra-articular injection [258]. dGEMRIC has been used to diagnose and stage osteoarthritis in patients with femoroacetabular impingement [5] and for preosteotomy evaluation of patients with hip dysplasia [7,92]. Additional MR techniques for cartilage assessment have been tested in patients with hip diseases. T2 mapping has been used to evaluate cartilage in hip dysplasia patients [259]. Leg traction may improve delineation of the cartilage surfaces [150,256] and acetabular labrum [254] during MR arthrography. T1-rho may be a useful imaging technique in the detection of early cartilage degeneration [260,261].

Various techniques are used to reduce artifacts that can reduce imaging quality. When the FOV excludes parts of the pelvis that are within the sensitivity range of the coil (eg, when imaging a single hip), aliasing artifacts can be reduced by phase oversampling or by orienting the phase-encoding direction along the anteroposterior axis [252]. Ensuring patient comfort combined with gentle immobilization when necessary best controls involuntary patient motion [241]. Presaturation pulses and/or gradient moment nulling will reduce ghosting artifacts caused by flowing blood [262,263]. Imaging near metallic implants requires special care to reduce susceptibility to artifacts. Orienting the long axis of the implant along the frequency-encoding gradient [128,195,218,264], avoiding gradient-recalled sequences [195], and substituting STIR for chemical fat suppression [13,127,195,198,265] are important considerations. FSE sequences with short interecho spacing, multiple refocusing pulses (long-echo trains), and tailored RF pulses will further minimize metallic artifacts [127,194,196,218,264,266]. Metal artifact is further reduced by using a wide readout bandwidth and small pixel dimensions, which may require more signals averaged to maintain an adequate SNR and are better performed using MR systems with wider available receiver bandwidths [13,194,198,218,264]. Progress in metal artifact reduction techniques minimize metal-related artifacts while improving depiction of synovium and bone-implant interfaces [267,268]. Such techniques provide a diagnostically meaningful reduction of metal artifact around implants and can be used as an adjunct to optimized 2-D FSE sequences [267]. Lastly, artifacts from metal implants are less prominent on low-field systems compared with high-field systems [13].

It is the responsibility of the supervising physician to determine whether additional or unconventional pulse sequences or imaging techniques would confer added benefit for the diagnosis and management of the patient. Examinations that use techniques not approved by the Food and Drug Administration—such as the intra-articular injection of gadolinium chelates (direct MR arthrography) [269]—should be considered only when they are judged to be medically appropriate.

VI. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [270].

At a minimum, the report should address any abnormalities in the bone marrow, soft tissues, and joints. In selected cases, a description of findings in specific muscles and tendons, articular cartilage, fibrocartilage, synovium, neurovascular structures, lymph nodes, cortical bone, and surrounding bursae would be appropriate. For MR arthrograms of the hip, the report should also specifically indicate the condition of the acetabular labrum and articular cartilage. Whenever possible, the report should use standard anatomic nomenclature and precise terms and anatomic localization for describing identified abnormalities.

Specific policies and procedures related to MRI safety should be in place along 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. [204,205,271]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [272].

VII. EQUIPMENT SPECIFICATIONS

Equipment monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment [273].

The MRI equipment specifications and performance must meet all state and federal requirements. The requirements include, but are not limited to, specifications of maximum static magnetic strength, maximum rate of change of the magnetic field strength (dB/dt), maximum radiofrequency power deposition (specific absorption rate), and maximum acoustic noise levels.

VIII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *ACR Position Statement on Quality Control & 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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