ACR-SPR-SSR PRACTICE PARAMETER FOR THE PERFORMANCE AND INTERPRETATION OF MAGNETIC RESONANCE IMAGING (MRI) OF THE FINGERS AND TOES

The American College of Radiology, with more than 40,000 members, is the principal organization of radiologists, radiation oncologists, and clinical medical physicists in the United States. The College is a nonprofit professional society whose primary purposes are to advance the science of radiology, improve radiologic services to the patient, study the socioeconomic aspects of the practice of radiology, and encourage continuing education for radiologists, radiation oncologists, medical physicists, and persons practicing in allied professional fields.

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

Each practice parameter and technical standard, representing a policy statement by the College, has undergone a thorough consensus process in which it has been subjected to extensive review and approval. The practice parameters and technical standards recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice parameter and technical standard by those entities not providing these services is not authorized.

PREAMBLE

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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). It addresses magnetic resonance imaging (MRI) performed to evaluate musculoskeletal disorders and to investigate symptoms that are believed to originate in the musculoskeletal system. Practice parameters for wrist and ankle/hindfoot MRI are not discussed herein. See the ACR–SABI–SPR–SSR Practice Parameter for the Performance of Magnetic Resonance Imaging (MRI) of the Wrist and the ACR–SPR–SSR Practice Parameter for the Performance and Interpretation of Magnetic Resonance Imaging (MRI) of the Ankle and Hindfoot [1,2].

MRI is a proven, established imaging modality for the detection, evaluation, staging, and follow up of musculoskeletal conditions of the fingers and toes in adults and children. Properly performed and interpreted, MRI not only contributes to diagnosis but also serves as an important guide to treatment planning and prognostication [3-9]. However, MRI should be performed only for a valid medical reason and only after careful consideration of alternative imaging modalities. The strengths of MRI and other modalities should be weighed against their suitability in particular patients and in particular clinical conditions.

Radiographs should be the initial imaging study for suspected abnormalities of the fingers and toes, such as fractures, dislocations, and the presence of radio-opaque foreign bodies [10]. Sequential images are a key component in the postoperative evaluation of joint arthroplasty and other orthopedic procedures. Bone scintigraphy and PET/CT are used to screen the entire skeleton for conditions such as metastases and can detect radiographically occult fractures and osteonecrosis, infection, and stress changes associated with tendon insertions [11-13]. Ultrasound can be used for detecting and evaluating tendon or ligament tears, tenosynovitis, inflammatory arthritis/erosions, soft-tissue foreign bodies, and soft-tissue masses or fluid collections [14-24]. Ultrasound can also be used to guide percutaneous procedures. Conventional arthrography usually performed in conjunction with MRI can be used to evaluate joint capsular abnormalities, such as ligament tears or volar/plantar plate tears, in select cases [25-27], but it has been largely replaced by MRI and ultrasound for this purpose.

Computed tomography (CT) is often preferred to MRI for detailed evaluation of bony alignment and cortical pathology. CT systems can employ software that increase the utility of CT for orthopedic purposes. The software includes multiplanar 2-D reformatting and 3-D volume rendering. Typical applications include evaluation of the joints after fracture dislocations [28], preoperative planning for osteotomies [29], and evaluation of bone or soft-tissue tumors [30,31]. CT can detect radiographically occult fractures and stress fractures of the hallux sesamoid bones [32]. CT can detect erosions in patients with arthritis, and dual-energy CT may be used in the diagnosis and management of gout [33,34].

Although MRI is often the most sensitive, noninvasive diagnostic test for detecting anatomic abnormalities of the fingers and toes, its findings may be misleading if not closely correlated with the clinical history, physical examination, physiologic tests, 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 fingers or toes include, but are not limited to, screening, diagnosis, exclusion, grading, and/or prognostication of suspected:
    1. Tendon tears, including flexor/extensor tendons and adductor/abductor tendons of the thumb and great toe [24,35-42]
    2. Plantar plate injuries of the toes [43-47]
    3. Ligament tears, traumatic and/or degenerative, including gamekeeper’s thumb [5,6,26], Stener lesion of the thumb [78-82]
    4. Annular pulley injuries of the fingers [48-54][1].
    5. Sagittal band and extensor hood injuries of the fingers [55,56].
    6. Subungual tumors, including glomus tumors [15,57-64]2
    7. Congenital anomalies [65,66]
    8. Osteomyelitis, septic arthritis, and soft-tissue infection [67-75]

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

Inflammatory arthritis, tenosynovitis, or enthesitis, including rheumatoid arthritis, juvenile idiopathic arthritis, seronegative arthritis, and connective tissue disease [16,18,76-89]
    1. Radiographically occult traumatic or stress/insufficiency fractures [32,35,87,90-97
    2. Morton’s neuroma [19,95,98-103][2]
    3. Primary and secondary bone and soft-tissue tumors [7,15,20,104-108][2] (See also the ACR–SSR Practice Parameter for the Performance and Interpretation of Magnetic Resonance Imaging (MRI) of Bone and Soft Tissue Tumors [109])
    4. Joint dislocations [110,111]

C. MRI of the fingers or toes may be useful to evaluate specific clinical scenarios, including, but not limited to:
    1. Prolonged, refractory, or unexplained pain or disability [112]
    2. Overuse syndromes [113]
    3. Sesamoiditis [32,95,96,114-119]

4. Freiberg infraction [92,120]
5. Bone and/or joint deformity with or without suspected soft-tissue abnormalities, acquired or congenital [65,121-125]
6. Trigger finger [126,127]
7. Preoperative planning [112,128]
8. Surveillance after surgery or postoperative complications [129-132][2]
9. Neuropathy [133,134]
10. Nonneoplastic reactive/proliferative disorders, such as bizarre parosteal osteochondromatous proliferation (Nora lesion) and intravascular papillary endothelial hyperplasia [135]
11. Disorders of unclear etiology such as microgeodic disease [136]

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[1] Conditions in which intravenous (IV) contrast may be useful.

III. QUALIFICATIONS AND RESPONSIBLITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [137].

IV. SAFETY GUIDELINES

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI), the ACR Manual on Contrast Media, and the ACR Guidance Document on MR Safe Practices [137-139].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [140].

V. SPECIFICATIONS OF THE EXAMINATION

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

The written or electronic request for MRI of the fingers or toes 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 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.

V. SPECIFICATIONS OF THE EXAMINATION

A. Patient Selection

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

Certain indications require administration of intravenous (IV) contrast media. IV contrast enhancement should be performed using appropriate injection protocols and in accordance with the institution's policy on IV contrast utilization (see the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [141]).

Young patients or patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of moderate sedation may be needed to achieve a successful examination. If moderate sedation is necessary, refer to the ACR–SIR Practice Parameter for Minimal and/or Moderate Sedation/Analgesia [142].

V. 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.

V. SPECIFICATIONS OF THE EXAMINATION

C. Examination Technique

Diagnostic-quality finger and toe 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 higher signal-to-noise ratios (SNRs) than lower-field systems, providing greater flexibility to obtain high-resolution images in a reasonable amount of time [40,143,144]. Specifically, 3T MRI systems offer higher SNRs and may offer improvements in assessment of joint erosions and small structures, such as joint cartilage, ligaments, and finger pulleys [42,51,79].

Unlike larger anatomic parts elsewhere in the body, high-resolution imaging of the small structures in the fingers and toes almost always requires the use of a local coil [6]. The coil should be as small as possible to provide a field of view (FOV) adequate to cover the area of interest. Multichannel coils can provide higher SNR. Coils with cylindrical housing into which the finger or toe can be placed, such as those designed for wrist or extremity imaging, are widely available and can provide extended FOV if necessary, such as for imaging the proximal extent of tendons, staging of tumors that may extend into the hand/wrist, or arthritis screening of the entire hand/wrist. Larger patients may require a knee/extremity coil as opposed to a wrist coil for adequate anatomic coverage of the toes. Specially designed small receiver coils can provide higher SNR with higher spatial resolution than larger coils but are not as widely available commercially [144,149].

For imaging of the fingers, the patient can be positioned supine or decubitus with the hand at the side of the patient. This is generally more comfortable for the patient than prone or semiprone positioning because it does not require shoulder abduction [6,150]. If coil design permits, the hand can also be placed overhead with the patient semiprone so that the fingers can be centered in the bore of the MRI unit to reduce field heterogeneity, which can be problematic with the hand at the periphery of the bore of the MRI unit. For certain clinical indications, such as inflammatory arthritis, simultaneous imaging of both hands in the "prayer position" can decrease examination time and facilitate assessment of disease symmetry [151,152]. Comfortable positioning and padding/splint immobilization of the fingers can minimize involuntary motion [6,150]. Fingers should generally be extended and aligned with the long axis of the fingers parallel to the main magnetic field of the MRI unit to minimize magic angle artifact. When imaging of an annular pulley injury, the finger of interest can be imaged at 35–40 degrees of flexion to depict bowstringing of the tendon as a secondary sign of pulley injury [48,153]. If the thumb is to be imaged along with the rest of the fingers, the thumb should be placed in adduction to prevent magic angle artifacts in the thumb tendons. If the thumb is of primary clinical interest, the hand should be positioned so that the thumb is aligned parallel to the main magnetic field in a slightly abducted position, which may necessitate slight wrist extension and placement of a towel roll or foam pad in the palm of the hand.

For imaging of the toes, coil choices will dictate patient positioning. A "chimney”-type extremity coil designed for imaging of the foot with the ankle in neutral position will require supine patient positioning. Other extremity coils and wrist coils may require ankle plantar flexion, which may be better maintained by prone patient positioning. This position may also reduce involuntary toe movement because it allows for better immobilization of the foot and may improve visualization of Morton neuromas [102]. Small surface coils may be used with the patient in either prone or supine position depending on patient comfort or the ability to effectively reduce patient motion. The toes should ideally be aligned parallel or perpendicular to the main magnetic field to minimize magic angle artifact. Saline bags or a silicone device [154] over the distal tips of the extremities can help reduce regional magnetic field inhomogeneity, allowing more uniform fat suppression [154].

Primary imaging planes for imaging of the fingers and toes depend on which structures are of clinical concern. The imaging planes for axial, coronal, and sagittal acquisitions need to be prescribed with respect to the fingers or toes rather than the hand or foot, respectively. If the thumb is of primary interest, it is important to describe the imaging planes along the planes of the thumb and not the fingers [42,155]. The collateral ligaments of the joints are best imaged along their course with axial or coronal images [156], whereas the course of the flexor and extensor tendons is best seen with sagittal images. The dorsal and volar/plantar joint capsule plates are also best seen with sagittal images [6,42,45]. The phalangeal physes and anomalous longitudinal epiphyseal brackets are best depicted on coronal images [65]. Joint alignment should be assessed on both sagittal and coronal images if a deformity is of clinical concern. The digital neurovascular bundles are best seen discretely on axial (short axis) images, as are the finger pulleys, the intersesamoidal ligaments, and intermetatarsal bursae. Axial images are used to evaluate rotational deformities, such as those secondary to fractures [29]. Oblique images aligned orthogonal to the phalanges may be helpful to view the various phalanges if there are deformities that prevent straightening of the digit during imaging [157]. Regardless of the anatomy of clinical interest, at least two orthogonal imaging planes should be used, one of which is axial . Many, if not most, cases will require a third orthogonal imaging plane.

As in all imaging procedures, the FOV should be tailored to the size of the patient and the structures being examined, with special care to minimize FOV in order to maximize spatial resolution. Typically, this should be 6-12 cm. Use of rectangular FOV for transverse and sagittal images will reduce scan time without sacrificing FOV by reducing the number of phase-encoding steps [158]. A larger FOV may be required if the source of pain originates from several different anatomic structures or abnormalities that extend proximally into the hand or foot. Examples of clinical scenarios that may require a larger FOV include tendon tears of indeterminate anatomic level, infection or tumors extending proximally, and inflammatory arthritis evaluation. Low-field MRI units may require a larger FOV to maintain adequate SNR at the expense of spatial resolution [159].

Slice thickness should be minimized as well to achieve small voxel volume and high spatial resolution, keeping SNR acceptably high. High-resolution imaging requires slice thickness of no more than 2 to 3 mm for sagittal and coronal images and 3 to 4 mm for transverse images. A 512 × 512 imaging matrix should be used as the SNR permits. High SNR systems such as 3T MRI units and specially designed local receiver coils may allow higher imaging resolutions, such as up to a 1,024 × 1,024 matrix. Increased imaging matrix size will generally increase scan time, which can lead to patient discomfort and involuntary motion. Parallel imaging, which is available on many MRI systems, allows faster image acquisition without a loss in image quality at the expense of occasional image reconstruction artifacts [160]. Parallel imaging can also mitigate undesired energy deposition on higher field MRI systems like 3T scanners [161]. An interslice gap can increase coverage and decrease signal loss due to crosstalk [162] but should be no more than 33% of the slice width and should not impair visualization of the intra-articular structures. Many modern MRI scanners exhibit minimal crosstalk, and a slice gap is not necessary in these cases.

A wide variety of pulse sequences is available to image the fingers and toes [42,163]. The choice of sequences, like other aspects of the imaging protocol, can be tailored to optimize the examination to answer specific clinical questions and may vary because of local preferences. Short repetition 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/long TE (T2-weighted), long TR/intermediate TE (intermediate-weighted), and short-tau inversion recovery (STIR) images are frequently obtained using FSE techniques for more rapid image acquisition than with SE techniques. Gradient-recalled sequences tend to produce larger artifacts and may result in lower soft-tissue contrast [164,165] but may be advantageous at lower field strengths [159] and for selected applications such as demonstration of hemosiderin in tumors [107] or evaluation of articular or unossified cartilage [149]. Gradient-echo and modified FSE sequences can also be acquired as a 3-D volume, which can produce images of high SNR and spatial resolution that may provide better assessment of joint cartilage and allow oblique image reformations as well [149,164]. Three-dimensional imaging is also used for MR angiography [166].

An imaging protocol will be composed of one or more pulse sequence types. For each sequence, the exact TR, TE, inversion time (TI), and flip angle chosen will depend on the field strength of the magnet and the desired image contrast weighting. A typical minimal MRI examination of the fingers and toes might consist of coronal or sagittal SE or FSE T1-weighted and fat-suppressed FSE T2- or intermediate-weighted or STIR images, and transverse T1-weighted and T2- or intermediate-weighted sequences [42,163]. The T1-weighted images optimally show anatomic details such as fracture lines and marrow signal abnormalities suggestive of marrow replacement, such as osteomyelitis or neoplasm, whereas T2-weighted, fat-suppressed intermediate-weighted, or STIR images demonstrate fluid collections and edema within the soft tissue and bone marrow; the combination is an effective screen for a variety of pathologies. T1-weighted sequences also have a role in characterizing various stages of hemorrhage [167] and for showing enhancement when IV gadolinium-based contrast agents are used [168]. T1-weighted images with fat suppression—either 2-D spin-echo or FSE [52] or 3-D spoiled gradient-echo [169]—are also used when MR arthrography or MR angiography is performed with a gadolinium-based contrast agent. At least one T2-weighted or proton-density weighted sequence with fat saturation should also be performed with MR arthrograms to show abnormalities that do not communicate with the injected joint. Additionally, at least 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 at the expense of some loss of SNR. Fat suppression can use spectral suppression of water protons, water excitation, a phase-dependent method such as the Dixon technique, or an STIR sequence [170-172]. The latter two methods may be necessary on low-field systems [173]. Fat suppression increases the conspicuity of marrow abnormalities and soft-tissue edema on fluid-sensitive sequences [174], and it is useful with a T1-weighted sequence when using gadolinium-based contrast agents [99]. Water excitation is an alternative to fat suppression and has been investigated for evaluating articular cartilage [175].

For specific finger and toe disorders, IV contrast may be useful. Contrast enhancement may increase the conspicuity of soft-tissue injuries such as pulley tears [52] or plantar plate tears [46]. IV contrast can also aid in the evaluation of disease activity in inflammatory arthritis and tenosynovitis [76,82]. IV contrast may be useful for characterizing tumors [7,15,105,107].

MR arthrography with injection of dilute gadolinium contrast into the joint (direct arthrography) may improve accuracy in the detection of thumb ulnar collateral ligament tears [26] and improve visualization of great toe structures [27].

Various techniques are used to reduce artifacts that can reduce imaging quality. When the FOV excludes parts of the hand or foot that are within the sensitivity range of the coil, aliasing artifacts can be reduced by phase oversampling, or by orienting the phase-encoding direction along the long axis of the finger or toe. Ensuring patient comfort combined with gentle immobilization or sedation when necessary best controls involuntary patient motion [180]. Presaturation pulses and/or gradient moment nulling will reduce ghosting artifacts caused by flowing blood [181,182].

Imaging near metallic implants requires special care to reduce susceptibility to artifacts. Swapping phase and frequency encoding directions based on the specific anatomic structures of interest adjacent to the hardware [183], orienting the long axis of the hardware as parallel to the direction of the main magnetic field [184], avoiding gradient-recalled sequences [165,185], and substituting STIR or Dixon techniques for chemical fat suppression [186] are important. FSE sequences with short interecho spacing, multiple refocusing pulses (long echo trains), and tailored RF pulses will further minimize metallic artifacts [187,188]. 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 MRI systems with wider available receiver bandwidths [165,187]. Artifacts from metal implants are less prominent on low-field systems compared with high-field systems [147]. View-angle tilting techniques and multispectral imaging (MAVRIC, SEMAC) may reduce artifact sizes as well [189-192].

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) [193] 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 [194].

At a minimum, the report should address any abnormalities in the bone marrow and cortex, tendons, and joints. In selected cases, a description of findings in ligaments, articular cartilage, growth cartilage, physes, synovium, plantar or volar plates, sesamoid bones, tendon sheaths, annular pulleys, extensor hoods, neurovascular structures, bursae, and nail beds would be appropriate. Whenever possible, the report should use standard anatomic nomenclature and precise terms and anatomic localization for describing identified abnormalities.

VII. EQUIPMENT SPECIFICATIONS

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

Equipment monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment [195].

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

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *Position Statement on QC & Improvement, Safety, Infection Control*, *and Patient Education* on the ACR website (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).

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 [136,188,189]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [190].

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