2006 (Res. 7,35)
Effective 10/01/06

PRACTICE GUIDELINE FOR THE PERFORMANCE AND INTERPRETATION OF PEDIATRIC MAGNETIC RESONANCE IMAGING (MRI)

PREAMBLE

These guidelines are an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. They are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care. For these reasons and those set forth below, the American College of Radiology cautions against the use of these guidelines in litigation in which the clinical decisions of a practitioner are called into question.

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

The practice of medicine involves not only the science, but also the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment.

Therefore, it should be recognized that adherence to these guidelines will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The sole purpose of these guidelines is to assist practitioners in achieving this objective.

I. INTRODUCTION

This guideline was developed and written collaboratively by the American College of Radiology (ACR) and the Society for Pediatric Radiology (SPR).

Magnetic resonance imaging (MRI) is a proven, established imaging modality for the detection, evaluation, assessment, staging, and follow-up of diseases. 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 only after careful consideration of alternative imaging modalities. An analysis of the strengths of MRI and other modalities should be weighed against their suitability in particular patients and in particular clinical conditions.

This guideline will address the following areas: chest, abdomen, pelvis, shoulder, elbow, hand/wrist, hip/thigh, knee, and foot/ankle.

While MRI is often the most sensitive, noninvasive diagnostic test for detecting anatomic abnormalities, its findings may be misleading if not closely correlated with

the clinical history, clinical and physical examination, radiographs and other imaging studies, and with physiologic tests such as pulmonary function tests, manometry, and electrocardiography. Adherence to the following guidelines will enhance the probability of detecting such abnormalities.

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

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

III. INDICATIONS

Primary indications for MRI include, but are not limited to, the following:

A. Chest [1-19]
   1. Suspected extracardiac vascular disorders:
      a. These include congenital vascular abnormalities such as vascular rings, pulmonary slings, pulmonary vein abnormalities (e.g., anomalous course), systemic-to-pulmonary collateral vessels or other congenital processes, including known or suspected bronchopulmonary sequestration. Assessment of these vascular structures postoperatively is also a potential primary application where evaluation is not limited by surgical hardware or the presence of a cardiac pacer. Inherited diseases predisposing the child to vascular disorders (e.g., aortic aneurysm or dilation in Marfan syndrome) are also a potentially primary application for MR in the pediatric chest.
      b. In addition, acquired disorders of the great vessels (e.g., medium or large vessel vasculitides, aneurysms, infectious or other inflammatory conditions) and posttraumatic evaluation are potential primary applications. Assessment includes acute aortic dissection or transection and pulmonary embolus in settings where CT is contraindicated, such as contraindication for iodinated contrast media.
      c. For cardiac evaluation, see the ACR Practice Guideline for the Performance and Interpretation of Cardiac Magnetic Resonance Imaging (MRI).
   2. Evaluation of suspected or known posterior mediastinal processes, especially masses, and evaluation of other mediastinal processes not adequately assessed by radiography or ultrasonography. CT is a primary consideration for mediastinal disorders if lung parenchymal detail or airway information is necessary.
   3. Evaluation of chest wall disorders, including mass (e.g., vascular malformations), or mass-like conditions, inflammation/infection, trauma, or congenital abnormality not adequately addressed by radiography or sonography.
   4. Evaluation of parenchymal disorders by MRI should follow consideration of radiographic and CT assessment. Exceptions include, but are not limited to, secondary involvement of regions listed above (mediastinum, great vessels, and chest wall) by primary lung disorders such as infection.

B. Abdomen [20-27]
   1. Evaluation of neoplastic conditions, vascular malformations, or other suspected or known mass or mass-like condition particularly of the liver, adrenal gland, and kidney.
   2. Suspected or known biliary disorders (e.g., obstruction) or pancreatic ductal disorders when sonography is inconclusive.
   3. Assessment of congenital or acquired urinary obstruction, or other urinary tract anomalies (such as mass) where sonography is inconclusive. Dynamic, contrast enhanced renal MRI can also be used in assessing renovascular causes of hypertension or for assessing known or suspected asymmetric decreased renal function.
   4. Diagnosing or assessing involvement in patients with inflammatory bowel disease as an adjunct to conventional radiographic, fluoroscopic, or CT evaluation.
   5. Assessment of diffuse liver disease, including fatty infiltration and iron overload.
   6. Vascular mapping (covered elsewhere).
   7. Assessment of inflammatory, traumatic, congenital, or neoplastic or mass-like disorders of the abdominal wall not adequately assessed by sonography.
   8. Patients with indication for contrast enhanced abdominal CT who have contraindication to iodinated intravenous contrast material.

C. Pelvis [28-34]
   1. Congenital anomalies of the genital tract suspected or not adequately assessed by sonography.
   2. Anorectal malformations, preoperatively or postoperatively.
   3. Inflammatory conditions such as osteomyelitis of the pelvic bones, myositis, or other complex inflammatory conditions not adequately assessed by sonography.
   4. Mass or mass-like conditions of pelvic organs, including vascular malformations for diagnosis, therapeutic planning, and surveillance.
   5. Assessment of arterial or venous patency in a setting of suspected thrombosis, assessment of vascular access, or therapeutic planning.

6. Patients with indication for pelvic CT, but who have an allergy to iodinated contrast or a contraindication to CT.

D. Shoulder [35-43]
   1. Evaluation of acute and/or chronic trauma with suspected internal derangement.
   2. Evaluation of trauma or dislocation complications (such as glenoid labral tear).
   3. Avascular necrosis or bone infarct with normal radiographs.
   4. Diagnosis and/or follow-up of suspected bone or soft tissue mass or mass-like condition or vascular malformation.
   5. Complicated bone, soft tissue, or articular infection or inflammation.
   6. Unexplained suspected arthritis or known arthritis for assessment of joint damage and/or active synovitis.
   7. Congenital malformations not adequately assessed by conventional radiographs or sonography.
   8. Unexplained persistent pain and/or swelling.
   9. Evaluation of suspected bone marrow abnormality.

E. Elbow [44-52]
   1. Evaluation of acute and/or chronic trauma with suspected internal derangement.
   2. Follow-up of fracture complications (such as premature growth plate fusion and intra-articular loose bodies).
   3. Diagnosis and/or follow-up of osteochrondritis dessicans.
   4. Diagnosis and/or follow-up of suspected bone or soft tissue mass or mass-like condition or vascular malformation.
   5. Complicated bone, soft tissue, or articular infection or inflammation.
   6. Unexplained suspected arthritis or known arthritis for assessment of joint damage and/or active synovitis.
   7. Congenital malformations not adequately assessed by conventional radiographs or sonography.
   8. Unexplained persistent pain and/or swelling.
   9. Evaluation of suspected bone marrow abnormality.

F. Hand and Wrist [53-61]
   1. Evaluation of acute and/or chronic trauma with suspected internal derangement.
   2. Evaluation of fracture complications (such as premature growth plate fusion).
   3. Diagnosis and/or follow-up of osteochondritis dessicans.
   4. Diagnosis and/or follow-up of suspected bone or soft tissue mass or mass-like condition or vascular malformation.
   5. Complicated bone, soft tissue, or articular infection or inflammation.
   6. Unexplained suspected arthritis or known arthritis for assessment of joint damage and/or active synovitis.
   7. Congenital malformations not adequately assessed by conventional radiographs.
   8. Unexplained persistent pain and/or swelling.
   9. Evaluation of suspected bone marrow abnormality.

G. Hip and Thigh [62-73]
   1. Evaluation of acute and/or chronic trauma with suspected internal derangement including labral tears and occult fractures. This includes suspected slipped capital femoral epiphysis.
   2. Evaluation of complications of prior trauma (including loose bodies and chondrolysis).
   3. Suspected complicated bone, soft tissue, or articular infection.
   4. Noninfectious inflammatory conditions of joint or soft tissue (e.g., dermatomyositis).
   5. Suspected or know bone or soft tissue mass or mass-like condition for diagnosis and/or follow-up.
   6. Suspected avascular necrosis (including Legg-Calve-Perthes) or bone infarct with normal radiographs.
   7. Congenital malformations not adequately assessed by conventional radiographs or sonography, including postoperative assessment of reduction of congenital hip dislocation.
   8. Evaluation of suspected bone marrow abnormality.
   9. Persistent pain and/or swelling unexplained by other methods.

H. Knee [74-90]
   1. Evaluation of acute and/or chronic trauma with suspected internal derangement.
   2. Grading or follow-up of osteochrondritis dessicans.
   3. Follow-up of fracture complications (such as premature growth plate fusion, intra-articular loose bodies, and nonunion).
   4. Suspected bone or soft tissue mass or mass-like condition for diagnosis and/or follow-up.
   5. Suspected avascular necrosis or bone infarct with normal radiographs.
   6. Complicated bone, soft tissue, or articular infection or inflammation.
   7. Unexplained suspected arthritis or known arthritis for assessment of joint damage and/or active synovitis.

8. Congenital or syndromic malformations not adequately assessed by conventional radiographs.
9. Unexplained persistent pain and/or swelling.
10. Evaluation of suspected bone marrow abnormality.

I. Foot and Ankle [91-101]
1. Evaluation of acute and/or chronic trauma with suspected internal derangement.
2. Follow-up of fracture complications (such as premature growth plate fusion and intra-articular loose bodies).
3. Diagnosis and/or follow-up of osteochrondritis dessicans.
4. Diagnosis and/or follow-up of suspected bone or soft tissue mass or mass-like condition or vascular malformation.
5. Complicated bone, soft tissue, or articular infection or inflammation.
6. Unexplained suspected arthritis or known arthritis for assessment of joint damage and/or active synovitis.
7. Congenital malformations not adequately assessed by conventional radiographs.
8. Evaluation of suspected marrow disorder.
9. Unexplained persistent pain and/or swelling.

IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the ACR Practice Guideline for Performing and Interpreting Magnetic Resonance Imaging (MRI) and the ACR White Paper on Magnetic Resonance Safety.

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

V. SPECIFICATIONS OF THE EXAMINATION

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

The written or electronic request for pediatric MRI examinations 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. 2006 (Res. 35)

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

A. Patient Selection

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

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

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

B. Facility Requirements

An appropriately equipped emergency cart must be immediately available to treat adverse reactions associated with administered medications. The cart should be monitored for inventory and drug expiration dates on a regular basis and comply with institutional policies.

C. Examination Technique

1. Chest

   The coil used varies depending on the size of the infant/child's chest. In general, the radiologist strives to use smallest coil possible to achieve most optimal signal to noise ratio and spatial resolution. For example, an infant's chest may be optimally assessed using a head coil. A torso phased array coil is often used for larger children.

   Imaging sequences should include a combination of T1-weighted, proton density, and/or T2-weighted sequences in at least two planes (axial, sagittal, or coronal, or slight obliquities thereof). The slice thickness will vary depending on the size of the area of concern and the size of the patient. Slice thickness can be 3 mm, 4 mm, or 5 mm for spin echo images. Use of chemical fat saturating pulses with fast or turbo spin echo sequences may improve detection of pathology on proton density and T2-weighted sequences. Short TI inversion recovery (STIR) sequences can also be used as an alternative or as an adjunct to sequences with chemical fat saturation. Additional sequences to visualize vascularity may be performed. These include 2D or 3D time-of-flight (TOF) gradient echo sequences, phase contrast, and postgadolinium 3D angiographic sequences. These are often volume acquired with display thickness of 1 mm or 1.5 mm.

   The use of intravenous contrast agents such as gadolinium chelates may be helpful in situations such as mass/tumor evaluation/follow up and infectious or inflammatory conditions.

2. Abdomen

   Coil selection will depend on patient size and the region being imaged. In small neonates, a surface, head, or spine coil should be considered while larger patients may be imaged with a cardiac, torso, spine, or body coil. Commercially available combined coil arrays may also be suitable.

   Imaging sequences should include T1- and T2-weighted sequences, preferably in two planes. This can be achieved using conventional, fast or turbo spin echo, or gradient echo sequences with slice thickness dependent on the area to be imaged (usually 4-8 mm). Heavily T2-weighted fast sequences are useful for evaluating fluid filled structures, such as the biliary tree and urinary and GI tract. Vendor supplied physiologic motion suppression techniques and software may help optimize image quality, as can breath-hold sequences.

   Use of intravenous contrast agents such as gadolinium chelates may increase conspicuity of lesions. Dynamic enhancement sequences may help in lesion characterization. For MR urographic evaluation, delayed evaluation following contrast administration in coronal plane (with or without the axial plane) may be useful in evaluating the urinary collecting system.

3. Pelvis

   Coil selection and field of view will depend on patient size and the region being imaged. In small neonates, a surface, head, or spine coil should be considered while larger patients may be imaged with a cardiac, torso, spine, or body coil. Commercially available combined coil arrays may also be suitable.

   Imaging sequences should include T1- and T2-weighted sequences, preferably in two planes. This can be achieved using conventional, fast or turbo spin echo, or gradient echo sequences with slice thickness dependent on the area to be imaged (usually 4-8 mm). Fat suppression techniques with T2 weighting are optional as are in-phase and out-of-phase imaging sequences. Vendor supplied physiologic motion suppression techniques and software may help optimize image quality.

   Use of intravenous contrast agents such as gadolinium chelates may increase conspicuity of pathology and define avascular areas.

4. Shoulder

   Coil selection will depend on patient size and the size of the area to be imaged. For very tiny patients, the smallest available surface coil is appropriate. Most shoulder abnormalities in children and adolescents should be adequately evaluated with a dedicated shoulder coil. For larger patients or when both shoulders are being imaged for comparison, a cardiac, torso, or body coil may be necessary.

   Imaging sequences should include a combination of T1-weighted, proton density, and/or T2-weighted sequences in at least two planes (axial, sagittal, or coronal with obliquities as necessary for anatomy) with slice thickness preferably in the range of 3-5 mm. Slice thickness may be altered depending on the area being imaged. Use

of chemical fat saturating pulses with fast or turbo spin echo sequences may improve detection of pathology on T2-weighted sequences. Short TI inversion recovery (STIR) sequences may be more appropriate at low field strengths or as an alternative to chemical fat saturation. Optional series such as gradient echo sequences (2D or 3D) may help supplement evaluation of cartilaginous structures.

The use of intravenous contrast agents such as gadolinium chelates is optional in several circumstances such as evaluation or follow up of tumors and diagnosis of infectious or inflammatory conditions. Intra-articular administration of contrast prior to scanning may be indicated in select cases where labral pathology or intra-articular loose body is the main diagnostic consideration. Indirect MR arthrography may be achieved by delayed imaging after intravenous contrast administration though without the benefit of capsular distension.

5. Elbow
   Coil selection will depend on patient size and the size of the region to be imaged. Small surface coils are appropriate for small patients or where high resolution of small structures is necessary. A dedicated elbow or extremity coil will be appropriate in most patients with elbow pathology. For larger areas or when standard elbow positioning is not possible, a head, cardiac, or torso coil can be used.

   Imaging sequences should include a combination of T1-weighted, proton density, and/or T2-weighted sequences in at least two planes (axial, sagittal, or coronal with obliquities as necessary for anatomy) with slice thickness preferably in the range of 3-5 mm. Slice thickness may be altered depending on the area being imaged. Use of chemical fat saturating pulses with fast or turbo spin echo sequences may improve detection of pathology on T2-weighted sequences. Short TI inversion recovery (STIR) sequences may be more appropriate at low field strengths or as an alternative to chemical fat saturation. Optional series such as gradient echo sequences (2D or 3D) may help supplement evaluation of cartilaginous structures.

   The use of intravenous contrast agents such as gadolinium chelates is optional in several circumstances such as evaluation or follow up of tumors and diagnosis of infectious or inflammatory conditions. Intra-articular administration of contrast prior to scanning may be indicated in select cases where intra-articular loose body or cartilage integrity is the main diagnostic consideration. Indirect MR arthrography may be achieved by delayed imaging after intravenous contrast administration though without the benefit of capsular distension.

6. Hand and Wrist
   Coil selection will depend on patient size and the size of the region to be imaged. Small surface coils are appropriate for small patients or where high resolution of small structures is necessary. A dedicated wrist coil is preferred for most wrist pathology. An extremity coil may be required in larger patients or where both wrist and hand are to be imaged together.

   Imaging sequences should include a combination of T1-weighted, proton density, and/or T2-weighted sequences in at least two planes (axial, sagittal, or coronal with obliquities as necessary for anatomy) with slice thickness preferably in the range of 2-5 mm. Slice thickness may be altered depending on the area being imaged. Use of chemical fat saturating pulses with fast or turbo spin echo sequences may improve detection of pathology on T2-weighted sequences. Short TI inversion recovery (STIR) sequences may be more appropriate at low field strengths or as an alternative to chemical fat saturation. Optional series such as gradient echo sequences (2D or 3D) may help supplement evaluation of cartilaginous structures.

   The use of intravenous contrast agents such as gadolinium chelates is optional in several circumstances such as evaluation or followup of tumors and diagnosis of infectious or inflammatory conditions. Intra-articular administration of contrast prior to scanning the wrist may be indicated in select cases such as where ligamentous injury is the main diagnostic consideration. Indirect MR arthrography may be achieved by delayed imaging after intravenous contrast administration though without the benefit of capsular distension.

7. Hip and Thigh
   Coil selection will depend on the size of the patient being imaged and the spatial detail required based on the indication for imaging. The body coil may be required for large patients where high spatial detail is not necessary whereas a small surface coil may be more appropriate for a small patient in whom greater anatomic detail is required. For most pediatric

patients, a torso, cardiac, or head coil will be appropriate for imaging either one or both hips.

Imaging sequences should include a combination of T1-weighted, proton density, and/or T2-weighted sequences in at least two planes (axial, sagittal, or coronal, or slight obliquities thereof) with slice thickness preferably in the range of 3-5 mm though slice thickness may need to be increased where larger areas need to be covered such as the thighs. Use of chemical fat saturating pulses with fast or turbo spin echo sequences may improve detection of pathology on T2-weighted sequences. Short TI inversion recovery (STIR) sequences may be more appropriate at low field strengths or as an alternative to chemical fat saturation. Optional series such as gradient echo sequences (2D or 3D) may help supplement evaluation of cartilaginous structures.

The use of intravenous contrast agents such as gadolinium chelates are optional in several circumstances such as evaluation or follow up of tumors and diagnosis of infectious or inflammatory conditions. Intra-articular administration of contrast prior to scanning may be helpful in select cases where labral tear and/or intra-articular loose body are the main diagnostic considerations. Indirect MR arthrography may be achieved by delayed imaging after intravenous contrast administration though without the benefit of capsular distension.

8. Knee
   Ideally, the use of a dedicated knee or extremity coil is preferred. For smaller knees, small parts coils or surface coils may be more appropriate. In the setting of physical limitations such as large patient size or knee contracture, larger coils such as a head, cardiac, or torso coil may be necessary.

   Imaging sequences should include a combination of T1-weighted, proton density, and/or T2-weighted sequences in at least two planes (axial, sagittal, or coronal, or slight obliquities thereof) with slice thickness in the range of 3-5 mm. Slice thickness may need to be increased to improve coverage in select circumstances. Use of chemical fat saturating pulses with fast or turbo spin echo sequences may improve detection of pathology on T2-weighted sequences. Short TI inversion recovery (STIR) sequences may be more appropriate at low field strengths or as an alternative to chemical fat saturation. Optional series such as gradient echo sequences (2D or 3D) may help supplement evaluation of cartilaginous structures.

   The use of intravenous contrast agents such as gadolinium chelates are optional in several circumstances such as evaluation or follow up of tumors and diagnosis of infectious or inflammatory conditions.

   Intra-articular administration of contrast prior to scanning may be helpful where cartilage integrity or meniscal injury after previous meniscal surgery is the main diagnostic consideration.

9. Foot and Ankle
   Coil selection will depend on patient size and area to be imaged. Small surface coils are more appropriate for imaging babies and smaller children or when higher resolution is needed to evaluate small structures. For older children, an extremity/knee coil is usually appropriate though a head coil may be used especially when imaging both feet and ankles together. In some cases, a torso coil may be necessary to evaluate more extensive areas of abnormality into the calf.

   Imaging sequences should include a combination of T1-weighted, proton density, and/or T2-weighted sequences in at least two planes (axial, sagittal, or coronal with obliquities as necessary for anatomy) with slice thickness preferably in the range of 3-5 mm. Slice thickness may be altered depending on the area being imaged. Use of chemical fat saturating pulses with fast or turbo spin echo sequences may improve detection of pathology on T2-weighted sequences. Short TI inversion recovery (STIR) sequences may be more appropriate at low field strengths or as an alternative to chemical fat saturation. Optional series such as gradient echo sequences (2D or 3D) may help supplement evaluation of cartilaginous structures.

   The use of intravenous contrast agents such as gadolinium chelates is optional in several circumstances such as evaluation or follow up of tumors and diagnosis of infectious or inflammatory conditions. Intra-articular administration of contrast prior to scanning may be helpful in select cases where intra-articular loose body or cartilage integrity is the main diagnostic consideration. Indirect MR arthrography may be achieved by delayed imaging after intravenous contrast administration though without the benefit of capsular distension.

Examinations that employ techniques not approved by the Food and Drug Administration —— such as the intra-articular injection of gadolinium chelates —— should be considered only when they are judged to be medically appropriate.

VI. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Guideline for Communication of Diagnostic Imaging Findings.

VII. EQUIPMENT SPECIFICATIONS

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

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

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 Concerns appearing elsewhere in the ACR Practice Guidelines and Technical Standards book.

Specific policies and procedures related to MRI safety should be in place with documentation that is updated annually and compiled under the supervision and direction of the supervising MRI physician. Guidelines should be provided that deal with potential hazards associated with the MRI examination of the patient as well as to others in the immediate area. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination.

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

ACKNOWLEDGEMENTS

This guideline was developed according to the process described in the ACR Practice Guidelines and Technical Standards book by the ACR Commission on Body Imaging in collaboration with the Society for Pediatric Radiology.

Principal Drafter: Donald P. Frush, MD

Society for Pediatric Radiology, CT and MR Committee
Kathleen Emery, MD
Sunny Pitts, MD
Ian Cassell, MD

Additional Committee Member
Elmar Merkle, MD

Commission on Body Imaging
N. Reed Dunnick, MD, Chair
Lincoln L. Berland, MD
Jeffrey J. Brown, MD
Ella A. Kazerooni, MD
Donald G. Mitchell, MD
Geoffrey D. Rubin, MD
Meghan E. Blake, MD

REFERENCES/LITERATURE REVIEW

1. Siegel MJ, Luker GD. Pediatric chest MR imaging: noncardiac clinical uses. *Magn Reson Imaging Clin N Am* 1996;4:599-613.
2. Hernandez RJ. Magnetic resonance imaging of mediastinal vessels. *Magn Reson Imaging Clin N Am* 2002;10:237-251.
3. Neimatallah MA, Ho VB, Dong Q, et al. Gadolinium-enhanced 3D magnetic resonance angiography of the thoracic vessels. *J Magn Reson Imaging* 1999;10:758-770.
4. Beekman RP, Hazekamp MG, Sobotka MA, et al. A new diagnostic approach to vascular rings and pulmonary slings: the role of MRI. *Magn Reson Imaging* 1998;16:137-145.
5. Simoneaux SF, Bank ER, Webber JB, et al. MR imaging of the pediatric airway. *Radiographics* 1995;15:287-298.
6. Aluquin VP, Albano SA, Chan F, et al. Magnetic resonance imaging in the diagnosis and follow up of Takayasu's arteritis in children. *Ann Rheum Dis* 2002;61:526-529.
7. Karmazyn B, Davis MM, Davey MS, et al. Imaging evaluation of chest wall tumors in children. *Acad Radiol* 1998;5:642-654.
8. Newman B, Gondor M. MR evaluation of right pulmonary agenesis and vascular airway compression in pediatric patients. *AJR* 1997;168:55-58.
9. Siegel MJ, Ishwaran H, Fletcher BD, et al. Staging of neuroblastoma at imaging: report of the Radiology Diagnostic Oncology Group. *Radiology* 2002;223:168-175.
10. Groom KR, Murphey MD, Howard LM, et al. Mesenchymal hamartoma of the chest wall: radiologic manifestations with emphasis on cross-

sectional imaging and histopathologic comparison. *Radiology* 2002;222:205-211.
11. Donnelly LF, Bisset GS 3rd. Airway compression in children with abnormal thoracic configuration. *Radiology* 1998;206:323-326.
12. Lee KH, Yoon CS, Choe KO, et al. Use of imaging for assessing anatomical relationships of tracheobronchial anomalies associated with left pulmonary artery sling. *Pediatr Radiol* 2001;31:269-278.
13. Moeller KH, Rosado-de-Christenson ML, Templeton PA. Mediastinal mature teratoma: imaging features. *AJR* 1997;169:985-990.
14. Wagner M, Bowing B, Kuth R, et al. Low field thoracic MRI: a fast and radiation free routine imaging modality in children. *Magn Reson Imaging* 2001;19:975-983.
15. Sallustio G, Pirronti T, Lasorella A, et al. Diagnostic imaging of primitive neuroectodermal tumor of the chest wall (Askin tumor). *Pediatr Radiol* 1998;28:697-702.
16. Hungate RG, Newman B, Meza MP. Left mainstem bronchial narrowing: a vascular compression syndrome? Evaluation by magnetic resonance imaging. *Pediatr Radiol* 1998;28:527-532.
17. Slovis TL, Meza MP, Cushing B, et al. Thoracic neuroblastoma: what is the best imaging modality for evaluating extent of disease? *Pediatr Radiol* 1997;27:273-275.
18. Donnelly LF, Strife JL, Bailey WW. Extrinsic airway compression secondary to pulmonary arterial conduits: MR findings. *Pediatr Radiol* 1997;27:268-270.
19. Newman B, Meza MP, Towbin RB, et al. Left pulmonary artery sling: diagnosis and delineation of associated tracheobronchial anomalies with MR. *Pediatr Radiol* 1996;26:661-668.
20. Carneiro RC, Fordham LA, Semelka RC. MR imaging of the pediatric liver. *Magn Reson Imaging Clin N Am* 2002;1:137-164.
21. Darbari A, Sena L, Argani P, et al. Gadolinium-enhanced magnetic resonance imaging: a useful radiological tool in diagnosing pediatric IBD. *Inflamm Bowel Dis* 2004;2:67-72.
22. Gylys-Morin V, Hoffer FA, Kozakewich H, et al. Wilms tumor and nephroblastomatosis: imaging characteristics at gadolinium-enhanced MR imaging. *Radiology* 1993;88:517-521.
23. Jones RA, Perez-Brayfield MR, Kirsch AJ, et al. Renal transit time with MR urography in children. *Radiology* 2004;233:41-50.
24. Meyer JS, Harty MP, Khademian Z. Imaging of neuroblastoma and Wilms' tumor. *Magn Reson Imaging Clin N Am* 2002;2:275-302.
25. Noone TC, Semelka RC, Chaney DM, et al. Abdominal imaging studies: comparison of diagnostic accuracies resulting from ultrasound, computed tomography, and magnetic resonance imaging in the same individual. *Magn Reson Imaging* 2004;22:19-24.
26. Pfluger T, Schmied C, Porn U, et al. Integrated imaging using MRI and 123I metaiodo-benzylguanidine scintigraphy to improve sensitivity and specificity in the diagnosis of pediatric neuroblastoma. *AJR* 2003;181:1115-1124.
27. Sofka CM, Semelka RC, Kelekis NL, et al. Magnetic resonance imaging of neuroblastoma using current techniques. *Magn Reson Imaging* 1999;17:193-198.
28. Economy KE, Barnewolt C, Laufer MR. A comparison of MRI and laparoscopy in detecting pelvic structures in cases of vaginal agenesis. *J Pediatr Adolesc Gynecol*. 2002;15:101-104.
29. Lang IM, Babyn P, Oliver GD. MR imaging of paediatric uterovaginal anomalies. *Pediatr Radiol* 1999;29:163-170.
30. McHugh K, Dudley NE, Tam P. Pre-operative MRI of anorectal anomalies in the newborn period. *Pediatr Radiol* 1995;25:S33-36.
31. Sachs TM, Applebaum H, Touran T, et al. Use of MRI in evaluation of anorectal anomalies. *J Pediatr Surg* 1990;25:817-821.
32. Siegel MJ. Magnetic resonance imaging of the adolescent female pelvis. *Magn Reson Imaging Clin N Am* 2002;10:303-324.
33. Siegel MJ, Hoffer FA. Magnetic resonance imaging of nongynecologic pelvic masses in children. *Magn Reson Imaging Clin N Am* 2002;10:325-344.
34. Troiano RN, McCarthy SM. Mullerian duct anomalies: imaging and clinical issues. *Radiology* 2004;233:19-34.
35. Azouz EM, Oudjhane K. Disorders of the upper extremity in children. *Magn Reson Imaging Clin N Am* 1998;6:677-695.
36. Chung CB, Corrente L, Resnick D. MR arthrography of the shoulder. *Magn Reson Imaging Clin N Am* 2004;12:25-38.
37. Harty MP, Mahboubi S, Meyer JS, et al. MRI of the pediatric shoulder: nontraumatic lesions. *Eur Radiol* 1997;7:352-360.
38. Kothari NA, Pelchovitz DJ, Meyer JS. Imaging of musculoskeletal infections. *Radiol Clin North Am* 2001;39:653-671.
39. Long G, Cooper JR, Gibbon WW. Magnetic resonance imaging of injuries in the child athlete. *Clin Radiol* 1999;54:781-791.
40. Ritchie DA, Davies AM. MR imaging of tumors and tumor-like lesions of the shoulder girdle. *Magn Reson Imaging Clin N Am* 2004;12:125-141.
41. Steinbach LS, Palmer WE, Schweitzer ME. MR arthrography. *Radiographics* 2002;22:1223-1246.
42. Waters PM, Smith GR, Jaramillo D. Glenohumeral deformity secondary to brachial plexus birth palsy. *J Bone and Joint Surg Am* 1998;80:668-677.

43. Weishaupt D, Schweitzer ME. MR imaging of septic arthritis and rheumatoid arthritis of the shoulder. *Magn Reson Imaging Clin N Am* 2004;12:111-124.
44. Azouz EM, Oudjhane K. Disorders of the upper extremity in children. *Magn Reson Imaging Clin N Am* 1998;6:677-695.
45. Bowen RE, Otsuka NY, Yoon ST, et al. Osteochondral lesions of the capitellum in pediatric patients: role of magnetic resonance imaging. *J Pediatr Orthop* 2001;21:298-301.
46. Chung CB, Kim HJ. Sports injuries of the elbow. *Magn Reson Imaging Clin N Am* 2003;11:239-253.
47. Griffith JF, Roebuck DJ, Cheng JC, et al. Acute elbow trauma in children: spectrum of injury revealed by MR imaging not apparent in radiographs. *AJR* 2001;176:53-60.
48. Jbara M, Patnana M, Kazma F, et al. MR imaging: arthropathies and infectious conditions of the elbow, wrist, and hand. *Magn Reson Imaging Clin N Am* 2004;12:361-379.
49. Kothari NA, Pelchovitz DJ, Meyer JS. Imaging of musculoskeletal infections. *Radiol Clin North Am* 2001;39:653-671.
50. Long G, Cooper JR, Gibbon WW. Magnetic resonance imaging of injuries in the child athlete. *Clin Radiol* 1999;54:781-791.
51. Shankman S, Kolla S, Beltran J. MR imaging of tumors and tumor-like lesions of the upper extremity. *Magn Reson Imaging Clin N Am* 2004;12:349-359.
52. Steinbach LS, Palmer WE, Schweitzer ME. MR arthrography. *Radiographics* 2002;22:1223-1246.
53. Azouz EM, Oudjane K. Disorders of the upper extremity in children. *Magn Reson Imaging Clin N Am* 1998;6:677-695.
54. Azouz EM, Babyn PS, Mascia AT, et al. MRI of the abnormal pediatric hand and wrist with plain film correlation. *J Comput Assist Tomogr* 1998;22:252-261.
55. Cook PA, Yu JS, Wiand W, et al. Suspected scaphoid fractures in skeletally immature patients: application of MRI. *J Comput Assist Tomogr* 1997;4:511-515.
56. Hobby JL, Dixon AK, Bearcroft PW, et al. MR imaging of the wrist: effect on clinical diagnosis and patient care. *Radiology* 2001;220:589-593.
57. Jbara M, Patnana M, Kazmi F, et al. MR imaging: arthropathies and infectious conditions of the elbow, wrist, and hand. *Magn Reson Imaging Clin N Am* 2004;12:361-379.
58. Kothari NA, Pelchovitz DJ, Meyer JS. Imaging of musculoskeletal infections. *Radiol Clin N Am* 2001;39:653-671.
59. Long G, Cooper JR, Gibbon WW. Magnetic resonance imaging of injuries in the child athlete. *Clin Radiol* 1999;54:781-791.
60. Shankman S, Kolla S, Beltran J. MR imaging of tumors and tumor-like lesions of the upper extremity. *Magn Reson Imaging Clin N Am* 2004;12:349-359.
61. Steinbach LS, Palmer WE, Schweitzer ME. MR arthrography. *Radiographics* 2002;22:1223-1246.
62. Argyropoulou MI, Fanis SL, Xenakis T, et al. The role of MRI in the evaluation of hip joint disease in clinical subtypes of juvenile idiopathic arthritis. *Br J Radiol* 2002;75:229-233.
63. Boutin RD, Newman JS. MR imaging of sports-related hip disorders. *Magn Reson Imaging Clin N Am* 2003;11:255-281.
64. Buchmann RF, Jaramillo D. Imaging of articular disorders in children. *Radiol Clin North Am* 2004;42:151-168.
65. Gabriel H, Fitzgerald SW, Myers MT, et al. MR imaging of hip disorders. *Radiographics* 1994;14:763-781.
66. Hernandez RJ, Teo EH. Diffuse marrow disorders in children. *Magn Reson Imaging Clin N Am* 1998;6:605-626.
67. Hernandez RJ, Sullivan DB, Chenevert TL, et al. MR imaging in children with dermatomyositis: musculoskeletal findings and correlation with clinical and laboratory findings. *AJR* 1993;161:359-366.
68. Johnson K, Haigh SF, Ehtisham S, et al. Childhood idiopathic chondrolysis of the hip: MRI features. *Pediatr Radiol* 2003;33:194-199.
69. Laor T, Burrows PE. Congenital anomalies and vascular birthmarks of the lower extremities. *Magn Reson Imaging Clin N Am* 1998;6:497-519.
70. Laor T, Roy DR, Mehlman CT. Limited magnetic resonance imaging examination after surgical reduction of developmental dysplasia of the hip. *J Pediatr Orthop* 2000;20:572-574.
71. Sebag GH. Disorders of the hip. *Magn Reson Imaging Clin N Am* 1998;6:627-641.
72. Steinbach LS, Palmer WE, Schweitzer ME. Special focus session: MR arthrography. *Radiographics* 2002;22:1223-1246.
73. Vialle R, Pannier S, Odent T, et al. Imaging of traumatic dislocation of the hip in childhood. *Pediatr Radiol* 2004;34:970-979.
74. Al-Otaibi L, Siegel MJ. The pediatric knee. *Magn Reson Imaging Clin N Am* 1998; 43-660.
75. Connolly LP, Connolly SA, Drubach LA, et al. Acute hematogenous osteomyelitis of children: assessment of skeletal scintigraphy-based diagnosis in the era of MRI. *J Nucl Med* 2002;43:1310-1316.
76. Craig JG, van Holsbeeck M, Zaltz I. The utility of MR in assessing Blount disease. *Skeletal Radiol* 2002;31:208-213.
77. Gylys-Morin VM, Graham, TB, Blebea JS, et al. Knee in early juvenile rheumatoid arthritis: MR imaging findings. *Radiology* 2001;220:696-706.
78. Hempfing A, Placzek R, Gottsche T, et al. Primary subacute epiphyseal and metaepiphyseal osteomyelitis in children: diagnosis and treatment guided by MRI. *J Bone Joint Surg Br* 2003;85:559-564.

79. Jaramillo D, Laor T, Gebheardt MC. Pedatric musculoskeletal neoplasms: evaluation with MR images. *Magn Reson Imaging Clin N Am* 1996;4:749-770.
80. Kleinman PK. A regional approach to osteomyelitis of the lower extremities in children. *Radiol Clin N Am* 2002;40:1033-1059.
81. Major NM, Beard LN, Helms CA. Accuracy of MR imaging of the knee in adolescents. *AJR* 2003;180:17-19.
82. O'Connor MA, Palaniappan M, Khan N, et al. Osteochondritis dissecans of the knee in children: a comparison of MRI and arthroscopic findings. *J Bone Joint Surg Br* 2002;84:258-262.
83. Oeppen RS, Connolly SA, Bencardino JT, et al. Acute injury of the articular cartilage and subchondral bone: a common but unrecognized lesion in the immature knee. *AJR* 2004;182:111-117.
84. Oudjhane K, Azouz EM. Imaging of osteomyelitis in children. *Radiol Clin N Am* 2001;39:251-266.
85. Poyhia T, Azouz EM. MR imaging evaluation of subacute and chronic bone abscesses in children. *Pediatr Radiol* 2000;30:763-768.
86. Ramsey SE, Cairns RA, Cabral DA, et al. Knee magnetic resonance imaging in childhood chronic monarthritis. *J Rheumatol* 1999;26:2238-2243.
87. Rubin DA, Paletta, GA Jr. Current concepts and controversies in meniscal imaging. *Magn Reson Imaging Clin N Am* 2000;8:243-270.
88 Samoto N, Kozuma M, Tokuhisa T, et al. Diagnosis of discoid lateral meniscus of the knee on MR imaging. *Magn Reson Imaging* 2002;20:59-64.
89. Umans H, Haramati H, Flusser G. The diagnostic role of gadolinium enhanced MRI in distinguishing between acute medullary bone infarct and osteomyelitis. *Magn Reson Imaging* 2000;18:255-262.
90. Zobel MS, Borrello JA, Siegel MJ, et al. Pediatric knee MR imaging: pattern of injuries in the immature skeleton. *Radiology* 1994;190:397-401.
91. De Smet AA, Fisher DR, Burnstein MI, et al. Value of MR imaging in staging osteochondral lesions of the talus (osteochondritis dissecans): results in 14 patients. *AJR* 1990;154:555-558.
92. Graif M, Schweitzer ME, Deely D, et al. The septic versus nonseptic inflamed joint: MRI characteristics. *Skeletal Radiol* 1999;28:616-620.
93. Harty MP, Hubbard AM. MR imaging of pediatric abnormalities in the ankle and foot. *Magn Reson Imaging Clin N Am* 2001;9:579-602.
94. Llauger J, Palmer J, Roson N, et al. Pigmented villonodular synovitis and giant cell tumors of the tendon sheath: radiologic and pathologic features. *AJR* 1999;172:1087-1091.
95. Loredo R, Sanders TG. Imaging of osteochondral injuries. *Clin Sports Med* 2001;20:249-278.
96. Maldjian C, Rosenberg ZS. MR imaging features of tumors of the ankle and foot. *Magn Reson Imaging Clin N Am* 2001;9:639-657.
97. Morrison WB, Ledermann HP, Schweitzer ME. MR imaging of inflammatory conditions of the ankle and foot. *Magn Reson Imaging Clin N Am* 2001;9:615-637.
98. Stazzone MM, Hubbard AM. The pediatric foot and ankle. *Magn Reson Imaging Clin N Am* 1998;6:661-675.
99. Wechsler RJ, Schweitzer ME, Deely DM, et al. Tarsal coalition: depiction and characterization with CT and MR imaging. *Radiology* 1994;193:447-452.
100. Weishaupt D, Schweitzer ME, Alam F, et al. MR imaging of inflammatory joint diseases of the foot and ankle. *Skeletal Radiol* 1999;28:663-669.
101. Zoga AC, Schweitzer ME. Imaging sports injuries of the foot and ankle. *Magn Reson Imaging Clin N Am* 2003;11:295-310.