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**COMMISSIONS, COMMITTEES & TASK FORCES:**

| Commission on Publications and Lifelong Learning | Commission on Membership & Communications |
| Commission on Informatics | Commission on Research |
| Commission on Ultrasound | Commission on Breast Imaging |

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### ACR STAFF:

Director: Dina Hernandez  
Observer: Sadaf Ulomi  
Moderator: Helen Abernathy  
Assistant to Society Representatives: Ashraful Azim  
Recorder: Dee Salem  
Attorney: Gloria Romanelli, JD  
Assistant: Sherry Schmidt
RESOLUTION NO. 23

Ten Year Extension of Policy

WHEREAS, the ACR bylaws state that “All official actions and policies of the Council are effective for only ten years unless extended for an additional ten year period by the Council…,” and

WHEREAS, the various components of the College feel that the following policy should be extended for an additional ten year period; therefore

BE IT RESOLVED, that the following policies of the American College of Radiology be extended for an additional ten year period:

(a) I. RADIOLOGICAL PRACTICE AND ETHICS

2. ACR POLICY ON DEVELOPMENT OF PRACTICE PARAMETERS AND TECHNICAL STANDARDS

b. ACR Radiation Oncology Practice Parameters and Technical Standards

After completion of field review and the CSC chaired conference call, the proposed collaborative radiation oncology practice parameter or technical standard work product will then be reviewed by the ACR Commission on Radiation Oncology and ACR Commission on Medical Physics. After review and approval by the ACR Commission on Radiation Oncology and the ACR Commission on Medical Physics, it will next be reviewed by the ACR Council Steering Committee. After review and approval by the ACR Council Steering Committee it will be sent to the ACR Board of Chancellors for final review and approval by the College; adopted 2010 (Res. 8).

(b) I. RADIOLOGICAL PRACTICE AND ETHICS

2. ACR POLICY ON DEVELOPMENT OF PRACTICE PARAMETERS AND TECHNICAL STANDARDS

y. Revision of Practice Parameters and Technical Standards Review Cycle

ACR practice parameters and technical standards will be reviewed by the Council every five years, or sooner if directed by the Council Steering Committee, the Board of Chancellors or the Commission on Quality and Safety; 2000, amended 2010 (Res. 10-d).

(c) I. RADIOLOGICAL PRACTICE AND ETHICS
5. MISCELLANEOUS RADIOLOGIC PRACTICE AND ETHICS
POLICIES

f. Direct Patient Communication

Radiologists are encouraged to increase direct communication with their patients in a manner appropriate to the clinical circumstances and in accordance with the patient's wishes; adopted 2000, 2010 (Res. 10-e).

(d)  I. RADIOLOGICAL PRACTICE AND ETHICS

5. MISCELLANEOUS RADIOLOGIC PRACTICE AND ETHICS
POLICIES

n. Conflict of Interest Disclosure

All ACR leaders (including BOC and CSC members and those running for office in the above) must comply with the disclosure requirements of ACR Conflict of Interest Policies, with such required disclosures, including, but not limited to, all management, board membership or ownership relationships with companies that consult with hospitals or provide radiology services. These disclosures should be listed prominently in the election manual and ACR meeting materials; adopted 2010 (Res. 53-a).

(e)  I. RADIOLOGICAL PRACTICE AND ETHICS

5. MISCELLANEOUS RADIOLOGIC PRACTICE AND ETHICS
POLICIES

q. Efficacy

2. Thermography Efficacy

The position of the American College of Radiology is that thermography has not been demonstrated to have value as a screening, diagnostic, or adjunctive imaging tool; adopted 1990, 2000, 2010 (Res. 1-d).

(f)  J. TECHNOLOGISTS AND ALLIED HEALTH PROFESSIONS

7. OTHER NON-PHYSICIAN RADIOLOGY PROVIDERS (NPRP)
PERFORMING FLUOROSCOPIC PROCEDURES

It is the policy of the American College of Radiology that other ancillary personnel Non-Physician Radiology Providers (NPRP) who are qualified and duly licensed or certified under applicable state law may, under supervision by a radiologist or other qualified physician, perform fluoroscopic examinations or fluoroscopically guided imaging procedures. Supervision by a radiologist or other qualified physician must be direct or personal, and must comply with local, state, and federal
All ancillary personnel, non-physician radiology providers (NPRP) using fluoroscopy should be credentialed for those fluoroscopic examinations or procedures and should have completed 40 hours of didactic education or its equivalent CME that meets applicable state or other laws and regulations to become competent in the following:

digital image acquisition and display, contrast media, fluoroscopic unit operation and safety, image analysis, radiation biology, radiation production and characteristics, and radiation protection. 40 hours of.

Additionally, NPRP using fluoroscopy should have sufficient clinical experience and be supervised by a radiologist or medical physicist to demonstrate competency in those fluoroscopic examinations or procedures for which they are credentialed. Medical physicists should be involved in the radiation safety and image quality aspects of fluoroscopy. Required CME for other ancillary personnel NPRP performing fluoroscopy should include education in radiation dosimetry, radiation protection, and equipment performance related to the use of fluoroscopy; adopted 2010 (Res. 52).

Sponsored by: ACR Council Steering Committee
To support the resolution for Ten Year Extension of Policy, the ACR would incur the following estimated costs:

**Costs:**

- De minimis (< $10,000)
NOT FOR PUBLICATION, QUOTATION, OR CITATION

RESOLUTION NO. 24

BE IT RESOLVED,

that the American College of Radiology adopt the ACR–SAR–SPR Practice Parameter for the Performance of Computed Tomography (CT) Enterography

Sponsored By: ACR Council Steering Committee

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

The American College of Radiology will periodically define new practice 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.

2015 (Resolution 18)*

ACR–SAR–SPR PRACTICE PARAMETER FOR THE PERFORMANCE OF COMPUTED TOMOGRAPHY (CT) ENTEROGRAPHY

PREAMBLE

These Practice Parameters are 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 care1. For these reasons and those set forth below, the American College of Radiology cautions against the use of these Practice Parameters 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 Practice Parameters, standing alone, does not necessarily imply that the approach was below the standard of care1. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in the Practice Parameters when, in the reasonable judgment of the practitioner, such course of action is indicated by the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of the Practice Parameters. However, a practitioner who employs an approach substantially different from these Practice Parameters is advised to document in the patient record information sufficient to explain the approach taken.

1Iowa 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.
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 Practice Parameters 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 Practice Parameters is to assist practitioners in achieving this objective.

I. INTRODUCTION

This practice parameter was developed revised collaboratively by the American College of Radiology (ACR), Society for Pediatric Radiology (SPR), and the Society of Abdominal Radiology (SAR) (authors are members of both organizations).

CT enterography (CTE) is an examination using neutral oral contrast agents (with density of < 20-30 HU) as well as and intravenous (IV) contrast medium, with multidetector CT (MDCT) in the evaluation of small-bowel diseases, primarily Crohn’s disease and obscure gastrointestinal bleeding [1-20]. Currently, this examination is also used worldwide for evaluating acute and chronic mesenteric ischemia (in acute cases, oral contrast media administration may not be necessary), detection of small-bowel neoplasms (often in the setting of obscure gastrointestinal bleeding), and evaluating celiac disease, as well as in the nontraumatic patients who have acute abdominal pain [20]. In most active centers caring for patients with Crohn’s disease patients, CT and now MR enterography (MRE) has become the standard of care and have supplanted traditional barium-based fluoroscopic techniques (small-bowel series and enteroclysis) [21] (see the ACR–SAR–SPR Practice Parameter for the Performance of Magnetic Resonance (MR) Enterography [22]).

II. INDICATIONS AND CONTRAINDICATIONS

Clinical indications and contraindications for CTE include, but are not limited to, the following:

A. Indications

1. Known Crohn’s inflammatory bowel disease not in the perioperative period
2. Suspected Crohn’s disease or other causes of small-bowel inflammation
3. Suspected small-bowel bleeding (formally obscure gastrointestinal bleeding). This study should be performed if upper and lower endoscopy fail to identify bleeding source. Note: Suspected acute as well as small-bowel bleeding should be evaluated with multiphasic technique and not uniphasic CTE.
4. Suspected small-bowel disease (e.g., celiac disease)
5. Chronic diarrhea and/or abdominal pain
6. Suspected chronic mesenteric ischemia

B. Contraindications (most are relative) when Other Examinations may be more Efficacious

1. Patients with a known, severe iodinated contrast media allergy who are able to undergo a contrast enhanced MRE
2. Patients with chronic kidney disease whose estimated glomerular filtration rate (eGFR) is < 30 mL/min/1.73 m², in whom iodinated contrast material or oral fluid volume is considered harmful. In these patients, consider hydration or MRE.
3. Patients who have had multiple CT examinations in their lifetime and in whom the examination is not considered urgent or emergent. In such cases, consider MRE, especially in younger patients with Crohn’s disease
4. Patients in the postoperative period (within 2-3 weeks) in whom an abscess or anastomotic leak is considered more likely; this will require the use of a positive oral contrast agent, generally iodinated contrast either orally and/or rectally if there is an anastomosis, rather than CTE. **In the acute, emergency department setting, the choice of a conventional CT with positive or high attenuation oral contrast or a CTE should be based upon whether the patient is in the postoperative period or not. If the patient is not in the postoperative period and there is a history of Crohn’s disease, a CTE should be considered.**

5. In pediatric patients, the relative advantages and disadvantages of CTE and MRE should be considered. In particular, the potential need for sedation/anesthesia should be weighed cautiously.

Clinical Scenarios in which CTE may not be Efficacious

Patients with an eGFR <30 mL/min/1.73 m², who should not receive gadolinium agents, will likely be better assessed with nonenhanced MRE (relying on T2-weighted pulse sequences and diffusion-weighted imaging) rather than unenhanced CTE.

CTE is not efficacious without IV contrast. The issues related to the use of gadolinium-based and iodinated contrast media in patients with acute and chronic kidney disease have recently been addressed and significantly changed when compared with prior recommendations. It is beyond the scope of this practice parameter to address these issues. Any questions concerning the appropriate use of these contrast agents for CTE and MRE should be addressed in the ACR Manual on Contrast Media [23]. It documents the use of low and iso-osmolality iodinated contrast media in CTE in patients with stable renal function and an eGFR of >30 mL/min/1.73 m². The risk of contrast-induced nephropathy is low or nonexistent, all other factors being equal. The use of group II gadolinium-based contrast agents in MRE in any patient with acute or chronic kidney disease is now considered to be safe.

Crohn’s Patients with inflammatory bowel disease who have had multiple prior CT examinations and are not acutely ill may be better evaluated with contrast-enhanced MRE rather than with enhanced CTE. **This particularly applies in the pediatric population, for whom efforts to apply ALARA principles should be maintained.** In the perioperative period, even in patients with Crohn’s disease, an anastomotic leak may not be identified when neutral oral contrast medium is used. Lastly, there is no evidence that CTE can detect the cause of incomplete, low-grade, or recurrent small-bowel obstructions, which are commonly due to adhesive disease. These patients are better evaluated with either a standard, fluoroscopic small-bowel follow-through series or CT enteroclysis [24].

In this patient cohort, an MRE without intravenous IV contrast may be preferred.

For the pregnant or potentially pregnant patient, see the ACR-SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation [25].

III. QUALIFICATIONS OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [26].

IV. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for CT enterography should provide sufficient information to demonstrate the medical necessity of the examination and allow for the proper performance and interpretation of the examination.
Oral Contrast Media for CT Enterography CTE

CTE requires some form of bowel distension in order to accurately assess the small bowel [18,19,27-29], including the interface between the wall and the lumen. Traditional positive or high attenuation contrast agents obscure this interface; therefore, oral agents currently used for CTE are much lower in attenuation, generally 0 - 30 HU, depending upon the agent, and are called neutral oral agents. Water, milk, lactulose, polyethylene glycol, methylcellulose, sorbitol, mannitol, a commercially available sugar alcohol beverage, and a commercially available 0.1% barium suspension are all currently in use as neutral oral contrast agents [11,30-38]. The 0.1% barium suspension is has a density between 15 and 25 HU in clinical practice. Attenuation depends upon the location in the bowel and amount of water absorption. CTE neutral oral contrast agents retard absorption of water along the length of the small bowel, maintaining distension and allowing for bowel-wall assessment. Because water is absorbed over the length of the small bowel, use of specially designed oral contrast agents is preferred for CTE (see below for exceptions).

Oral Contrast Media Ingestion Regimens

CTE oral contrast ingestion protocols vary between institutions [11,30-38]. Regardless, oral contrast must be ingested over 30 - 60 minutes. CT image acquisition is generally begun after 45 to 70 minutes for patients with an intact gastrointestinal system and 30–45 minutes for patients with surgically altered intestinal anatomy, ileocelecal resections, ileostomies, multiple small bowel resections, or total proctocolectomies with ileo-anal pouch anastomoses. The volume of contrast ingested varies, but most adult protocols require the ingestion of at least 1350 - 1,000 - 1,350 mL cc of contrast agent, and in pediatric patients, the volume varies and is prescribed according to patient weight, eg, 20 mL/kg, up to adult dose (corresponds to 3 bottles of the commercially available 0.1% barium suspension), and often supplemented at the end by water. Immediately The water is administered just before the scan acquisition in an attempt to distend the stomach and duodenum and jejunum since water absorption is not a concern at this time. It is best for the patient to consistently and slowly ingest the oral contrast material over the time period, rather than rapidly ingest each bottle of contrast. This method will facilitate consistent proximal-to-distal small-bowel distension. For the most consistent bowel distension, it is optimal that Ideally, the patients ingesting the contrast should be located in the radiology department while ingesting the contrast so that a technologist, or nurse, or designated individual can directly observe the patients both to encourage them to drink and to identify those patients who are having trouble ingesting the agent, and provide encouragement. Patient compliance with enteric contrast drinking can be enhanced by contrast refrigeration or addition of sugar-free fruit flavoring. Ileal distension appears to improve when the patient ingests the agent while sitting or supine, as opposed to in the right lateral decubitus position [37]. If the patient cannot ingest the oral contrast agent, either a feeding tube or NG (nasogastric) tube an enteric tube can be placed to allow for administration or the patient can be encouraged to drink the balance of and removed prior to imaging. Alternatively, if the patient has ingested some contrast medium, the required volume balance can be completed with water. Some sites encourage patients to ingest a few sips of water between bottles of the commercially available 0.1% barium suspension, to aid patient compliance. They have found that this simple method improves patient compliance. If only water is used, imaging should be performed earlier (ie, 30 minutes after beginning drinking) as water is rapidly absorbed. If patients are unable to drink the prescribed volume of neutral oral contrast agent, the
supervising physician should make the determination whether the patient should substitute water for the remaining volume of contrast or continue the study.

IV Contrast Enhancement for CTE

For CTE, **IV intravenous** contrast enhancement is essential for the assessment of bowel wall enhancement pattern, enhanced bowel wall lesions and/or intraluminal contrast extravasation, and in the case of acute gastrointestinal bleeding. Scan timing relative to the start of iodinated contrast injection for CTE is somewhat variable. Schindera et al reported that the normal small-bowel wall appears to have the greatest level of enhancement during the enteric phase (approximately 40-50 seconds postinitiation of contrast injection) [39]. This investigation did not take into account the location of the small bowel when assessing bowel wall enhancement, which is relevant because the normal number of folds decreases from duodenum to ileum, and the duodenum enhances more than the jejunum and the jejunum more than the ileum [1]. Thus, some investigators believe that the ideal time to scan in patients with Crohn’s disease is at 50 seconds (or 14 seconds after peak abdominal aortic enhancement) after initiating contrast injection, although if the injection rate is limited by technical factors, timing should be delayed. Other investigators using timed MR scanning after an injection of contrast have shown that the maximal difference between normal and active inflammatory small-bowel Crohn’s disease occurs much later, even several minutes after contrast injection [40]. Furthermore, an investigation of CTE showed that the detection of active inflammatory small-bowel Crohn’s disease did not differ was not different between scans obtained after 40 seconds and 70 seconds post contrast enhancement [41]. In most academic institutions, CTE obtained for assessment of Crohn’s disease is performed using a single phase of enhancement acquired between 50 and 70 seconds post contrast injection (i.e., either the enteric or portal venous phase). Recently, a split-bolus technique has been investigated, yielding a greater contrast-to-noise ratio for active Crohn’s disease and improving disease detection [42].

In the evaluation of suspected small-bowel bleeding obscure gastrointestinal bleeding, suspected acute or chronic mesenteric ischemia, and suspected small-bowel masses, multiphasic scanning is essential [7-10]. Some centers perform a low-dose precontrast evaluation in order to eliminate the confusion that high-attenuation, intraluminal objects, such as pills, may cause (any intraluminal high-attenuation object that does not change during multiple phases postcontrast must be considered as inert and not significant). Most perform an arterial phase examination, with scan timing based on bolus tracking techniques, with a region of interest placed over the aorta at the diaphragmatic hiatus. This is followed by an enteric phase examination at approximately 50 seconds post contrast injection as well as a more delayed portal venous phase for even longer, >70-80 seconds. Some centers only perform arterial and portal venous phase scans for these indications. **If a dual-energy CT scanner is utilized,** the unenhanced portion of the examination can be eliminated because virtual noncontrast images can be generated.

Scan Position and Range

Patients are scanned in the supine position through the abdomen and pelvis. Importantly, technologists should include the perineum in order to identify perianal fistulas and abscesses in patients with known or suspected Crohn’s disease.

Reconstruction Techniques for CTE

For reconstruction purposes, CTE created from MDCT data sets must be processed in orthogonal planes, typically axial and coronal. Some sites routinely reconstruct in the sagittal plane; some only when this plane provides additional information to a specific case, or **for presurgical planning.** Multiplanar reconstructions facilitate the identification of fistulæ and sinus tracts. The sagittal plane is particularly helpful in identifying the origin of the celiac axis and superior mesenteric artery and assessing for stenosis or occlusion in patients with suspected acute or chronic mesenteric ischemia. In patients scanned for vascular disease, 3-D angiograms can be easily reconstructed with various techniques on modern workstations. Modern workstations can also allow for assessment of the scan data in unlimited planes. However, it is best to provide the referring gastroenterologist and surgeon at
least the axial and coronal planes. Specialists are most familiar with evaluating the small bowel in the frontal or coronal plane, the plane that most imitates the overhead films radiographs routinely obtained in a small bowel barium series. The combination of axial, coronal, and sagittal planes can be utilized and helpful in identifying fistulae, sinus tracts, and presurgical planning. Maximum intensity projection (MIP) images are helpful particularly in multiphasic gastrointestinal bleeding studies to quickly assess for sites of active extravasation or focal enhancing masses. In patients with Crohn’s disease, reconstructing 10-mm, coronal, thick MIP images facilitates the detection of chronic mesenteric vein occlusion.

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [43].

It is recommended The 2018 SAR/American Gastroenterological Association (AGA)/SPR consensus document recommends that a templated, standardized reporting method be used for CTE in Crohn’s disease [44]. Others recommend this as well [18,19,45-47]. Systematic reporting using a template and standardized terms for the findings and conclusions will facilitate communication and allow for outcomes measures. Findings on CTE and MRE are increasingly important in directing both medical and surgical management [48-52]; therefore, consistency in reporting is critical. The report should indicate that CTE was performed specifically indicate that the abdomen and pelvis CT with oral and IV contrast was a CTE examination utilizing neutral oral contrast media. Additionally, every effort should be made to use the standardized terms for radiographic findings of Crohn’s disease as well as the accepted impressions summarizing those findings [44].

As an example, the report should address the following for patients with Crohn’s disease (for non-Crohn’s patients, the template can be adjusted to the specific disease process (eg, suspected small-bowel obscure gastrointestinal bleeding):

- Presence, location, number, and length of disease segments (describe where wall thickening and abnormal enhancement are present)
- Presence of luminal narrowing without and with upstream dilation
- Presence of penetrating disease, including sinus tracts and fistulae
- Presence of inflammatory mass (or phlegmon, a term no longer recommended) and abscess
- Presence of ancillary findings: vasa recta distension, fibrofatty proliferation, perienteric edema, or inflammatory mass, gallstones, renal stones, mesenteric venous thrombosis, sacroiliitis, or avascular necrosis of hips

In the conclusion, the following terms can be used (it should be noted that these terms are currently under consideration by a multidisciplinary group of gastrointestinal radiologists, gastroenterologists, and bowel surgeons and may change over time):

- Active inflammatory small-bowel Crohn’s disease
- Quiescent or inactive small-bowel Crohn’s disease
- Strictureing disease with or without findings of active inflammation (This term should only be used if there is both luminal narrowing and upstream bowel dilation >3 cm.)
- Penetrating Crohn’s disease (in addition to active or stricturing disease; most often occurs with stricturing disease)

A standardized nomenclature and reporting template for findings is being developed by the Small Bowel Special Interest Group of the SAR in conjunction with gastrointestinal and colorectal surgery societies in order to achieve effective communication. The use of a standardized nomenclature and reporting template will address the important issues in Crohn’s disease.
The impressions for CTE recommended by the SAR/AGA/SPR consensus are:

- Nonspecific small-bowel inflammation
- Active inflammatory small-bowel Crohn’s disease without luminal narrowing
- Active inflammatory small-bowel Crohn’s disease with luminal narrowing
- Crohn’s disease with no imaging signs of active inflammation
- Stricture with imaging findings of active inflammation
- Stricture without imaging findings of active inflammation
- Penetrating Crohn’s disease (often with luminal narrowing or stricture with imaging findings of active inflammation)
- Perianal Crohn’s disease
- Other complications of Crohn’s disease (eg, gallstones, nephrolithiasis, primary sclerosing cholangitis, or aseptic necrosis of femoral heads)
- Other important non-Crohn’s disease findings

For specific issues regarding CT quality control, see the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [26].

VI. EQUIPMENT SPECIFICATIONS

Equipment performance monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [53].

A. Performance Parameters

To achieve acceptable clinical CT scans of the small bowel, a CT scanner should meet or exceed the following capabilities [18]:

1. MDCT with detector row ≥16
2. Helical or volume acquisition with appropriate adaptation of pitch so that images of the abdomen and pelvis are acquired in a single breath-hold
3. Scan rotation time: ≤1 sec
4. Minimum slice thickness: <2 mm; maximum slice thickness: 3–4 mm with overlapping reconstructions
5. Limiting spatial resolution: ≥8 lp/cm for ≥32 cm display field of view (DFOV) and ≥10 lp/cm for <24 cm DFOV
6. Creation of multiplanar images (minimum axial and coronal; sagittal images added for disease process)

With the proliferation of dual-energy CT scanners (fast-switch kVp, dual-source or dual-layer, detector based), many sites are beginning to scan patients to create monoenergetic low keV (generally 50 keV) and iodine-map images. Some have found that these scanners more easily and accurately detect disease yet with no increased radiation exposure and with the ability to decrease the volume of iodinated contrast media administered [54,55]. An alternate solution is to utilize low kVp to accentuate areas of abnormal enhancement. This approach is especially useful in smaller patients, whereas in larger patients this may result in greater noise.

B. 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. A soft-copy workstation (PACS station) review capability should be available to radiologist and clinicians. CD or DVD capability also should be available. For additional information on image sharing and security, see the ACR–AAPM–SIIM Technical Standard for Electronic Practice of Medical Imaging [56] and the ACR–AAPM–SIIM Practice Parameter for Electronic Medical Information Privacy and Security [57].

VII. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, registered radiologist assistants, radiologic technologists, and all supervising physicians have a responsibility for safety in the workplace by keeping radiation exposure to staff, and to society as a whole, “as low as reasonably achievable” (ALARA) and to assure that radiation doses to individual patients are appropriate, taking into account the possible risk from radiation exposure and the diagnostic image quality necessary to achieve the clinical objective. All personnel that work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection and application of dose limits) and the principles of proper management of radiation dose to patients (justification, optimization and the use of dose reference levels) http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1578_web-57265295.pdf.

Nationally developed guidelines, such as the ACR’s Appropriateness Criteria®, should be used to help choose the most appropriate imaging procedures to prevent unwarranted radiation exposure.

Facilities should have and adhere to policies and procedures that require varying ionizing radiation examination protocols (plain radiography, fluoroscopy, interventional radiology, CT) to take into account patient body habitus (such as patient dimensions, weight, or body mass index) to optimize the relationship between minimal radiation dose and adequate image quality. Automated dose reduction technologies available on imaging equipment should be used whenever appropriate. If such technology is not available, appropriate manual techniques should be used. Additional information regarding patient radiation safety in imaging is available at the Image Gently® for children (www.imagegently.org) and Image Wisely® for adults (www.imagewisely.org) websites. These advocacy and awareness campaigns provide free educational materials for all stakeholders involved in imaging (patients, technologists, referring providers, medical physicists, and radiologists).

Radiation exposures or other dose indices should be measured and patient radiation dose estimated for representative examinations and types of patients by a Qualified Medical Physicist in accordance with the applicable ACR technical standards. Regular auditing of patient dose indices should be performed by comparing the facility’s dose information with national benchmarks, such as the ACR Dose Index Registry, the NCRP Report No. 172, Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States or the Conference of Radiation Control Program Director’s National Evaluation of X-ray Trends. (ACR Resolution 17, adopted in 2006 – revised in 2009, 2013, Resolution 52)

Radiation Exposure Dose Issues with CTE

CT contributes the single source of man-made ionizing radiation to the American public, and this contribution continues to has substantially increased since 2009 [58]. This is of special concern in patients with a chronic illness such as Crohn’s disease, which often starts in childhood or adolescence, and who are more likely to undergo frequent imaging examinations.

Several studies have shown that some patients with Crohn’s disease can receive large cumulative exposures doses (over 100 mSv) over the course of their disease and often are examined with CT 2–3 times a year [59-65]. In one series encompassing a 15 year period of time, the mean ionizing radiation dose was 36.1 mSv. Over the entire study period there was an increasing use of CT, and although CT accounted for only 16.2% of all imaging studies, it accounted for 77.2% of the radiation dose. Further in this study, the total ionizing radiation exceeded 75 mSv in 15.5% of the patients [61]. Crohn’s patients with onset of disease before 17 years of age, who have upper gastrointestinal tract or penetrating disease, who require intravenous steroids or infliximab, or who have had
multiple surgeries receive higher doses. [59,61] Given the recent evidence that radiation exposure from CT scans in children may result in an increased risk of brain tumors and leukemia [66,67], CT dose optimization reduction remains at the forefront of quality efforts in radiology, especially in pediatric patients. Notwithstanding these observations, however, the benefits of CT far outweigh potential risks in symptomatic patients with Crohn’s disease. Two recent studies have shown that CT in emergency department patients with Crohn’s disease results in substantial patient management changes in a large proportion of these patients (particularly in patients with bowel obstruction and abscesses) [68,69]. Another study showed that about 50% of outpatients with known or suspected Crohn’s disease had their management plans changed as a result of CTE [49]. One of these groups consequently concluded, “These numbers reflect the fact that patients with Crohn’s disease are at high risk for complications given the nature of the disease and the risks of immunosuppression. Although radiation exposure in patients with Crohn’s disease is a concern, clinicians must also weigh the risk of missing a potential urgent diagnosis when they forego a CT” [69]. The medical justification for CTE depends upon the perceived benefit versus risk for any particular patient as well as the availability and clinical feasibility of alternative imaging modalities, such as MRE.

Efforts to reduce the dose from CT are ongoing and include in the last decade, there have been many investigations comparing full or standard exposure CTE with lower exposure CTE utilizing alterations in kVp and mAs appropriate to body habitus, weight, and body mass index (BMI), and altering the scan pitch. These changes can lead to an increase in the image noise that can be offset with newer image reconstruction algorithms, generally called iterative reconstruction, applied to the initial lower-exposure dose images to reduce noise [70-97]. Dose reductions from CT dose index (CTDIvol) between 15–20 mGy to < 10 mGy, and even below 5 mGy, have been achieved without apparent loss of efficacy. However, these lower-exposure techniques reconstructed with new noise-reducing algorithms often result in images that are unfamiliar to some radiologists. In the research setting, these examinations are often rated by readers as suboptimal or nondiagnostic [70,82]. What is not known is how these images are interpreted in day-to-day practice and whether these lower exposure examinations result in more equivocal interpretations.

It remains to be seen whether sub-millie Sievert imaging is possible without data loss. Crohn’s disease identification in the small bowel is a high-contrast issue with CT (ie, identifying a process with a higher attenuation versus background; small bowel wall hyperenhancement is a primary finding in active inflammatory Crohn’s disease). Recent investigations have shown that low-contrast objects (an object of lower attenuation versus background) can be lost with lower-dose CT even using iterative reconstruction techniques, including model-based iterative reconstruction [79,87-93,95].

In this evolving field, when CTE is performed, every effort should be made by the protocolling radiologist to reduce the radiation exposure as low as reasonably achievable (ALARA) dose and still achieve a diagnostic examination as low as reasonably achievable (ALARA). Several investigations have already shown that diagnostic examinations can be achieved using lower-dose techniques, techniques that result in doses much lower than many radiologists are familiar with, and resulting in examinations that radiologists unfamiliar with the new changes judge as suboptimal or nondiagnostic [70-78].

For radiation exposure dose reduction in patients with Crohn’s disease, a very appropriate alternative to CTE is MRE. Comparisons of the two techniques show equivalent efficacy in detecting both uncomplicated and complicated Crohn’s disease [44]. The advantage of CT is the rapid scan acquisition time and superior spatial resolution. The 3T magnet technology approaches the spatial resolution of CT, but MRE can be more challenging to perform because it is more likely to be affected by patient motion given the longer acquisition times. This is especially an issue for imaging young children and first-time MRI studies on patients. MRE, especially on a 3T, is more susceptible to bowel peristalsis, a problem that can be improved by the use of antiperistaltic agents such as glucagon, hyoscyamine sulfate, or scopolamine butyl bromide, which is not available in the United States. The challenges of MRE are offset by its superior signal-to-noise ratio and excellent tissue characterization when compared with CTE and avoidance of ionizing radiation. Furthermore, multiple pulse sequences can be performed. These advantages make MRE a feasible and viable alternative to CTE.
In **many** **most** institutions, adult patients over the age of 18 **years** with known or suspected Crohn’s disease are imaged with CTE at presentation. This initial examination offers excellent spatial resolution, is unaffected by motion-related artifacts, and provides a baseline study. If subsequent follow-up examinations are indicated, a CTE can be substituted with MRE (see the ACR–SAR–SPR Practice Parameter for the Performance of Magnetic Resonance (MR) Enterography [22]), depending upon the clinical presentation and scanner availability. Acutely ill patients require rapid imaging in order to exclude an abscess. **Thus, CTE is more appropriate in this population.** Postoperative patients are best evaluated with CT using positive oral contrast agents in order to exclude an anastomotic leak (oral and/or rectal, positive contrast administration, depending upon the site of the anastomosis).

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 and Improvement, Safety, Infection Control and Patient Education on the ACR website (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).

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REFERENCES


*Practice Parameters and Technical Standards are published annually with an effective date of October 1 in the year in which amended, revised, or approved by the ACR Council. For Practice Parameters and Technical Standards published before 1999, the effective date was January 1 following the year in which the parameter or standard was amended, revised, or approved by the ACR Council.

Development Chronology for this Practice Parameter

2015 (Resolution 18)
BE IT RESOLVED,

that the American College of Radiology adopt the ACR–SAR–SPR Practice Parameter for the Performance of Magnetic Resonance Imaging (MRI) of the Abdomen (Excluding the Liver)

Sponsored By: ACR Council Steering Committee

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

The American College of Radiology will periodically define new practice 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.

Revised 2015 (Resolution 2) *

ACR–SAR–SPR PRACTICE PARAMETER FOR THE PERFORMANCE OF MAGNETIC RESONANCE IMAGING (MRI) OF THE ABDOMEN (Excluding the Liver)

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 care1. For these reasons and those set forth below, the American College of Radiology cautions 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 physician or medical physicist in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent

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1 Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, 826 N.W.2d 831 (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.
to publication of this document. However, a practitioner who employs an approach substantially different from this Practice Parameter 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 Practice Parameters 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 this Practice Parameter is to assist practitioners in achieving this objective.

I. INTRODUCTION

Magnetic resonance imaging (MRI) of the abdomen is a proven and useful tool for the evaluation, assessment of severity, and follow-up of diseases of the abdomen. It should be performed only for a valid medical reason. MRI of the abdomen is an evolving technology involving a variety of pulse sequences and protocols that are continuously being modified and improved. Detailed imaging protocols are not presented here to avoid promoting obsolete methodology. This document pertains to the MRI assessment of the abdomen, excluding the liver. For practice parameters pertaining to the liver, see the ACR–SAR–SPR Practice Parameter for the Performance of Magnetic Resonance Imaging (MRI) of the Liver [1].

The choice of MRI of the abdomen requires an analysis of the strengths of MRI as well as its suitability for each unique the particular patient and particular clinical situation. In patients without a contraindication (see Section IV below), MRI is appropriately used for For characterization of suspected lesions requiring a technique that offers a high degree of soft tissue contrast (lesion characterization requiring high soft-tissue contrast), to provide a multiplanar evaluation of a lesion not well depicted on other imaging modalities, and multiphasic contrast enhanced imaging, to provide intravenous contrast enhanced abdominal imaging in patients who have, a contraindication to iodinated contrast media, including allergy or renal dysfunction MRI benefits from a lack of ionizing radiation. and to perform cross-sectional abdominal imaging without ionizing radiation, MRI might be the procedure of choice provided that the patient does not have a contraindication (See section IV below). See the ACR Guidance Document on MR Safe Practices: 2013 [2] and the ACR Manual on Contrast Media [3].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [2,4].

II. INDICATIONS

Indications for MRI of the abdomen (excluding the liver) include, but are not limited to, the following:

A. Pancreas

1. Detection of pancreatic masses and preoperative staging in patients unable to receive iodinated contrast media and preoperative assessment of pancreatic neoplasms
2. Characterization of indeterminate lesions and/or unexplained gland enlargement detected with other imaging modalities
3. Identification of causes of pancreatic duct obstruction, including calculi, stricture, or mass
4. Detection and characterization of pancreatic duct anomalies
5. Evaluation of pancreatic or peripancreatic fluid collections or fistulae
6. Evaluation of chronic pancreatitis, including assessment of pancreatic exocrine function, evaluation of complicated acute pancreatitis, and associated complications
7. Postoperative/treatment follow-up after pancreatic surgery
NOT FOR PUBLICATION, QUOTATION, OR CITATION

B. Spleen
1. Characterization of indeterminate lesions detected with other imaging modalities
2. Detection and characterization of suspected diffuse abnormalities of the spleen
3. Evaluation of suspected accessory splenic tissue

C. Kidneys, Ureters, and Retroperitoneum
1. Detection of renal tumors
2. Characterization of indeterminate lesions detected with other imaging modalities
3. Preoperative assessment of renal neoplasms to include evaluation of the arterial supply, renal vein, and inferior vena cava
4. Evaluation of the urinary tract for abnormalities of anatomy or physiology (MR urography)
5. Postprocedure surveillance after renal tumor ablation or surgical extirpation via partial or complete nephrectomy
6. Evaluation of ureteral abnormalities
7. Evaluation of suspected retroperitoneal fibrosis and other benign lesions
8. Characterization and staging of retroperitoneal malignant neoplasms
9. Evaluation or follow-up of lymphadenopathy
10. Surveillance imaging of the upper urinary tract in patients with urothelial carcinoma
11. Characterization of complex congenital anomalies
12. Identification of causes of urinary tract obstruction

D. Adrenal Glands
1. Detection of suspected pheochromocytoma and functioning adrenal adenoma
2. Characterization of indeterminate lesions detected with other imaging modalities
3. Staging of malignant adrenal neoplasms
4. Detection and characterization of congenital anomalies

E. Vascular (see the ACR–NASCI–SPR Practice Parameter for the Performance of Body Magnetic Resonance Angiography (MRA) [5]).

F. Bile Ducts and Gallbladder
1. Detection, staging, and posttreatment follow-up of bile duct and gallbladder cancer
2. Detection of bile duct or gallbladder stones
3. Evaluation of bile duct dilation and/or narrowing
4. Evaluation of suspected congenital abnormalities of the gallbladder or bile ducts
5. Detection and anatomic delineation of bile leaks
6. Delineation of ductal anatomy prior to liver transplantation
7. Assessment of post–liver transplant biliary complications

G. Gastrointestinal Tract and Peritoneum
1. Preoperative assessment of gastric neoplasms
2. Detection of small-bowel neoplasms
3. Assessment of inflammatory disorders of the small or large bowel and mesenteries (including MR enterography); for MR enterography, see the ACR–SAR–SPR Practice Parameter for the Performance of Magnetic Resonance (MR) Enterography [6]
4. Assessment of peritoneal adhesive disease
5. Detection and evaluation of primary and metastatic peritoneal or mesenteric neoplasms
6. Detection and characterization of intra-abdominal fluid collections as well as follow-up after percutaneous or surgical drainage
7. **Second-line imaging tests after an initial ultrasound for diagnosis of acute appendicitis in children and adults, including pregnant women [7-9]**

8. **Evaluation and follow-up of lymphadenopathy**

**H. Other**

- Imaging follow-up of abnormalities of the abdomen deemed indeterminate on initial MRI and for which surgery is not advised
- Detection and characterization of extraperitoneal neoplasms other than those mentioned above
- Evaluation of the abdomen as an alternative to CT when radiation exposure is an overriding concern in susceptible patients, such as pregnant or pediatric patients or in patients with a contraindication to iodinated contrast agents
- Assessment of treatment response to medical therapy of malignant neoplasms of the abdomen
- Determining organ of origin of an indeterminate (benign or malignant) lesion in the abdomen when the origin is not obvious from other imaging modalities
- Identification and characterization of vascular malformations (see the ACR–NASCI–SPR Practice Parameter for the Performance of Body Magnetic Resonance Angiography (MRA) [5])
- Evaluation of abdominal wall abnormalities not adequately assessed by other imaging modalities
- Assessment of traumatic injury of the abdomen when CT is contraindicated

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [10], the ACR Guidance Document on MR Safe Practices: 2013 [2], and the ACR Manual on Contrast Media [3].

**III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL**

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [10].

**IV. SPECIFICATIONS OF THE EXAMINATION**

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

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

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

The supervising physician must have adequate 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 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 on a regular basis periodically.

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 by the technologist performing the examination. Patients and any family members or others who will accompany the patient into the MRI suite must be screened and interviewed prior to the examination to exclude individuals who may be at risk by exposure to the MR environment. All sites should have an established and documented screening mechanism for establishing MRI compatibility.

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 use (see the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [11]).

Patients suffering from anxiety or claustrophobia, or who are unable to cooperate or suspend respiration, may require sedation or additional assistance. Administration of sedation may be necessary to achieve a successful examination. If sedation is necessary, refer to the ACR–SIR Practice Parameter for Sedation/Analgesia [12].

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. Furthermore, regular training on the use of such equipment and medication is recommended for those providing patient care in the MRI environment.

All sites should employ site-access restrictions, with clear demarcation of safety zones I–IV, utilizing signage and physical barriers as appropriate (see the ACR Guidance Document on MR Safe Practices: 2013 [2]).

C. Examination Technique

A phased array surface coil should be used unless precluded by patient body habitus or condition. In pediatric patients, coil selection will depend on patient size and the region being imaged. In small neonates, a surface coil should be considered, whereas infants and children may be imaged with a cardiac, flex teso, or body coil, depending on the size of the abdomen. The field of view (FOV) should be selected to provide the highest resolution possible to include the entire region or organ of interest, allowing for an adequate signal-to-noise ratio (SNR) and minimization of relevant artifacts. Multiple acquisitions with repositioning of the surface coil may be necessary when the region of interest exceeds the potential FOV of the surface coil. For most applications, evaluation of the abdomen should include T1 and T2-weighted images. Acquisitions in multiple imaging planes may be beneficial in defining anatomic relationships. For most applications, slice thickness for acquisitions should not exceed 8 mm, with the interslice gap not exceeding 3–2 mm, although thinner slices and gaps are desirable. In children, slice thicknesses typically range from 3–8 mm, depending on the size of the area to be imaged.

T1-weighted imaging may be performed using an echo train spin-echo (turbo spin-echo [TSE] or fast spin-echo [FSE]) sequence, although the gradient-echo technique is typically favored because it has a much shorter acquisition time sequence. T2-weighted images may be accomplished using one of the echo train spin-echo sequences (TSE or FSE) or a hybrid gradient and spin-echo technique [13]. Fat suppression is frequently beneficial and may be accomplished using short tau inversion recovery (STIR), chemically selective fat saturation, or spectral presaturation inversion recovery (SPIR), or other forms of fat suppression such as water excitation and chemical shift/Dixon-based techniques [14-16].
Although fast gradient-echo T1-weighted images can usually be acquired during breath-holding, some patients are unable to cooperate with even short breath holds. Compressed sensing, often in combination with parallel imaging (PI) and view sharing or non-Cartesian acquisition, is a technique offered by multiple vendors that allow dramatic reduction in scan time and even free-breathing dynamic postcontrast imaging [17-19]. The duration of conventional and FSE T2-weighted imaging is often too long for complete acquisition during breath holding. Breath-hold techniques can be used for T2-weighted imaging if the scan time is reduced by a) long echo trains, b) partial-Fourier imaging, c) use of PI techniques, and/or d) dividing the volume of interest into several smaller volumes that can each be imaged in individual breath holds. Traditional strategies to reduce respiratory motion during free-breathing image acquisition include respiratory compensation (respiratory-ordered phase encoding), respiratory triggering with respiratory bellows, the use of navigator pulses [20,21], the acquisition of k-space data in concentric rectangular strips [22] and signal averaging. Familiarity with these methods is helpful when scanning young children or other patients who may not be able to follow breath-hold commands, as well as sedated/anesthetized patients. Other advances that can reduce imaging times and/or correct for motion include the acquisition of k-space data in concentric rectangular strips [22].

Inclusion of at least one in-phase and out-of-phase gradient-echo sequence is useful for detecting intracellular lipid within certain adrenal (eg, adenoma) and renal (eg, clear-cell carcinoma) tumors and to confirm fatty infiltration of organs, such as the pancreas [23-27]. The technique can also be useful for the detection of hemosiderin, such as can occur in renal masses, or other sources of susceptibility artifact [28,29]. A single dual-echo gradient-echo sequence is more effective than separate gradient-echo sequences that differ in echo times (TEs) because the former will depict the exact same anatomy, without misregistration artifacts. It is essential that the out-of-phase TE is shorter than the in-phase TE so that signal reduction on the out-of-phase TE will be unambiguous evidence of lipid content. Breath-held dual-echo sequences are generally preferable. These may be either T1-weighted or proton density-weighted sequences.

Three-dimensional (3-D) techniques are available for both T1 and T2-weighted imaging. Numerous advantages over traditional two-dimensional (2-D) sequences include higher inherent SNR, higher in-plane and through-plane resolution, and homogenous fat suppression, most of which are better realized in T1-weighted imaging. Isotropic voxel dimensions allow for multiplanar reconstructions that may obviate the need for additional acquisition in other planes. Several publications have illustrated the value of T2-weighted 3-D imaging for the depiction of complex anatomy and volumetric imaging [30-32].

IV contrast enhancement with gadolinium chelates is gadolinium-based contrast agents (GBCAs) are beneficial to detect and characterize many intra-abdominal neoplasms, vascular abnormalities, and inflammatory processes. However, the use of those agents gadolinium may be omitted when noncontrast images are sufficiently diagnostic if, in the opinion of the supervising physician such that the administration of IV contrast is unlikely to be of further benefit to the patient or where the risks of the administration outweigh the potential benefits. IV contrast may also be omitted when there is a) no IV access, b) a history of prior allergic-type reaction to GBCAs gadolinium chelates and the patient has not been premedicated, c) a relative contraindication exists to parenteral exposure to gadolinium chelates (such as, eg, pregnancy), d) severe renal insufficiency with an estimated glomerular filtration rate (eGFR) <30 mL/min/1.73 m² or acute renal injury insufficiency of any severity, or e) known or suspected diagnosis of nephrogenic systemic fibrosis. Of note, is for an eGFR of 15–30, many practices are now opting to perform a clinically indicated contrast-enhanced MR examination utilizing a macrocyclic GBCA gadolinium agent.

Detailed information that can help in forming practice-specific policies regarding handling of GBCA gadolinium administration is provided in the ACR Manual on Contrast Media [3].

Multiphase contrast-enhanced sequences acquired through the abdomen are commonly composed of precontrast, arterial, venous, and delayed phase images, which are beneficial for evaluating various blood vessels and tumors of the solid organs tumors [33,34]. Subtraction images may also be generated, which can aid in identifying tumor enhancement [35]. Postcontrast enhanced imaging may be performed with a 2-D or 3-D...
The use of fat suppression during dynamic contrast-enhanced, T1-weighted imaging is strongly encouraged, as it improves the conspicuity of enhancing structures and abnormalities. Fat suppression can typically be accomplished using chemically-selective fat-frequency selective saturation techniques, water excitation, or chemical shift/Dixon techniques. STIR–Inversion recovery sequences should be avoided for gadolinium-enhanced T1-weighted postcontrast imaging, as the relative enhancement of tissues due to gadolinium is that falls within the nulling range for fat is also suppressed by this technique.

Specific timings and adjunctive measures in dynamic contrast-enhanced imaging can be employed for particular applications. For instance, delayed postcontrast T1-weighted imaging (5 minutes or later greater after extracellular-gadolinium-based contrast administration of extracellular GCBA) can be useful in excretory MR urography for detecting pathology of the urinary tract (excretory MR urography) [37,38], and IV hydration and/or diuretic administration has been shown to improve visualization of the nondilated collecting system [39] and ureters [40] during excretory MR urography. Delayed imaging with extracellular gadolinium-based agents may also be useful in diagnosing cancer of the biliary system [41]. Note that different GBCAs intravenous gadolinium chelates that allow are targeted toward visualization of particular organs and organ systems are available. Specifically, hepatobiliary agents (eg, gadoxetate disodium, gadobenate dimeglumine) localize to the liver and biliary tree, and fat-suppressed T1-weighted imaging during the hepatobiliary phase timing varies depending on the agent) provide images based on hepatocyte uptake and biliary excretion of these agents [42]. (See the ACR–SAR–SPR Practice Parameter for the Performance of Magnetic Resonance Imaging (MRI) of the Liver [1].) Similarly, blood-pool agents target the vascular system on postcontrast T1-weighted imaging [43].

The addition of a heavily T2-weighted MR cholangiopancreatography (MRCP) sequence may be beneficial for evaluating the biliary and pancreatic ducts [41-43]. Such heavily T2-weighted sequences may also serve to evaluate dilated renal collecting systems (static-fluid MR urography) [34,44] as well as in the evaluation of the lymphatic system to demonstrate pathologic lymphatic structures and the presence and distribution of lymphatic fluid in different body cavities [45,46].

The use of secretin has been shown to significantly improve visualization of the pancreatic duct during MRCP, which can aid in the diagnosis of anatomic variants [44-46], chronic pancreatitis [47,48], and side-branch intraductal papillary mucinous neoplasms [49]. Secretin has also been used to measure pancreatic exocrine function [50,51]. T2-weighted imaging can be performed using a rapid acquisition relaxation enhancement (RARE) or half-Fourier single-shot echo train spin-echo sequence. These sequences can be performed as a thick slab acquisition in multiple projections or as multiple thin (< 5 mm) slices in at least one imaging plane during breath holding. 3-D respiratory triggered T2-weighted FSE techniques can also be used, potentially offering improved SNR and isotropic spatial resolution [52]. Additional sequences, such as postcontrast T1-weighted and FSE T2-weighted sequences, can aid in the assessment of periductal tissues, the evaluation for causes of extrinsic ductal compression, and the staging of cholangiocarcinoma [54,55].

The use of an oral contrast agent for MRI of the abdomen is considered optional but may occasionally be beneficial for gastrointestinal imaging [47]. For MR enterography, see the ACR–SAR–SPR Practice Parameter for the Performance of Magnetic Resonance Imaging (MR) Enterography [6]. Negative oral contrast agents may be helpful in selected cases to suppress signal and reduce artifact from bowel contents when imaging other organs or structures, such as the peritoneum, pancreaticobiliary tree, or urinary system. When using oral contrast media for assessing the small bowel and its serosal surface, a nonabsorbable agent that produces a dark enteric lumen on T1-weighted images can be recommended to distend the bowel and optimize detection of mural enhancement after IV administration of GBCA a gadolinium chelate. Administration of spasmylic agents, such as glucagon [48], can reduce peristalsis and its resultant motion artifact. This can be particularly helpful for contrast-enhanced fast gradient-echo T1-weighted imaging of the bowel [49] or for evaluating the mesentery and peritoneal surfaces [50].
The addition of a heavily T2-weighted magnetic resonance cholangiopancreatography (MRCP) sequence may be beneficial for evaluating the biliary and pancreatic ducts [51-53]. The use of secretin has been shown to significantly improve visualization of the pancreatic duct during MRCP, which can aid in the diagnosis of anatomic variants [54-56], chronic pancreatitis [57,58], and side branch intraductal papillary mucinous neoplasms [59] and in quantifying pancreatic exocrine function [41,60]. T2-weighted imaging can be performed using a rapid acquisition relaxation enhancement (RARE) or half-Fourier single-shot echo train spin-echo sequence. These sequences can be performed as a thick slab acquisition in multiple projections or as multiple thin (less than 5 mm) slices in at least one imaging plane during breath-holding. Three-dimensional respiratory triggered T2-weighted FSE techniques can also be used, potentially offering improved SNR and isotropic spatial resolution [61]. Such heavily T2-weighted sequences may also serve to evaluate dilated renal collecting systems (static-fluid MR urography) [37,62]. Additional sequences, such as postcontrast T1-weighted and FSE T2-weighted sequences, can aid in the assessment of periductal tissues, in the evaluation for causes of extrinsic ductal compression, and in the staging of cholangiocarcinoma [63,64].

Steady-state free-precession (SSFP) sequences display bright fluid and blood while minimizing motion and flow-related artifacts. Such sequences can provide a rapid abdominal survey [65] and can be useful for cine imaging of the bowel during MR enterography and for demonstration of intra-abdominal adhesions [65-68].

3T imaging systems have become widely available, and potential advantages include increased SNR [69], increased conspicuity of enhancement after administration of a gadolinium chelate [70], and more rapid chemical shift-type sequences (based on shorter in-phase and out-of-opposed-phase TE s compared with 1.5T). Potential disadvantages include decreased image contrast on T1-weighted images, increased susceptibility artifact, increased chemical shift artifact, increased specific absorption rate (SAR), and standing wave phenomena from signal B1 inhomogeneity [71]. The latter can be partially compensated for by the use of radiofrequency cushions [72]. In short, 3T imaging can offer substantial improvements in SNR and spatial resolution and/or decreases in imaging times, but careful sequence optimization is required to maintain desired image contrast and reduce artifacts [73,74].

PI techniques take advantage of spatial sensitivity information from multiple independent receiver coil elements in order to reduce the number of phase encoding steps, thereby reducing scan times [75]. Parallel imaging (PI) techniques These can also expand the options for breath-hold imaging and provide shorter effective TE s and decreased blurring on echo-train sequences, such as single-shot FSE. The primary penalty of this method o for this time savings is reduced SNR [76]. However, there is a potentially synergistic effect between PI and imaging at 3T: 1) the decreased SNR inherent to PI is partially offset by the increased SNR of 3T, and 2) the SAR issues inherent to 3T can be offset by a reduced number of excitations [77]. Recently, 2-D PI techniques have become available, which provide higher-order acceleration factors by reducing the number of measurements required to fill k-space in both the phase and partition directions [78,79]. Emerging applications are also being developed with other means of image acquisition acceleration, such as non-Cartesian kernels and simultaneous multislice techniques (SMS) [80].

Diffusion-weighted imaging (DWI) can be utilized for abdominal application [81]. Most research to date has centered on oncologic applications, either for staging disease or monitoring response to therapy [82-88]. The most common technique uses single-shot echo-planar imaging (SS-EPI). Breath-held, free-breathing multiple-averaging, and respiratory-gated SS-EPI techniques have been described [89,90]. PI can be used to decrease imaging time, reduce susceptibility-related signal loss by shortening the effective TE, and has been shown to result in accurate apparent diffusion coefficient (ADC) values [91]. DWI has shown promising results in early research and at least appears to be is a value-added adjunct sequence capable of improving lesion detection and characterization, as restricted diffusion can be quite sensitive in suggesting the presence of hypercellularity, such as with small metastases or the purulent core of an abscess, and is useful in examinations for which IV contrast is not or cannot be utilized revealing additional sites of disease in the abdomen [92]. There is also increasing evidence of its utility in the evaluation of infectious and inflammatory processes, possibly obviating the need for IV gadolinium-based contrast in the study of inflammatory bowel disease during MR enterography and for the diagnosis of acute appendicitis and its postoperative complications [93-99]. ADC maps can be generated to help
differentiate between restricted diffusion and T2 shine-through when at least 2 b-values are obtained, including such as \( b = 0 \) to 50 \( \text{s/mm}^2 \) and \( b = 500 \) to 1,000 \( \text{s/mm}^2 \). Many vendors offer computed DWI, in which additional higher b-value images are generated from a set of measured \( v \)-values by voxel-wise fitting, thus providing images with greater diffusion weighting in less time and with higher relative SNR than directly acquired DWIs [100]. In addition, more complex models of diffusion, such as the intravoxel incoherent motion (IVIM) model, have shown the potential to separate perfusion effects from true restricted diffusion values and may provide more robust measures of diffusion compared with the ADC model [101].

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [102].

VI. EQUIPMENT SPECIFICATIONS

Equipment performance monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance (MR) Imaging Equipment [103].

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 magnetic field strength (dB/dt), maximum radiofrequency power deposition (specific absorption rate), and maximum acoustic noise levels.

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

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

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PRACTICE PARAMETER 15 MRI Abdomen 2020 Resolution No. 25

OLD REFERENCES

*Practice Parameters and Technical Standards are published annually with an effective date of October 1 in the year in which amended, revised, or approved by the ACR Council. For Practice Parameters and Technical Standards published before 1999, the effective date was January 1 following the year in which the Practice Parameters and Technical Standards was amended, revised, or approved by the ACR Council.

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Amended 2006 (Resolution 35)
Revised 2010 (Resolution 16)
Amended 2014 (Resolution 39)
Revised 2015 (Resolution 2)
NOT FOR PUBLICATION, QUOTATION, OR CITATION

RESOLUTION NO. 26

BE IT RESOLVED,
that the American College of Radiology adopt the ACR–SAR–SPR Practice Parameter for the Performance of Magnetic Resonance (MR) Enterography

Sponsored By: ACR Council Steering Committee

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

The American College of Radiology will periodically define new practice 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.

2015 (Resolution 9) *

ACR–SAR–SPR PRACTICE PARAMETER FOR THE PERFORMANCE OF MAGNETIC RESONANCE (MR) ENTEROGRAPHY

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. 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 in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document 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.

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.

PRACTICE PARAMETER

MR Enterography

2020 Resolution No. 26
I. INTRODUCTION

Magnetic Resonance enterography (MREnt) is a proven and useful tool for the diagnosis, assessment of severity and complications, and follow-up of small-bowel disease of diseases of the small bowel [1-10]. MREnt is especially useful and is most widely used in patients with inflammatory bowel disease (IBD), particularly Crohn’s disease (CD). MREnt is a noninvasive imaging test that does not employ ionizing radiation. For these reasons MREnt may be considered a primary imaging modality for patients, especially the pediatric population, patients with IBD who require repeated imaging for disease assessment and therapeutic monitoring [11,12]. Performance of MREnt requires adequate technical and clinical expertise and may not be appropriate for routine use in centers that do not possess this skillset.

II. INDICATIONS

Indications for MREnt include, but are not limited to, the following:

1. Diagnosis of IBD, including assessment of disease activity, and extent, and distribution.
2. Follow-up of known IBD, including assessment of disease activity and response to therapeutic intervention.
3. Evaluation of suspected IBD-related complications, such as stricture and obstruction or penetrating disease (eg, fistula, sinus tract, or abscess). High-resolution pelvic MRI sequences may be added to the routine MREnt or obtained as a separate examination for dedicated evaluation of perianal disease.
4. Differentiation of CD from ulcerative colitis in children with “indeterminate colitis,” searching for features that are more characteristic for CD, which include transmural and periserosal disease, terminal ileal or other small-bowel involvement, asymmetric involvement of the mesenteric border of the small bowel, associated penetrating complications (eg, fistulas or sinus tracts), lack of involvement of the rectum and distal large bowel, or skip lesions.
5. Nonemergent evaluation of suspected bowel disease with prior negative computed tomography (CT) examination and/or endoscopy, or in place of these other tests, and including a variety of disease processes, such as subacute bowel obstruction or non-IBD enteritis (eg, due to infection or vasculitis)
6. Evaluation of polyposis syndromes and small bowel mass(es)

MREnt protocols are specifically tailored to allow detailed assessment of the small intestine. However, in some IBD patients, additional evaluation of IBD-related diseases or conditions may be desired at the time of MREnt. Variations in MREnt scanning protocols, usually requiring added pulse sequences, can allow for concurrent appraisal of the pancreatobiliary tree (eg, in the setting of a known or suspected sclerosing cholangitis), perianal/perineal region (eg, in the setting of known or suspected perianal fistula or abscess), and sacroiliac joints. Although additional imaging will lengthen the MREnt examination and increase the likelihood of motion-related artifacts due to patient discomfort and/or pain, this approach may be desired when imaging is to be performed under sedation or general anesthesia (eg, in the pediatric population). However, combined studies should be performed in a manner that does not adversely affect image quality or overall diagnostic performance of either examination.

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [13].
IV. 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 the MRI interpretation must be knowledgeable about have a clear understanding and knowledge of the anatomy and pathophysiology relevant to the MRI examination.

The written or electronic request for MREnt should provide sufficient information to demonstrate the medical necessity of the examination and allow for the proper performance and interpretation of the examination. Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). The provision of additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

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

The supervising physician must also understand the pulse sequences that are used and their imaging appearance, including the appearance of image artifacts. Standardized imaging protocols should be established but may be 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 phone 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.

The majority of MREnt examinations require the administration of intravenous (IV) gadolinium-based contrast media (GBCA) [14,15]. IV GBCA administration 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 [16]). Noncontrast examinations may be considered in select cases in which the presence/absence of active bowel inflammation is the only clinical question and it is felt that the clinical question may be resolved with T2-weighted (T2W) fat-suppressed sequences and/or diffusion-weighted imaging (DWI) [17-19]. Noncontrast examinations may also be considered in patients with contraindications to IV GBCA contrast administration, such as during pregnancy or diminished renal function.

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. Physicians working in or near the MRI area must have current training in MRI safety, preferably Level 2 training [20], as well as the management of contrast reactions.
C. Patient Preparation

Bowel preparation is generally regarded as helpful for improving the diagnostic performance of MREnt [21-24]. The goal of bowel preparation is to 1) achieve maximal distension of bowel loops to minimize false-positive instances of bowel-wall thickening, 2) improve the visibility of mural postcontrast enhancement, luminal disease; 3) reduce bowel peristaltic activity to improve the diagnostic quality of motion-sensitive MR sequences, and 4) displace air within bowel loops that can cause susceptibility artifacts on gradient-echo sequences.

Oral contrast may be administered to patients prior to MREnt to improve small-bowel distension. Patients may be asked to fast 4 to 6 hours prior to the examination to improve compliance with ingestion of enteric contrast preparations and minimize filling defects within the small bowel. Though the types and volumes of enteric contrast may vary across centers, oral contrast agents should provide some osmotic effect to prevent water absorption by the gut, and a viscosity agent to promote distension. In addition, the generally favored contrast agents should be biphasic, demonstrating bright signal on T2W images and dark signal on T1-weighted (T1W) images, to achieve maximum contrast with the bowel wall. This is especially important on T1W postcontrast sequences in which the bowel wall will enhance and the distended lumen will remain low signal [25-27]. Patient compliance with enteric contrast (especially pediatric patients) can be improved by contrast refrigeration and flavor additives, although caution should be employed with color additives if contemporaneous endoscopy is planned. A defined time delay from administration of oral contrast to imaging allows for adequate distal passage of contrast to the terminal ileum prior to image acquisition. The amount of contrast and the specified time delay may vary according to center-specific experience. A recommendation is to follow prescriptions as used for CT oral contrast administration at the corresponding imaging facility. Rectal contrast may assist in visualization of the ileocecal junction [25].

Antiperistalsis medications may also be administered prior to and during the imaging examination. An oral, over-the-counter liquid anticholinergic agent may be mixed with the patient’s enteric contrast to reduce bowel motility [28-31]. Administration of IV glucagon as a spasmylytic agent is a commonly employed method to reduce bowel motion artifact [31]. However, because of the short-acting half-life of glucagon, it is recommended that it be administered immediately prior to motion-sensitive sequences (typically T1W dynamic contrast-enhanced sequences), which may require interruption of image acquisition; both intramuscular (IM) and IV routes of administration are available. IM administration is longer lasting but less reliable [32]. Evaluation for any potential contraindications or drug interactions should be investigated prior to administration.

Enteroclysis is an invasive method for improving small-bowel distension through intubation of the jejunum with a nasojejunal feeding tube and direct administration of enteric contrast through the tube [23,33]. Though enteroclysis may provide increased small-bowel distension more reliably compared with routine oral contrast administration [33], the impact on clinical decision-making pathways has not been well documented [34]. For this reason, enteroclysis is not considered an absolute requirement for routine applications of MREnt. Furthermore, dedicated colon cleansing and administration of rectal contrast is another potential patient preparation step that may be considered on a case-by-case basis [35,36].

D. Examination Technique

A phased array surface coil should be used unless precluded by patient body habitus. The field of view should be selected to cover as much of the bowel as possible, ensuring the inclusion of the anal region while providing the highest possible signal-to-noise ratio with adequate spatial resolution. The patient may be imaged prone or supine. Although some centers have found prone imaging to improve bowel motion artifacts effects and bowel separation, there is no consensus on this point, and there are patients who will prefer supine positioning for comfort. Prone positioning may also be uncomfortable for patients with a stoma device and should be avoided in these instances. Adequate performance of MREnt requires imaging in both the axial and coronal planes; imaging in the coronal plane is a key feature of MREnt, allowing for maximum visualization and inclusion of bowel loops in each slice, with optimum display of the terminal ileum. For most applications, MREnt should include both T1W, and T2W, and, if available, DWI [9,14,17,37-40].
T2W imaging may be performed with an accelerated spin-echo sequence (turbo-spin-echo (TSE) or fast spin-echo (FSE)), gradient-echo (GRE) sequence, or a hybrid gradient and spin-echo (GRASE) technique. Given the motion effects of a contracting bowel that cannot be corrected with breath-holding or triggering techniques, motion-insensitive fast spin-echo (FSE) T2W imaging with acquisition of all necessary phase lines in one repetition time (TR) interval (“single shot” technique) is the most reliable method for T2W imaging of the bowel. Slice thickness is typically 4-5 mm, and the interslice gap should not exceed 10% of the slice thickness.

T2W imaging is a fluid-sensitive sequence that is used for identifying fluid collections, edema, fluid-filled fistulas and sinus tracts. T2W imaging with fat suppression is a key component of MREnt for identifying evaluation of active bowel wall and mesenteric edema, which are signs of active inflammation. Fat suppression may be accomplished through a variety of techniques, including short tau inversion recovery (STIR), chemically selective fat saturation, water excitation, or Dixon-based methods. Spectral adiabatic inversion recovery (SPAIR) fat suppression is a newer technique that combines elements of both inversion recovery and chemical fat suppression techniques to provide an extremely a very reliable and robust degree of fat suppression while continuing to preserve water signal [19,41,42].

T1W imaging may be performed using a 3-D accelerated gradient-echo with fat suppression, or accelerated spin-echo (TSE or FSE) methods. Three-dimensional (3-D) image acquisition methods are available for both gradient-echo and spin-echo sequences, allowing for higher through-plane resolution, improvements in SNR and more homogeneous fat suppression. Use of surface coils is important for improved signal. T1W 3-D gradient-echo acquisitions have the advantage of rapid acquisitions within a breath-hold, reducing breathing-motion artifact without the need for time-consuming respiratory navigation and triggering techniques. These acquisitions should be no longer than 15-19 seconds. However, antiperistaltic agents, administered prior to T1W 3-D imaging, are recommended to reduce bowel peristalsis and bowel wall motion artifacts. These acquisitions should be no longer than 15-19 seconds. Radial acquisition methods, such as radial 3-D gradient-echo (GRE) sequences, are also available for patients that are less sensitive to image deterioration from bowel peristalsis and breathing motion and may be used in patients unable to hold their breath at all [43,44].

IV contrast enhancement with GBCAs gadolinium chelates is an important component of a comprehensive MREnt examination, especially for the accurate diagnosis and detection of bowel wall inflammation, delineation of chronic bowel disease and fibrotic strictures, fistulas, abscesses, and perianal fistulas. Every Standard extracellular GBCAs should be used because there is no benefit in using a liver-uptake GBCA or blood pool agent. Attempts should be made to use IV contrast material except when there is 1) no IV access, 2) history of prior allergic-type reactions to GBCAs gadolinium-chelates and the patient has not been premedicated, 3) relative contraindication to gadolinium chelates (such as pregnancy), or 4) known or suspected nephrogenic systemic fibrosis (NSF) or particular concerns regarding NSF risk that may outweigh the benefits of a contrast-enhanced MREnt examination. The standard MREnt examination will include multiple dynamic postcontrast phases, which ideally would include a late arterial or enteric phase and portal venous phase usually obtained in the coronal plane. Axial and coronal Venous delayed phase postcontrast images obtained at least 2 minutes or up to several minutes after the start of the injection in both the axial and coronal plane, are also can be the key sequences to depict fibrosis within the bowel wall, which will appear thickened and will retain contrast [1,3,45-48]. Similarly, late enhancement is a feature of fibrotic adhesions that may be associated with tethered bowel loops or fistula [49].

DWI can be an important component of an MREnt examination and should be performed if possible. DWI evaluates for abnormal water mobility in tissues. With DWI, ideally, multiple b-values (eg, b-values of 0, 20, and 800 s/mm²) are obtained, having varying degrees of diffusion weighting as well as an apparent diffusion coefficient (ADC) map. Low b-value images (eg, 20 s/mm²) can be used to identify edema and fluid. High b-value images of at least 500 s/mm² can be used to identify bowel wall inflammation, abscesses, and lymph nodes that will have high signal intensity on high b-value images and low signal on the ADC map. DWI sequences may be additionally helpful in MREnt examinations in which IV GBCAs cannot be administered, in addition to fat-suppressed T2W imaging (which is essential for the detection of edema and inflammation).

Additional MR sequences, although considered optional, may provide added value to bowel imaging. Dynamic, real-time cine MRI of the bowel may be obtained by a heavily T2W coronal slab or a single-shot balanced
steady-state free-precession sequence or a heavily T2W coronal slab centered over a region of interest [50-52]. Repeated image acquisitions over time with these techniques may be used to produce real-time cine imaging of the bowel to evaluate bowel motility and also aid in evaluating of any the potential functional significance of fibrotic strictures and fixed luminal narrowing. However, even in the absence of real-time cine images, comparison of different sequences that are acquired at different time points during the study acquisition or over multiple examinations is helpful to discern bowel peristalsis from a fixed fibrotic stricture. A quantitative perfusion sequences are is an additional MRI technique that may can be performed for bowel imaging [17,53-57]. DWI detects abnormally restricted water motion, and these images can show areas of inflamed bowel wall and adjacent soft tissue. Quantitative perfusion may be able to help discriminate between inflammation or fibrosis in a region of abnormally thickened bowel wall, where inflammation leads to increased vascularity and accelerated contrast arterial phase enhancement.

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [58].

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 that deal with the potential hazards associated with MRI examination of the patient as well as to others in the immediate area should be provided. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination.

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [13], the ACR Guidance Document on MR Safe Practices: 2013 [20], and the ACR Manual on Contrast Media [59].

VI. EQUIPMENT SPECIFICATION

Equipment monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance (MR) Imaging Equipment [16].

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 magnetic field strength (dB/dt), maximum radiofrequency power deposition (specific absorption rate), and maximum acoustic noise levels. Additional considerations include the use of surface coils that can provide coverage of the entire abdomen and pelvis. In addition, it may be commonly necessary to use at least 2 fields of view (FOV) to capture all of the entire abdomen and pelvis. Acquisition and postprocessing of these images may be facilitated by systems with specific software that allows merging of at least 2 imaging fields.

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

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control and Patient Education appearing under the heading ACR Position Statement on Quality Control and Improvement, Safety, Infection Control and Patient Education on the ACR website (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).
This practice parameter was revised according to the process described under the heading The Process for Developing ACR Practice Parameters and Technical Standards on the ACR website (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) by the Committee on Body Imaging (Abdominal) of the Commission on Body Imaging and by the Committee on Practice Parameters – Pediatric Radiology of the Commission on Pediatric Radiology, in collaboration with the SAR and the SPR.

**ACKNOWLEDGEMENTS**

This practice parameter was revised according to the process described under the heading The Process for Developing ACR Practice Parameters and Technical Standards on the ACR website (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) by the Committee on Body Imaging (Abdominal) of the Commission on Body Imaging and by the Committee on Practice Parameters – Pediatric Radiology of the Commission on Pediatric Radiology, in collaboration with the SAR and the SPR.

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**PRACTICE PARAMETER**

7

MR Enterography

2020 Resolution No. 26
NOT FOR PUBLICATION, QUOTATION, OR CITATION

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REFERENCES


PRACTICE PARAMETER

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PRACTICE PARAMETER
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RESOLUTION NO. 27

BE IT RESOLVED,
that the American College of Radiology adopt the ACR–SAR–SPR Practice Parameter for the Performance of Magnetic Resonance Imaging (MRI) of the Liver

Sponsored By: ACR Council Steering Committee

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

The American College of Radiology will periodically define new practice 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.

Revised 2015 (Resolution 3) *

ACR–SAR–SPR PRACTICE PARAMETER FOR THE PERFORMANCE OF MAGNETIC RESONANCE IMAGING (MRI) OF THE LIVER

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. 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 in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document is advised to document in the patient record information sufficient to explain the approach taken.

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.
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 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 sole purpose of this document is to assist practitioners in achieving this objective.

I. INTRODUCTION

Magnetic resonance imaging (MRI) of the liver is a proven and useful tool for the evaluation, assessment of severity, and follow-up of diseases of the liver. Although liver MRI is one of the most sensitive diagnostic tests for detection and characterization of hepatic lesions, findings may be misleading if not closely correlated with the results of previous imaging studies, clinical history, physical examination, or laboratory tests. Adherence to the following parameters will enhance the probability of accurately assessing such abnormalities.

II. INDICATIONS

Indications for MRI of the liver include, but are not limited to, the following:

1. Detection of focal hepatic lesions
2. Focal hepatic lesion characterization (e.g., cyst, focal fat, hemangiomas, and vascular malformations), hepatocellular carcinoma (HCC), hepatoblastoma, metastasis, intrahepatic cholangiocarcinoma, focal nodular hyperplasia, and hepatic adenoma
3. Evaluation for known or suspected metastases, metastasis including preoperative mapping for liver resection
4. Evaluation of vascular patency, including Budd-Chiari and portal vein thrombosis
5. Evaluation and noninvasive quantification of iron, fat, and fibrosis in chronic liver disease, such as hemochromatosis, hemosiderosis, or steatosis nonalcoholic steatohepatitis (NASH) and hepatitis in adults and pediatric patients
6. Evaluation of cirrhotic liver and HCC surveillance
7. Clarification of findings from other imaging studies, laboratory abnormalities, or alternative imaging for contraindications to CT scans
8. Staging of liver and biliary cancers, including assessment of vascular and biliary invasion
9. Evaluation of infection
10. Potential liver donor evaluation, liver resection evaluation, liver transplant evaluation, and evaluation of postsurgical complications
11. Evaluation of tumor response to treatment, e.g., image-guided liver interventions/tumor ablation, chemoembolization, radioembolization, chemotherapy, radiotherapy, or surgery
12. Evaluation of known or suspected congenital abnormalities
13. Informing or guiding clinical decision making and treatment planning

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [1].

IV. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for MRI of the liver should provide sufficient information to demonstrate the medical necessity of the examination and allow for the proper performance and interpretation of the examination.
Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). The provision of additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

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

The supervising radiology 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 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. It is also critical to understand the different contrast agents used for liver MRI as well as the basis for choosing between them. 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 phone 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 (see the ACR Guidance Document on MR Safe Practices: 2003 [2]).

Certain indications require administration of intravenous (IV) contrast media. IV contrast administration 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 [3]).

Patients suffering from anxiety or claustrophobia or who are unable to cooperate or suspend respiration, such as children, may require sedation or additional assistance. Administration of sedation may be necessary to achieve a successful diagnostic examination. If sedation is necessary, refer to the ACR–SIR Practice Parameter for Sedation/Analgesia [4] and the American Academy of Pediatrics (AAP) - American Academy of Pediatric Dentistry(AAPD): Guidelines for Monitoring and Management of Pediatric Patients During and After Sedation for Diagnostic and Therapeutic procedures [5].

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

A phased array surface coil should be used [6] unless precluded by patient body habitus or scan indication. The field of view should be selected so that it includes the entire liver without introducing undesirable artifacts.

An adequate MRI examination of the liver is typically performed in the axial plane, and coronal plane images are added as necessary to improve the visualization of the liver dome, evaluate vasculature, and bile ducts and to facilitate interventional and surgical planning.

An adequate satisfactory MRI examination of the liver should include T2-weighted imaging, which may be performed with an accelerated fast spin-echo, or single-shot accelerated fast spin-echo (FSE), half-Fourier single-shot turbo spin-echo [HASTE] or single-shot fast spin-echo [SSFSE] or steady-state free precession (SSFP) sequence [7] in axial and/or coronal planes. T2-weighted images can be obtained using a breath-hold or non-breath-hold technique. When a non-breath-hold technique is used, every effort should be made to minimize the respiratory motion artifacts by using multiple signal averages and/or respiratory compensation or respiratory triggering, which could include bellows or navigator-triggered sequence. Other motion-correction strategies, including periodically rotated overlapping parallel lines, with enhanced reconstruction (PROPELLER), may be useful. For effective T2-weighting, an echo time (TE) between approximately 80 and 100 ms should be used at 1.5T and 70–100 ms at 3T. T2-weighted images are helpful to show abnormal increased fluid or inflammation content in diseased tissue and fluid-containing lesions (e.g., cysts, biliary hamartoma, hemangiomas, and vascular malformations) [7]. When using a 2-D technique, the slice thickness and interslice gap in one of the planes should not exceed 8 and 2 mm, respectively. Parallel MRI with suitable phased-array coils is often used to reduce scan time and increase spatial resolution. Fat suppression may be helpful to assess for fluid and inflammation and to improve image contrast dynamic range.

IV contrast enhancement with gadolinium chelates is critical for accurate diagnosis of various liver pathologies [8]. Every attempt should be made to use of IV contrast should be strongly considered except when there is a) no IV access, b) history of prior allergic-type reaction to gadolinium chelates and the patient has not been premedicated prior to the study, c) contraindication to gadolinium chelates (such as pregnancy), d) known or suspected nephrogenic systemic fibrosis (NSF) or particular concerns regarding NSF risk that outweigh the benefits of a contrast-enhanced liver MR, or e) contrast is not felt to be necessary for the diagnosis in question [2,9,10]. In patients with a high risk of NSF in whom contrast is not used, an unenhanced MR could still be helpful to assess the patient. Long-term safety of gadolinium-based contrast agent (GBCA) administration is not yet established, especially in young infants. A cautious risk/benefit approach is desirable with avoidance of GBCA when feasible in young infants. When contrast administration is required, lower dosing and macro cyclic agents should be considered. Dynamic fat-suppressed MRI should be performed after bolus administration of a gadolinium chelate contrast agent. T1-weighted images should be acquired before gadolinium contrast injection as well as during late hepatic arterial, portal venous, and 2- to 5-minute delayed phases using a 2-D or 3-D technique [11,12]. The 3-D techniques are preferred. Methods to obtain late hepatic arterial phase include using a bolus timing technique, such as automated bolus detection algorithm or fluoroscopic triggering, or obtaining multiple consecutive arterial-phase data sets with higher temporal but lower spatial resolution. An optimal late arterial phase is characterized by the following:

- Hepatic artery and branches are fully enhanced
- Hepatic veins not yet enhanced by antegrade flow
- Portal vein is enhanced

Additional delayed images with delays greater than 2 to 5 minutes may help characterize certain lesions, such as HCC, hemangiomas, and vascular malformations, or intrahepatic cholangiocarcinomas [13-15]. Fat-suppressed volumetric interpolated breath-hold images 3-D T1-weighted gradient-echo images have quality comparable to that of conventional fat-suppressed 2-D gradient-echo images [16]. It is advantageous to acquire 3-D data sets using the smallest voxel dimensions possible to achieve the highest resolution practical in each axis. Minimizing slice
thickness of a volumetric acquisition can reduce truncation artifacts in the axis of slice encoding, which can be a source of boundary artifacts at high-contrast borders. When using a 2-D technique, the slice thickness and interslice gap should not exceed 8 and 2 mm, respectively.

To aid in the detection of contrast-enhanced lesions, subtraction of unenhanced from contrast-enhanced images may be considered for lesions that are hyperintense on T1-weighted images prior to gadolinium administration, for example, in cases of hepatic lesions following locoregional therapy radiofrequency ablation or chemoembolization and T1 hyperintense nodules within cirrhotic livers. Efforts should be made to ensure that patients’ respirations are suspended in an identical manner during precontrast and postcontrast dynamic phases. However, misregistration artifacts have to be excluded to minimize erroneous interpretation of subtraction images. Other methods for postcontrast sequences include the combination of compressed sensing, radial sampling, and parallel imaging, which allow high-quality scans to be obtained during free breathing. This has several advantages; for instance, it is possible to perform free-breathing dynamic contrast-enhanced MRI in children or in patients who are ill, uncooperative, or hard of hearing [17].

The use of Hepatobiliary phase (HBP) images obtained between 45 min and 3 hours after the administration of gadobenate dimeglumine and approximately at least 20 minutes after the administration of gadoxetate disodium revealing retention of contrast within the lesion can confirm the diagnosis of focal nodular hyperplasia [18-20]. HBP images can also be used to detect and characterize malignant disease and assess its extent [21-23]. The use of hepatobiliary agents partially excreted in the biliary system, such as gadoxetate and gadobenate, can help delineate biliary anatomy [26-28]. When interpreting HBP images, it is important to ascertain the adequacy for diagnosis. For an adequate HBP image in patients without chronic liver disease, the liver parenchyma is unequivocally brighter than the intrahepatic blood vessels; otherwise, the HBP images are considered suboptimal. Poor enhancement of hepatic parenchyma may be seen in some patients with chronic liver disease. The use of hepatobiliary agents may not be advisable in patients with total bilirubin of greater than 2 mg/mL [24-26]. The use of hepatobiliary agents (gadoxetate and gadobenate) partially excreted in the biliary system such as gadoxetate and gadobenate can help delineate biliary anatomy [26-28]. T2-weighted imaging of the biliary tree (Magnetic resonance cholangiopancreatography (MRCP) images) must be completed before contrast is excreted into bile ducts because gadolinium within the enhanced bile will can shorten the T2 and result in the biliary tree not being visible not be visible on MRCP images. This can be prevented by obtaining MRCP images before or within 5 minutes after administration of gadoxetate or within several minutes after administering gadobenate dimeglumine. T2-weighted and diffusion-weighted images can be obtained after injection of gadobenate disodium to improve time efficiency, and diffusion-weighted imagining (DWI) sequences may be delayed more than 5 minutes after HBP agents.

In-phase and out-of-phase chemical shift gradient-recalled echo T1-weighted imaging should be included for lesion characterization and is a sensitive technique for confirmation of hepatic steatosis and iron overload; these sequences should be obtained prior to the administration of IV contrast material [27]. Out-of-phase images can be helpful to assess for signal loss from fat in fat-containing lesions, such as hepatic adenomas and HCC. Every effort should be made to ensure that the out-of-phase TE is shorter than the in-phase TE. A potential pitfall is Note that in livers with simultaneous iron overload and steatosis, a potential pitfall exists in which in-phase and out-of-phase imaging may show no comparative signal loss (ie, signal loss due to steatosis on the out-of-phase image may be counterbalanced by signal loss due to iron overload on the in-phase image). Another pitfall may occur when is that some scanners use a sequence design where in-phase images have a shorter TE than out-of-phase images. In these instances, signal loss on the out-of-phase echo could be from either iron overload, or steatosis, or a combination of both. Every effort should be made to ensure that the out-of-phase TE is shorter than the in-phase TE. In addition, the TEs for the in-phase and out-of-phase images at 3T are half that at 1.5T, which needs to be accounted for when assessing for fat or iron. A number of techniques have been developed, tested, and validated for quantitative measurement of liver iron and fat content [28-32]. These methods have been commercialized by many MR vendors and are available clinically for quantitative measurement of liver iron and fat. The current gold standard for fat quantification with MRI is proton density fat fraction (PDFF). PDFF
is the proportion of mobile protons in liver tissue attributable to fat and thus is a noninvasive MR-based biomarker of liver triglyceride concentration.

In recent years, 3T imaging systems are more have become widely more available. Potential advantages of 3T systems include an increased signal-to-noise ratio (SNR) [33] and an increased conspicuity of enhancement after administration of a gadolinium chelate contrast agent [34]. Potential disadvantages include decreased image contrast on T1-weighted images, increased predisposition to susceptibility artifact, increased chemical shift artifact, increased specific absorption rate, and signal inhomogeneity [35]. The latter can be partially compensated for by the use of radiofrequency (RF) cushions [36] and/or parallel transmit technology. In short, 3T imaging can offer substantial improvements in SNR and spatial resolution and/or decreases in imaging times, but sequence modifications are often required to maintain desired image contrast and reduce artifacts [37,38]. However, in patients with obesity or those with cirrhosis, 1.5T MRI may be considered because of the standing wave and dielectric artifacts seen on 3T MRI.

DWI has become commonly used recently been investigated for abdominal protocols application [39-44]. The most common technique uses single-shot echo-planar imaging (SS-EPI). Breath-hold, free breathing multiple-averaging, and respiratory-gated SS-EPI techniques can be used have been described [45,46]. Parallel imaging can be used to decrease imaging time and has been shown to result in accurate apparent diffusion coefficient (ADC) values [47]. DWI has shown promising results in detection and characterization of focal liver lesions, and in detection and staging of liver fibrosis, and appears to be at least a value-added adjunct sequence capable of revealing additional sites of disease in the abdomen [48,49]. The ability to depict areas of high cellularity can be helpful in hepatic lesion detection and in characterization in a noninvasive manner. DWI does not rely on IV gadolinium; therefore, its use is particularly attractive in patients who are unable to receive IV contrast agents with poor renal function who cannot receive contrast because of the potential risk of nephrogenic systemic fibrosis. ADC maps can be generated to help differentiate between restricted diffusion and T2 shine-through. At least 2 b-values are obtained, including b = 20–50 s/mm² and b = 400 to 1,000 s/mm². However, overlap exists between ADC values of solid benign hepatocellular lesions, such as focal nodular hyperplasia (FNH) or hepatocellular adenoma (HCA), and those of malignant lesions [40,43,50-56]. Thus, information provided by DWI needs to be interpreted in conjunction with lesion morphology and signal characteristics on other sequences. Moreover, ADC values are technique and scanner dependent; hence, diagnostic cutoff values reported in the literature may not be applicable to other scanners. Techniques such as simultaneous multislice (SMS) technique may allow DWI to be performed in under one minute [57].

MR elastography (MRE) is a technique that enables measurement of liver stiffness. Published data over the last 5 years show that this method has high accuracy in discriminating different stages of liver fibrosis [58-62].

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [63].

In patients with cirrhosis or those at high risk for HCC, please refer to the Liver Imaging Reporting and Data System (LI-RADS) (http://www.acr.org/Quality-Safety/Resources/LIRADS) for additional guidance on reporting of MRI in this population.

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 MRI examination of the patient as well as to others in the immediate area [64-73]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [64-73].
VI. EQUIPMENT SPECIFICATIONS

Equipment monitoring should be in accordance with the ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment [74].

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 magnetic field strength (dB/dt), maximum RF power deposition (specific absorption rate), and maximum acoustic noise levels.

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

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

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [1], the ACR Guidance Document on MR Safe Practices: 2003 [2], and the ACR Manual on Contrast Media [10].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [4-13]

ACKNOWLEDGEMENTS

This practice parameter was revised according to the process described under the heading The Process for Developing ACR Practice Parameters and Technical Standards on the ACR website (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) by the Committee on Body Imaging (Abdominal) of the Commission on Body Imaging and by the Committee on Practice Parameters – Pediatric Radiology of the Commission on Pediatric Radiology, in collaboration with the Society of Abdominal Radiology (SAR) and the Society for Pediatric Radiology (SPR).

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OLD REFERENCES


Parameters and standards are published annually with an effective date of October 1 in the year in which amended, revised, or approved by the ACR Council. For parameters and standards published before 1999, the effective date was January 1 following the year in which the parameter or standard was amended, revised, or approved by the ACR Council.

Development Chronology for this Parameter

2005 (Resolution 3)
Amended 2006 (Resolution 35)
Revised 2010 (Resolution 14)
Amended 2014 (Resolution 39)
Revised 2015 (Resolution 3)
BE IT RESOLVED, that the American College of Radiology adopt the ACR–SAR–SPR Practice Parameter for the Performance of Magnetic Resonance Imaging (MRI) of the Soft-Tissue Components of the Pelvis

Sponsored By: ACR Council Steering Committee

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

The American College of Radiology will periodically define new practice 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.

Revised 2015 (Resolution 4)*

ACR–SAR–SPR PRACTICE PARAMETER FOR THE PERFORMANCE OF MAGNETIC RESONANCE IMAGING (MRI) OF THE SOFT-TISSUE COMPONENTS OF THE PELVIS

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. 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 in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document is advised to document in the patient record information sufficient to explain the approach taken.

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.
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 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 sole purpose of this document is to assist practitioners in achieving this objective.

ABOUT THIS DOCUMENT

This collaborative practice parameter has undergone extensive revision and has been divided into sections with links as indicated below:

Section 1. Detection, Staging, and Recurrence Assessment of Gynecologic Malignancies: Uterus, Cervix, Ovaries, Vulva, and Vagina

Section 2. Evaluation of Pelvic Mass or Acute or Chronic Pelvic Pain, Including Detection of Adenomyosis, Ovarian Cysts, Torsion, Tubo-Ovarian Abscesses, Benign Solid Adnexal Masses, Obstructed Fallopian Tubes, Deep Pelvic Endometriosis, Endometriomas, and Fibroids

Section 3. Assessment of Pelvic Floor Defects Associated with Urinary or Fecal Incontinence

Section 4. Determination of Fibroid Number, Location, Size, and Type Prior to Intervention

Section 5. A. Detection, Staging, and Recurrence Assessment of Urologic Malignancy: Bladder

Section 5. B. Detection, Staging, and Recurrence Assessment of Urologic Malignancy: Prostate

Section 5. C. Detection, Staging, and Recurrence Assessment of Urologic Malignancy: Scrotum and Penis

Section 6. Evaluation of Complications Following Pelvic Surgery, Including Abscess, Urinoma, Lymphocele, Radiation Enteritis, and Fistula Formation

Section 7. Identification of Source of Lower Abdominal Pain in Pregnant Women: Appendicitis, Ovarian and Uterine Masses, and Urological Conditions

Section 8. Identification and Classification of Perianal Fistulas

Section 9. Identification and Characterization of Congenital Anomalies of the Female and Male Pelvis, Including the Anatomic Evaluation of Ambiguous Genitalia and Disorders of Sexual Development (DSD)

I. INTRODUCTION

Magnetic resonance imaging (MRI) of the pelvis is a proven and useful tool for the evaluation, assessment of severity, and follow-up of diseases of the male and female pelvic organs. It should be performed only for a valid medical reason.

MRI of the pelvis is the imaging modality of choice for many clinical situations involving pelvic pathology. This technique has superb soft-tissue contrast and has the advantage of providing multiplanar and 3-D depiction of anatomy and pathology. Additional benefits include absence of ionizing radiation and exposure to iodinated contrast material. Careful attention to patient comfort prior to beginning the MR examination will result in improved diagnostic quality. MRI for the detection, staging, and recurrence of rectal cancer is not considered in this parameter.

II. INDICATIONS

Indications for MRI of the pelvis include, but are not limited to, the following:

1. Detection and staging of gynecologic malignancies, including those originating in the vulva, cervix, uterus, ovaries, and fallopian tubes (see Section 1).
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2. Evaluation of **acute or chronic** pelvic pain or **pelvic** mass, including detection of adenomyosis, ovarian cysts, torsion, tubo-ovarian abscesses, benign solid adnexal masses, obstructed fallopian tubes, endometriomas, and **uterine** fibroids (see Section 2).

3. Assessment of pelvic floor defects associated with urinary or fecal incontinence (see Section 3).

4. Determination of number, location, size, and type (nondegenerating or degenerating) of fibroids for treatment selection and planning (see Section 4).

5. Planning and guidance for minimally invasive surgical and brachytherapy (see Sections 1 and 5b).

6. Assessment for recurrence of tumors of the bladder, prostate, or gynecologic organs following surgical resection or exenteration (see Sections 1, 5b, 5a, and 5c).

7. Detection and staging of malignancies of the prostate, bladder, penis, testis, and scrotum (see Sections 5b, 5a, and 5c).

8. Evaluation of complications following pelvic surgery, including abscess, urinoma, lymphocele, radiation enteritis, and fistula formation (see Section 6).

9. Identification of the source of lower abdominal pain in pregnant women, including appendicitis, ovarian condition or adnexal torsion, or uterine mass (see Section 7).

10. Identification and classification of perianal fistulas (see Section 8).

11. Identification and characterization of congenital anomalies of the male and female pelvic viscera, including the anatomic evaluation of ambiguous genitalia and disorders of sexual development (see Section 9).

### III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [1].

### IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINdicATIONS

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [1], the ACR Guidance Document on MR Safe Practices: 2013 [2], and the ACR Manual on Contrast Media [3].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [4,5].

### V. GENERAL SPECIFICATIONS OF THE EXAMINATION (additional specifications will be discussed in the relevant section)

The supervising physician should have a complete understanding of the indications, risks, and benefits of the examination as well as of 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 soft-tissue **pelvis** should provide sufficient information to demonstrate the medical necessity of the examination and allow for the proper performance and interpretation of the examination.

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

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

The supervising physician must 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 phone 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.

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 [6] and the ACR Manual on Contrast Media [3]).

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 conscious sedation is necessary, refer to the ACR–SIR Practice Parameter for Sedation/Analgesia [7].

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. General Technique (additional technical advances will be discussed in the relevant section)

Whenever possible, a multicoil array should be used to allow for smaller fields of view (FOV) and higher spatial resolution. Fasting for 6 hours prior to the examination will diminish bowel peristalsis and improve quality. Alternatively, glucagon could be administered subcutaneously or intramuscularly to diminish artifacts from bowel peristalsis, unless contraindicated.

The majority of information is obtained using T2-weighted (T2-W) images. Fast spin-echo (FSE), turbo spin-echo, or their equivalents are recommended in the orthogonal planes (see relevant section) to clearly demonstrate the relevant anatomy. Ultrafast T2-W pulse sequences, such as single-shot FSE (SSFSE) or half-acquisition turbo spin-echo may be substituted, yielding a significant time savings at the cost of mildly diminished spatial resolution and with less T2-W imaging than comparable spin-echo technique. Anterior saturation bands over the anterior subcutaneous fat help minimize phase-encoding artifacts.

Contrast enhancement is often critical for detecting tumor extent. Rapid T1-weighted (T1-W) gradient-echo images should be obtained pre- and postdynamic intravenous IV bolus administration of a gadolinium chelate contrast material to highlight sites of disease. Images obtained during the arterial and venous phase of enhancement may be useful in determining the vascular supply and enhancement pattern of a pelvic mass. A 3-D sequence, particularly on high field strength platforms magnets (>1.0 T), yields superb thin-section contrast-enhanced images. Additional pulse sequences, for example diffusion-weighted imaging (DWI) with apparent diffusion coefficient (ADC) map, may be used as required for diagnosis and evaluation of extent of disease. In the case of advanced disease, MRI of the abdomen should be considered to search for distant metastases. Endoluminal coils (eg, endorectal) may be used for some indications.
1. MRI of the pelvis may be performed for pregnant patients in the second and third trimester. For pregnant patients in the first trimester, MRI of the pelvis is only recommended if the benefits outweigh any potential risks and then only as an adjunct to initial evaluation with ultrasound (US). See the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation [8] and the ACR Manual on Contrast Media [3]. A multicoil array should be used with the patient fasting as tolerated to diminish fetal motion and bowel peristalsis. Diagnostic information can almost always be obtained using breath-hold (T1-W and T2-W) images. The patient may be imaged in the supine or left lateral decubitus position using a large FOV (38-44 cm).

D. Examination Technique (specific examination techniques will be discussed in the relevant section)

VI. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [9]. For detection and staging of prostate malignancy, the report should follow the guidelines for terminology, including descriptions of lesion features and location, as published in the Prostate Imaging Reporting and Data System (PI-RADS) v2.1 [10].

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 that deal with potential hazards associated with MRI examination of the patient as well as to others in the immediate area should be provided [4,5,11-16]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [4,13].

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 performance monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance (MR) Imaging Equipment [17].

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 and Improvement, Safety, Infection Control and Patient Education on the ACR website (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).

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PRACTICE PARAMETER 6 MRI Soft Tissue Pelvis 2020 Resolution No. 28
REFERENCES


Section 1. Detection, Staging, and Recurrence Assessment of Gynecologic Malignancies: Uterus, Cervix, Ovaries, Vulva, and Vagina

V. SPECIFICATIONS OF THE EXAMINATION (general specifications were discussed earlier in the document)

C. Technical Advances:

Diffusion-weighted MRI and dynamic contrast-enhanced (DCE) MRI are have become useful adjuncts to standard anatomic MR sequences [18]. High-field (3T) MRI has been more widely implemented for body-imaging applications, providing improved signal-to-noise ratio (SNR), spatial resolution, and anatomic detail as well as faster scanning techniques but with specific limitations due to magnetic susceptibility and motion artifacts and concerns about radiofrequency power deposition. Parallel imaging techniques increase SNR with reasonable specific absorption rates while markedly speeding up acquisition at 3T body imaging [19].

D. Examination Technique:

1. Detection and Staging

MRI is most valuable for extent of disease evaluation and staging in patients with known or clinically suspected gynecologic malignancy. It is used in treatment planning to guide surgery and/or radiation therapy, to monitor treatment response, and to detect local and regional recurrence [20,21]. For ovarian neoplasms and masses, MRI is typically used for problem solving after inconclusive pelvic US and is not routinely performed for staging (see Section 2).

Suggested sequences include the following:

i. Axial T1-W

ii. Orthogonal high-resolution T2-W FSE (relative to the uterus or cervix)

iii. Long- or short-axis precontrast and dynamic postcontrast 2-D T1-W or 3-D T1-W acquisition (with fat suppression)

iv. Axial T2-W of the pelvis to include the perineum (vaginal and vulvar cancers)

v. DWI with ADC map

vi. Optional: Vaginal gel for vaginal cancer or cervical cancer with clinical suspicion of vaginal invasion

Endoluminal coils (endovaginal or endorectal) for localization of cervical cancers and evaluation of parametrial extension allow have been reported to achieve high-resolution imaging images focally, but with a but are limited by the small FOV. These have not been widely adopted because of patient discomfort and limitations in imaging large tumors, extension to pelvic organs surrounding the primary site, and lymphadenopathy [22].

In staging for gynecologic malignancy, large FOV T1-W images are used to evaluate the abdomen and pelvis for lymphadenopathy, hydrourethronephrosis hydronephroureterectasis, and bone-osseous lesions. High-resolution long- and short-axis T2-W imaging of the uterine body is used for localization of endometrial cancer and for determining the depth of myometrial invasion and clearly demonstrates shows zonal anatomy to advantage [23]. Long- and short-axis imaging of the cervix is performed to show the local extent of the cervical cancer to identify search for parametrial invasion and to assess candidacy for trachelectomy (a fertility-sparing procedure) [24].

Precontrast- and postcontrast-enhanced dynamic multiplanar multiphase imaging using either 2-D long- and short-axis or volumetric T1-W gradient-echo sequences have shown myometrial invasion from endometrial carcinoma to advantage [25]. In patients with biopsy-proven adenocarcinoma involving both the lower uterine segment and cervix, DCE scans are useful in differentiating correct primary site of origin [26].

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DWI with both low and high b-values (800-1,000 s/mm²) respectively, combined with use of ADC maps and correlated with anatomic imaging can demonstrate restricted diffusion in malignancy [18]. DWI assists in lesion detection and extent of disease evaluation, including metastases to the peritoneum or adnexa [27], myometrial invasion in endometrial cancer [28], and tissue characterization of ovarian masses [29]. Limitations of this technique include false-positive results from inflammatory conditions and other benign processes, such as benign masses with high cellularity [22]. Use of DWI for detection of pelvic lymphadenopathy is controversial [19].

For evaluation of vulvar and vaginal cancers, MRI is excellent, especially with **multiplanar** T2-W images, and MRI is better than physical examination for determining tumor size, extent, and perivaginal spread [30]. Installation of vaginal gel to separate the walls of the vaginal canal can improve visualization of a vaginal mass **but is not required** [31]. Axial T1-W FSE images with a large FOV are performed for detection of abdominopelvic lymphadenopathy and bone marrow abnormalities. Detection of regional lymphadenopathy is the most important prognostic factor that is correlated with depth of tumor invasion. Presence or absence of adenopathy guides decision making about the need for radical vulvectomy and inguinal lymphadenectomy, both of which are associated with significant morbidity but improved survival if inguinal nodes are involved [32].

High-resolution orthogonal T2-W FSE images in the axial and coronal planes are used for evaluation of the primary tumor. DCE sagittal T1-W images with fat suppression and small FOV high-resolution axial T2-W images should be obtained to include the entire perineum, including the vulva. DCE scans with fat suppression are useful to detect small lesions and show involvement of the urethra and anus by vulvar cancer [33].

2. Postsurgical Recurrence of Gynecologic Malignancy

Preoperative MRI is accurate in assessing tumor extent before pelvic exenteration for recurrent gynecological cancers and can guide the type of pelvic exenteration. In particular, MRI accurately assesses bladder and rectal wall invasion before major surgery [34] and aids in differentiating posttreatment changes from active tumor [35]. Eligibility for pelvic exenteration requires exclusion of metastatic disease, which is best achieved by PET/CT [36]. The **MRI** examination technique has not been standardized. Suggested sequences include the following:

i. Two-plane orthogonal T2-W FSE  
ii. Precontrast and postcontrast fat-suppressed 3-D T1-W gradient echo  
iii. DWI with ADC map

Conventional imaging serves as a surgical roadmap of recurrent disease. DWI is useful for detecting tumor recurrence, both in the pelvis and in areas of disseminated disease in the peritoneum [37].

**REFERENCES**


Section 2. Evaluation of Pelvic Mass or Acute or Chronic Pelvic Pain, Including Detection of Adenomyosis, Ovarian Cysts, Torsion, Tubo-Ovarian Abscesses, Benign Solid Adnexal Masses, Obstructed Fallopian Tubes, Deep Pelvic Endometriosis, Endometriomas, and Fibroids

V. SPECIFICATIONS OF THE EXAMINATION (general specifications were discussed earlier in the document)

C. Technical Advances:

Perfusion and DWI MRI sequences increase the diagnostic accuracy of conventional MRI with the overall accuracy for MRI greater than 90% for adnexal mass characterization [29]. If DCE-MRI using postprocessing subtraction techniques shows early enhancement in solid elements, then the mass is much more likely to be malignant. The absence of enhancing solid elements is more likely benign [38]. Susceptibility-weighted imaging shows hemosiderin deposition in extravarian endometriosis and adenomyosis with increased sensitivity compared with conventional MRI [39]. ADC measurements on DWI may show quantitative differences between fibroids and adenomyosis [40]. 3-D T2-W MRI allows volumetric acquisition, providing submillimeter sections with multiplanar reformatting capability. There is a tradeoff between volume imaged, with both acquisition time and T2-weighting characteristics [41].

D. Examination Technique:

1. Detection and Characterization

The workup of adnexal masses is particularly challenging because the prevalence of ovarian malignancy is low compared with that of benign adnexal masses, and benign conditions frequently have an acute presentation. Because pelvic US is the initial study of choice for workup, MRI of the pelvis for adnexal mass or pelvic pain is useful after indeterminate pelvic US for problem solving. US is limited by its small FOV, obscuration of organs by overlying bowel gas, operator dependence, and limitations in patients with large body habitus. MR outperforms US with higher specificity due to its multiplanar imaging capabilities and excellent soft-tissue contrast for tissue characterization [42]. Adenomyosis is diagnosed when the junctional zone is thickened on T2-W images; however, less commonly, a myometrial contraction can mimic adenomyosis. Performing an additional sagittal T2-W sequence at the conclusion of the study can differentiate contraction from adenomyosis as the thickening will resolve with a contraction but will persist with adenomyosis [43]. The differential diagnosis of adnexal masses on MRI is based upon a systematic evaluation of their anatomic location, morphology (solid, cystic, or both), signal intensity (SI) characteristics, enhancement, and appearance on DWI. Deep pelvic endometriosis may present as an implant in the posterior, middle, and/or anterior pelvic compartments. MRI with vaginal and/or rectal gel may aid in detection of these implants but is considered optional [44]. Fasting 4 to 6 hours prior to imaging decreases artifacts from bowel peristalsis; alternatively, subcutaneous (SQ) or intramuscular (IM) glucagon may be administered if not contraindicated.

Suggested sequences include:

i. Orthogonal high-resolution T2-W FSE or a 3-D T2-W volumetric acquisition

ii. Axial in-phase, opposed-phase, and/or fat-suppressed T1-W gradient echo

iii. Pre- and dynamic postcontrast fat-suppressed 3-D T1-W gradient echo

iv. Optional: DWI with ADC map

v. Optional: T2-W with vaginal gel

vi. Optional: T2-W with rectal gel
Fluid, fat, blood, and fibrous tissues can be differentiated based upon MR signal characteristics that are often indeterminate on US. **When differentiating between hemorrhagic ovarian cyst and endometrioma, the T2 dark spot sign has high specificity for endometrioma compared with T2 shading but a lower sensitivity [45].** For solid adnexal masses, low T2 SI is usually correlated with benignity [42]. Most cystic ovarian masses are benign. **Guidelines have been established for evaluation of adnexal cysts based on patient menstrual status and symptoms [46,47].** Incidental functional ovarian cysts found on initial MRI do not require further workup if they are ≤3 cm in size in women of childbearing age, or ≤1 cm if postmenopausal [46]. In women of childbearing age with simple cysts >3 cm and ≤5 cm, cysts should be described and yearly US follow-up performed to ensure stability [46,47]. In postmenopausal women, simple cysts >1 cm and ≤7 cm can be described and yearly US follow-up performed to ensure stability. For simple cysts >7 cm in premenopausal or postmenopausal patients detected by initial pelvic US, pelvic MR may be performed to search for occult enhancing elements, or surgery may be considered [47].

Serous cystadenomas (the most common benign epithelial ovarian neoplasm) have fluid signal and thin walls [48]. Mucinous neoplasms are multilocular with varying MR SIs (“stained glass appearance”) [49]. The presence of papillary projections, wall thickening, and/or enhancement is worrisome for malignancy [50]. Restricted diffusion may be seen in malignancy, but there are many causes of false-positive findings [37].

Other fluid-containing extraovarian benign lesions have characteristic morphologies that suggest the correct diagnosis, such as the tubular shape and incomplete folds of a hydrosalpinx, the identification of a normal ovary or normal fallopian tube contiguous with a paraovarian or paratubal cyst, respectively, or the normal ovary embedded into the wall of peritoneal inclusion cyst [50].

In patients with acute pelvic pain from tubo-ovarian abscess, the diagnosis is usually evident clinically (cervical motion tenderness, discharge, leukocytosis). Further imaging is reserved for nonspecific clinical presentations or for patients who are refractory to medical therapy. CT is usually performed after equivocal pelvic US. **However, MRI may be performed in nonspecific cases or in young females when decreasing radiation exposure is a priority.** MR may show inflammation on contrast-enhanced scans and edema on fat-suppressed T2-W images [51].

Solid or mixed cystic and solid lesions are also characterized based upon morphology and tissue signal characteristics. Fat-suppressed and/or chemical shift MR techniques can be used to differentiate between bright signal from fat within mature cystic teratomas and blood within hemorrhagic cysts or endometriosis. Fat signal in mature cystic teratomas **manifested by and/or chemical shift artifact at the fat-fluid interface** (or **within the teratoma in cases of intracellular fat**) confirms the diagnosis [52]. T2 shading (bright T1 and dark T2 signal) in endometriosis is typical and results from chronic bleeding containing high protein and iron concentrations and protein cross-linking, all of which decrease both T1 and T2 relaxation time [53,54]. Ovarian fibromas have low T1 and T2 signal, similar to skeletal muscle due to fibroblasts and collagen. Fibromas may enhance [55].

Because acute ovarian torsion is a gynecologic emergency that is usually first evaluated with pelvic US, MR is not generally utilized in the acute setting. The use of MR generally has been limited to imaging subacute or chronic torsion. MR findings are those of an enlarged ovary with central stromal edema and/or hemorrhage, ipsilateral deviation of the uterus, fallopian tube thickening, and enlarged congested vessels with twisting of the vascular pedicle (beak sign) [51,56].

When a uterine fibroid resides in the broad ligament, it projects laterally from the uterine contour. This can be difficult to distinguish from a solid ovarian neoplasm both clinically and by pelvic US. MRI is valuable for further characterization, especially when the typical low SI of fibroids becomes complex because of degeneration. Identification of separate normal ovaries, continuity of the mass with uterine myometrium, and enhancing bridging vessels arising from the uterus supplying the mass [57] are key features that make the diagnosis of pedunculated fibroid or broad ligament fibroid.
In patients with dysmenorrhea and menorrhagia from adenomyosis, MRI shows the characteristic low-signal lenticular-shaped junctional zone thickening >12 mm diffusely or focally that distinguishes this condition from fibroids on T2-W images. Sometimes the two may coexist. Small hemorrhagic foci seen to best advantage on susceptibility-weighted images are helpful to identify adenomyosis and endometriosis [39]. MR can localize any associated macroscopic pelvic endometriosis. Deep pelvic endometriosis can affect the anterior, middle, or posterior pelvic compartments. Most common sites are retrocervical region, vagina, ovaries, bladder dome, rectosigmoid colon, and round ligaments. Less common sites in the pelvis include the abdominal wall in a Caesarean section scar, inguinal region, and pelvic nerves [58]. Cystic adenomyosis and subserosal polypoid adenomyomas can mimic an adnexal mass but typically are contiguous with myometrium forming a “beak sign,” indicating uterine origin [39].

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**Section 3. Assessment of Pelvic Floor Defects Associated with Urinary or Fecal Incontinence**

**V. SPECIFICATIONS OF THE EXAMINATION** (general specifications were discussed earlier in the document)

**D. Examination Technique**

MRI of pelvic floor dysfunction allows noninvasive, dynamic evaluation of all the pelvic organs in multiple planes with high soft-tissue and temporal resolution. Imaging consists of a 2-step process that combines high-resolution anatomic imaging and functional evaluation. MRI is most helpful in patients with multicompartiment physical examination findings or symptoms, posterior compartment abnormalities, severe prolapse, or recurrent pelvic floor symptoms after surgical repair [59-61].

Prior to beginning the examination, it is important to reassure patients about privacy and coach them appropriately regarding the maneuvers to ensure full patient cooperation. Patients are asked to empty their bladder and rectum within 1 hour prior to the examination, and rectal enema is optional prior to the examination. Although a recent study has shown superiority of the physiologic sitting position for the evaluation of defecography [62], such equipment is not readily available, and most patients are imaged in the supine position using conventional closed or wide-bore platforms with equal outcomes reported for both sitting and supine positions [63].

The patient is placed on a water-resistant pad on the MRI table, and approximately 100–120 cc of warmed US gel is instilled into the rectum. A measure of 10–20 cc of gel may also be used to opacify the vaginal canal. The patient is then positioned in the supine position and loosely wrapped in a waterproof incontinence pad. A multielement coil is necessary to achieve high-resolution imaging and optimal SNR and should be centered low enough to visualize prolapsed organs.

Suggested sequences include the following:

i. Axial and coronal T2-W FSE

ii. Sagittal T2-W SSFSE

iii. Sagittal midline rest, and straining, and defecography cine balanced steady-state free precession T2-W SSFSE

iv. Optional: axial or coronal rest and straining cine balanced steady-state free precession T2-W SSFSE

v. Optional: sagittal midline squeezing cine balanced steady-state free precession

Axial and coronal small FOV T2-W FSE is performed at rest to evaluate pelvic floor support structures. Following surgical repair, the superior aspect of the axial T2-W FSE image should begin at the level of the sacral promontory for patients who have undergone sacrocolpopexy. Sagittal half-Fourier SSFSE of the entire pelvis, from sidewall to sidewall, is then obtained to determine resting organ positions. Continuous imaging during straining and defecography has shown greater degrees of prolapse with a balanced acquisition with steady-state precession than with a SSFSE sequence given the improved temporal resolution [64]. Functional evaluation is performed by acquiring a single midsection sagittal SSFSE balanced steady-state free precession sequence with the anorectum at rest. The image should include the symphysis, bladder neck/urethra, vagina, anus/rectum, and coccyx. Thereafter, serial (cine) imaging is repeated during the straining phase and repeated 2 to 3 times with increasing straining to achieve maximal Valsalva maneuver. Straining exercises can also be performed in the axial or coronal plane sequence to evaluate prolapse and its effect on the supporting structures [59,65]. Cine evaluation is then performed in the defecography phase until complete evacuation of rectal contrast is achieved. However, continuous imaging during defecation has shown greater degrees of prolapse with a balanced acquisition with steady-state precession than with a SSFSE sequence given the improved temporal resolution [64]. Knee flexion supported by a pillow and slight hip abduction can maximize strain maneuvers and complete defecation. Imaging can also be acquired during the “squeeze maneuver” (ie, squeezing the buttocks as if trying to prevent the escape of urine) to
evaluate puborectalis muscle contraction. Throughout this process, the technologist must continuously interact with the patient to optimize the functional evaluation.

REFERENCES


Section 4. Determination of Fibroid Number, Location, Size, and Type Prior to Intervention

V. SPECIFICATIONS OF THE EXAMINATION (general specifications were discussed earlier in the document)

C. Technical Advances:

3-D T2-W MRI allows volumetric acquisition of the uterus, providing submillimeter sections with multiplanar reformatting capability. There is a tradeoff between volume imaged, acquisition time, and T2 characteristics [41].

DWI reflects water mobility and tissue cellularity. ADCs can be calculated from images with different b-values [66]. This technique can be useful when attempting to differentiate typical fibroids from uterine sarcomas [67]. ADC values may also show quantitative differences between fibroids and adenomyosis [40].

MR elastography (MRE) measures a tissue’s stiffness. MRE of uterine fibroids can be correlated with T2-W imaging. Less-stiff fibroids appear more T2 hyperintense and more-stiff fibroids appear more T2 hypointense [68].

D. Examination Technique:

Although US remains the initial imaging modality in the workup of patients with suspected symptomatic fibroids, MRI is the most accurate imaging technique for fibroid detection and localization [69]. It is increasingly performed in symptomatic patients being evaluated for minimally invasive uterine-sparing therapies, such as uterine fibroid embolization (UFE) [70] and more recently MR-guided focused US (MRgFUS) [71]. For UFE candidates, MRI provides additional information compared with US and affects clinical management in a significant number of patients [72]. Single-institution and multicenter randomized controlled trials report significant decrease in symptoms and improved health-related quality of life following UFE [73,74]. MRI following UFE and MRgFUS has also been used to monitor outcome and diagnose complications.

Imaging is performed with a pelvic phased array coil. Fasting 4–6 hours prior to imaging decreases artifacts from bowel peristalsis; alternatively, SQ or IM glucagon may be administered if not contraindicated. Patients are asked to void before the examination. A moderately distended, half-full urinary bladder may be optimal for the examination.

Suggested sequences include the following:

i. Orthogonal T2-W FSE (at least one plane should be a high-resolution sequence and/or a 3-D T2-W volumetric acquisition)

ii. Axial T1-W with and without fat suppression

iii. Precontrast and dynamic postcontrast 3-D T1-W fat-suppressed gradient-echo images

iv. Optional: DWI with ADC maps

v. Optional: large FOV upper abdomen T2-W to assess kidneys for hydronephrosis and metastases in suspected malignancy

Before treatment, orthogonal T2-W images allow fibroid detection, localization (submucosal, intramural, or subserosal), measurement of size, and characterization. Other uterine pathology, if present (eg, adenomyosis), is also diagnosed on T2-W images. The T1-W images provide information on the relationship of the fibroid to the uterus and adnexa as well as identify blood and fat in fibroids and/or concurrent uterine or adnexal disease.

The majority of nondegenerated fibroids are well-circumscribed round or ovoid masses with homogeneous low SI on T2-W images compared with myometrium. These imaging features reflect whorls of smooth-muscle cells with...
various amounts of intervening collagen. Nondegenerated cellular fibroids exhibit different imaging features—high
T2-W SI compared with myometrium—a function of compact smooth-muscle cells with a paucity of intervening
 collagen. On T1-W images, nondegenerated fibroids are low or isointense in SI to myometrium. Following contrast, nondegenerated fibroids enhance homogenously.

Degenerated fibroids have variable appearance on T1-W, T2-W, and postcontrast T1-W images. Types of fibroid
degeneration include hyaline, calcific, myxoid, cystic, necrosis (hyaline or coagulative), and red. Although a
combination of imaging features may suggest a specific type of degeneration, overlap in imaging features exists.
This is also true for distinguishing a degenerated fibroid from a uterine sarcoma. Imaging features that have been
reported in sarcomas include, but are not limited to, irregular margins, extensive hemorrhage, and necrosis [75-77].

DWI and ADC values may also add complementary information [78,79].

MRI features pertinent to the outcome of UFE include location, size, viability, ovarian arterial collateral supply to
the uterus, and comorbid conditions [70].

Following successful UFE, fibroids undergo hemorrhagic infarction. Imaging features of an infarcted fibroid
postembolization include hyperintense T1-W SI, increasing hyperintense T2-W SI over time, and no enhancement
following intravenous contrast administration [80]. Small amounts of gas within an infarcted fibroid may be normal.
Although follow-up imaging may not be necessary in patients who become asymptomatic following UFE, MRI can
be employed to diagnose complications such as fibroid passage or pyomyoma. Surveillance MRI can also be used
to assess for residual fibroid enhancement in patients with continued symptoms [81].

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Section 5. Detection, Staging, and Recurrence Assessment of Urologic Malignancy

A. Bladder

V. SPECIFICATIONS OF THE EXAMINATION (general specifications were discussed earlier in the document)

C. Technical Advances:

DWI, which reflects the degree of tissue cellularity, is can be complementary to conventional imaging. Additionally, MR cystography relies on 3-D T2-W data sets amenable to postprocessing to simulate conventional cystography.

D. Examination Technique:

1. Detection and Staging

MRI is usually used for T staging once the cancer has been diagnosed and is considered superior to contrast-enhanced CT in demonstrating extent of bladder wall invasion (nonmuscle invasive from muscle-invasive bladder cancer). The study of the bladder requires high spatial resolution with a multielement surface coil, thin section, and large matrix. Moderate bladder distention is necessary, and patients are asked to void approximately 1-2 hours prior to imaging or to drink 500-1,000 mL of water in the 30 minutes prior to the examination [82]. Administration of an antiperistaltic agent can reduce bowel peristalsis for assessment for extravesical disease [83].

Suggested sequences include the following:

i. Three-plane orthogonal T2-W FSE or 3-D T2-W volumetric acquisition

ii. 3-D fat-suppressed gradient-echo T1-W perpendicular to the tumor

iii. Precontrast fat-suppressed 3-D T1-W gradient echo and DCE T1-W

iv. Optional Whole-body or small FOV DWI with ADC maps

v. Optional: 3-D MR cystography

Non-fat-saturated small FOV high spatial resolution (slice thickness of 3–4 mm) FSE T2-W imaging is performed in 3 orthogonal planes to evaluate the detrusor muscle for tumor depth, extravesical disease, and invasion of surrounding organs. Anterior saturation bands should be applied for the axial and sagittal planes to minimize phase-encoding artifacts. SSFSE imaging may replace T2-W FSE sequences to decrease motion artifacts, although increased image blur and reduced intravoxel resolution and SNR can impair staging are slightly reduced. Recent advances have made 3-D T2-W imaging feasible with the introduction of shorter acquisition times, volumetric acquisition, and improved SNR.

Multiphase dynamic 3-D fat-suppressed gradient-echo T1-W imaging is obtained prior to and following contrast material administration. The plane of imaging should be perpendicular to the implantation base of the tumor. The majority of bladder tumors enhance briskly in the early phase (≤20 seconds) following contrast injection with the detrusor muscle enhancing late (60 seconds), thus allowing detection of small tumors and differentiation of superficial from muscle-invasive tumors [84,85]. Preliminary studies using DCE-MRI for quantitative analysis have shown correlation with T stage, tumor angiogenesis, and prediction of tumor response to neoadjuvant therapy [84,86-88].

Several recent studies have reported high b-value DWI to complement T2-W and gadolinium-enhanced imaging in improving the diagnosis of organ-confined muscle-invasive disease, extravesical extension, and prediction of tumor grade [88-95]. ADC values for bladder tumors are less than those for surrounding normal tissues. Given significant variation in ADC measurements, changes in SI in DWI must also be taken into consideration.
Trace high b-value DWI often depicts tumor better than ADC maps as there is more contrast between tumor and surrounding structures, and there is significant signal variation in ADC measurements [96,97]. Reduced FOV DWI has been shown to improve image quality, reduce artifacts, and yield high spatial resolution compared with whole-body DWI [98].

There has been interest in 3-D rendering techniques with MR data sets (including multiplanar reconstructions and creation of cystoscopy-like images) as a replacement for traditional cystoscopy and to assist in staging, where traditional cystoscopy may be contraindicated (urethral stricture) or suboptimal (narrow-necked bladder diverticula) [99].

2. Therapy Response and Pelvic Recurrence

MRI technique is similar to that described for preoperative staging evaluation regardless of whether the patient has undergone radical cystectomy, transurethral resection, or neoadjuvant chemotherapy. In particular, MRI can evaluate therapeutic response to induction chemoradiotherapy in patients with muscle-invasive bladder cancer; identify complete response; and optimize patient selection for bladder-sparing protocols as well as monitor recurrence [100]. Recent Some studies report DWI to be superior to contrast-enhanced MRI and T2-W imaging for differentiation between tumor recurrence from postoperative fibrosis and inflammation [101,102].

REFERENCES


Section 5. Detection, Staging, and Recurrence Assessment of Urologic Malignancy

B. Prostate

V. SPECIFICATIONS OF THE EXAMINATION (general specifications were discussed earlier in the document)

C. Technical Advances:

Multiparametric MRI, which combines DWI and DCE imaging, is complementary to conventional anatomic T2-W imaging. MR spectroscopy imaging (MRSI) can aid lesion characterization and provide information about tumor biology but is currently not routine.

D. Examination Technique:

1. Detection and Staging

The recommended use of MRI in prostate cancer detection, localization, staging, characterization, and risk stratification consists of multiparametric MRI (mp-MRI) [103]. Mp-MRI refers to the use of T2-W imaging in combination with functional imaging techniques: DWI, DCE-MRI, and MRSI [103,104]. The optimal combination of anatomic and functional sequences has yet to be established. However, the more functional sequences are utilized, the better the accuracy seems to be [105,106].

Imaging should be performed at either 1.5T or 3T. The fundamental advantage of 3T over 1.5T is increased SNR, which improves the spatial, temporal, and spectral resolution. However, certain situations warrant imaging at 1.5T, eg, implantable devices deemed incompatible at 3T, or the location of a device would compromise image quality at 3T. Several groups have reported comparable performance between multichannel phased array coil MRI of the prostate at 3T and endorectal phased array coil MRI at 1.5T [107-110]. At 3T, most of the benefits of MRI can be achieved with multichannel phased array coil (at least 8-16 channels), although use of an endorectal coil or endorectal phased array coil combination can incrementally improve detection and staging [111,112]. However, the use of an endorectal coil deforms the shape of the gland. Use of the endorectal coil may add both imaging time and cost and may diminish patient acceptance, which would need to be considered by the supervising radiologist. The supervising radiologist must strive to optimize MRI protocols to obtain the best and most consistent image quality.

To minimize the artifacts introduced from biopsy-related hemorrhage, which can interfere with lesion detection and staging, imaging can be delayed between 8 and 12 weeks after the biopsy procedure [101]. However, detection of clinically significant cancer at a site of postbiopsy hemorrhage without a corresponding abnormality on mp-MRI is low, and a recent study has shown the presence of extensive hemorrhage and short delay after biopsy did not negatively impact accuracy for tumor detection using mp-MRI [113]. So if When the primary purpose of the examination is to detect and characterize clinically significant cancer after a negative transrectal US-guided biopsy, a delay in mp-MRI may not be necessary [114]. Conversely, postbiopsy hemorrhage may adversely affect image interpretation for staging in some instances, and an interval between biopsy and MRI is appropriate and should be considered [115]. An antiperistaltic agent should be administered prior to imaging to reduce motion from bowel peristalsis; however, incremental cost and potential for adverse drug reactions should be taken into consideration.

Suggested sequences (regardless of coil) include the following:

i. Three-plane orthogonal high resolution T2-W FSE of the prostate

ii. Whole-body or small FOV DWI with ADC map

iii. Precontrast fat-suppressed 3-D T1-W gradient echo and DCE T1-W

iv. Large FOV axial T1-W and T2-W of the pelvis
v. Optional MRSI

High spatial resolution T2-W FSE imaging is used for detection, localization, and staging of prostate cancer and should be obtained in 3 planes. The axial T2-W imaging should cover the prostate gland and seminal vesicles, and locations should be the same as those used for DWI and DCE-MRI. Phase-encoding direction should be right to left to minimize motion and pulsation artifact overlapping the prostate gland. Recommended slice thickness is ≤3 mm and no gap. 3-D T2-W acquisition with a slice thickness <1.5 mm may be used as an adjunct to orthogonal T2-W FSE sequences, although soft-tissue contrast is not identical [116].

DWI improves the diagnostic performance for cancer detection when combined with T2-W images and provides information about tumor aggressiveness [117-121]. DWI should be acquired in the axial plane with motion-probing gradients applied in 3 orthogonal planes. Diffusion kurtosis effect occurs at b-values > 1,000 s/mm²; therefore, ADC maps should be calculated with b values that are ≤1,000 s/mm² [122]. Although the optimal b-values have not been determined for calculation of ADC map, it is agreed that at least two b-values are required and b values (s/mm²) should include low (0-100 s/mm² and preferably 50-100 s/mm²) and intermediate medium (400-500) and high (800-1,000 s/mm²) b values [10]. A meta-analysis has shown mixed results with higher b values (>1000) to suppress normal prostate tissue background signal [120]; however, in recent studies, acquired High b-values between 1,400–2,000 s/mm² can have added value for tumor localization, although field strength and coil selection, technical parameters—including SNR—and analysis of trace DWI and/or ADC maps will impact the utility of these higher b-values [120,123-131]. A high b-value DWI (≥ 1,400 s/mm²) should be acquired separately or calculated from the low and intermediate b-value images [10]. Alternatively, calculated high b-values from the acquired lower b-values can be used to create the ADC map to create images of high diagnostic value without added imaging time [122,123]. An ADC map is recommended, but b = 0 value, if possible, should be excluded from the calculation. Axial slice thickness should be ≤4 mm with no gap, and the location should ideally match the axial T2-W and DCE-MRI images without sacrificing SNR.

The added value of DCE-MRI over the combination of T2-W and DWI is not certain and may be secondary with only modest improvement in tumor detection, localization, and local staging. DCE-MRI should always be used in combination with T2-W FSE imaging and at least one other functional parameter (DWI or MRSI) given the decreased specificity for central gland tumors, or in the setting of posttreatment and postbiopsy hemorrhage [103,132,133]. Serial imaging of the gland should be performed prior to and following IV gadolinium administration (injection rate 2-4 cc/s), and a rapid T1-W 3-D gradient-echo sequence with fat suppression is the preferred acquisition [103,132]. Pharmacokinetic features require a high temporal resolution (<150 seconds per phase) with an observation period of at least 5 minutes to evaluate for washout [134,135]. Unenhanced T1-W images from this sequence can be used to detect postbiopsy hemorrhage. Axial slice thickness should be ≤3 mm no gap, and the location should match axial T2 and DWI axial images. Images can be evaluated qualitatively, semiquantitatively, or quantitatively.

MRSI has been shown to improve lesion detection and provide valuable information about lesion aggressiveness but requires expertise, use of an endorectal coil at 1.5T, and added time [103,133,136,137]. However, an recent American College of Radiology Imaging Network (ACRIN) multicenter trial showed no incremental benefit of MRSI in detection of cancer over 1.5T endorectal T2-W imaging [138]. The volume of interest (VOI) is aligned with the axial T2-W images to maximize coverage of the whole gland while minimizing surrounding tissue contamination. A multivoxel 3-D chemical shift imaging technique is preferred with a voxel size ≤0.5 cc.

Finally, a T1-W or T2-W imaging of the pelvis with a pelvic phased array coil is performed to assess for nodal or osseous metastasis, albeit limited given the morphologic limitations of MRI for lymph node assessment.

2. Local Recurrence after Radiation Therapy and Radical Prostatectomy

MRI can accurately detect local recurrence after radiation therapy and radical prostatectomy, allowing salvage radiotherapy as potential treatment option [139-141]. DCE-MRI in combination with T2-W imaging is...
particularly accurate in detecting recurrence after radiation therapy and radical prostatectomy. DWI, in combination with T2-W imaging, has been shown to be sensitive for detection of local recurrence in patients following radiation therapy but is inconsistent following interstitial brachytherapy or prostatectomy given the susceptibility artifacts from seeds and surgical clips, respectively [142-144]. However, studies evaluating DCE-MRI, DWI, and T2-W imaging following external-beam radiation therapy have shown no added benefit if DCE-MRI is added to DWI and T2-W imaging for recurrence [143,145]. The role of MRSI is controversial, especially given the metabolic changes that occur in the normal gland following radiation therapy and the theoretical undetectable citrate levels following prostatectomy, which complicates the metabolic criteria used for diagnosis. MRSI is also limited by spatial resolution and is sensitive to field inhomogeneity [139].

The multiparametric MRI technique can be tailored to the type of therapy with appropriate selection of functional parameters.

3. Ablative Therapy for Prostate Cancer

Ablative therapy techniques include cryotherapy, high-intensity modulated focused US, laser ablation therapy, radiofrequency ablation, and photodynamic therapy. Imaging criteria for focal therapy differ from imaging criteria for whole-gland treatment, as the objective of imaging is accurate localization and contouring of the index lesions [146]. Although research evidence for MRI in focal therapy is limited, mp-MRI may be the optimum approach needed to achieve the objectives for focal therapy.

REFERENCES


Section 5. Detection, Staging, and Recurrence Assessment of Urologic Malignancy
C. Scrotum and Penis

V. SPECIFICATIONS OF THE EXAMINATION (general specifications were discussed earlier in the document)

D. Examination Technique:

1. Scrotum

Although sonography remains the primary modality in the diagnosis of scrotal pathology, MRI provides valuable information in the detection and localization of scrotal masses (intratesticular versus paratesticular), morphology, and tissue characterization, especially when sonography is inconclusive [147-150]. MRI is also recommended for local staging of testicular germ cell tumors [150].

Patients are prepared by placing a towel under the scrotum to elevate both testes to a horizontal plane, and the penis is draped over the anterior abdominal wall. Either a small-diameter multipurpose or multielement pelvic coil is centered over the scrotum. MRI sequences of the scrotum should be performed with small FOV and high spatial resolution (slice thickness ≤4 mm and no gap).

Suggested sequences include the following:

i. Axial T1-W without and with fat suppression
ii. Axial T1-W, in-phase and opposed-phase
iii. Three-plane orthogonal T2-W FSE

iv. Optional DCE fat-suppressed T1-W 2-D SE or 3-D gradient-echo or fat-suppressed T1-W 2-D SE

v. Optional: Axial DWI with ADC maps

Axial T1-W spin-echo sequences with and without fat suppression, followed by axial, coronal, and sagittal T2-W FSE imaging, are optimal for lesion detection, characterization, and localization. T2-W sequence is best obtained with echo time (TE) of 100-140 ms to optimize contrast [150] differentiates tumor from normal structures. In-phase and opposed-phase imaging of the scrotum can identify the fat-water interface and can help depict hemorrhage due to the T2* effects of hemosiderin. DCE-MRI using 3-D gradient-echo T1-W imaging in 2 orthogonal planes has been shown to improve characterization of scrotal lesions [151,152]. Alternatively, postcontrast conventional 2-D spin-echo in 2 planes can be substituted [150]. Intravenous gadolinium can be administered when indeterminate pathologies are found using fat-suppressed 2-D spin-echo or 3-D gradient-echo T1-W imaging in 2 orthogonal projections.

Preliminary investigations report improvement in characterization of intratesticular lesions with ADC of carcinomas being lower than that of normal testes and some benign intratesticular lesions [153,154]. Axial DWI is recommended (slice thickness of 3-5 mm) with b-values including 0-100, 400-500, and 800-1,000 s/mm².

Staging is typically performed with CT for assessment of retroperitoneal nodes. However, MRI is an appropriate substitute with performance of either T1 or T2-W imaging to the level of the renal hila [155].

2. Penis

MRI is the most sensitive imaging modality for the local staging of penile carcinomas because of its high soft-tissue contrast and multiplanar capability. It is important for the penis to be placed in a position of comfort, not bent or rotated, and to remain fixed in position throughout the examination, which is typically achieved with
the penis draped and taped to the anterior abdominal wall. However, artifacts from excessive abdominal wall motion during breathing can degrade image quality, and the penis may need to be positioned inferiorly [156]. A small surface coil placed on the penis is optimal for high spatial resolution images (FOV: 14-16 cm), although a multielement pelvic coil can be used and enables a larger FOV to assess for inguinal and pelvic lymphadenopathy [156,157]. Suggested sequences include the following:

i. Three-plane orthogonal high-resolution T2-W FSE (optional fat suppression in one plane)

ii. Axial T1-W

High spatial resolution T2-W sequence (3-4 mm) provides excellent contrast resolution between the hypointense tunica albuginea and hyperintense corpora and urethra, and is most useful for local staging. Fat suppression may be used in one plane to increase the dynamic range. The use of IV gadolinium has not been shown to improve detection or local staging or to be advantageous to standard T2-W sequences [156,158-160]. Artificial erection by intracavernous injection of prostaglandins or combinations has been shown to increase diagnostic accuracy for invasion of the tunica albuginea and corpora but is rarely applied in practice given the risk of priapism [158,161]. Osseous structures can be assessed with a T1-W sequence and inguinal lymph node evaluation with either a T1-W or T2-W acquisition.

REFERENCES

Section 6. Evaluation of Complications Following Pelvic Surgery, Including Abscess, Urinoma, Lymphocele, Radiation Enteritis, and Fistula Formation (for parameter on performance of MRI for perianal fistulas, refer to the section Identification and Classification of Perianal Fistulas)

V. SPECIFICATIONS OF THE EXAMINATION (general specifications were discussed earlier in the document)

C. Technical Advances:

Fat-suppressed T2-W images are sensitive to edema, inflammation, and abscess formation [162]. The use of negative or biphasic endoluminal bowel-contrast agents (such as ferumoxsil oral suspensions or dilute barium suspensions) reduce the SI in the bowel lumen on T2-W images, thereby increasing the conspicuity of high signal inflammation and abscess on T2-W images [163]. DWI may assist in the differentiation between cystic lesions and from abscesses [164,165].

D. Examination Technique:

CT is usually the first study performed in the search for an abscess, especially in the setting of postoperative complications or for nonspecific symptoms and signs of infection. Because MR has better soft-tissue contrast and lacks ionizing radiation, it sometimes has been used as an alternative to CT in patients of child-bearing age and children [166].

MRI is performed with a pelvic phased array coil.

Suggested sequences include the following:

i. Orthogonal planes (axial and coronal) or 3-D T2-W fat-suppressed FSE or short tau inversion recovery (STIR) to highlight inflammation and/or edema

ii. Axial T1-W

iii. Precontrast and dynamic postcontrast fat-suppressed 3-D T1-W gradient echo

iv. Optional: DWI with ADC maps

v. Optional: MR enterography (see below)

Abscesses may be caused by postoperative complications or infectious or inflammatory bowel conditions (such as Crohn’s disease, appendicitis, diverticulitis, radiation enteritis, and pelvic inflammatory disease). On both CT and MR, an abscess is a collection of purulent fluid, pus, usually often with peripheral rim enhancement, that may contain gas air from gas-forming organisms [167]. Gas may cause blooming artifact on dual-echo gradient-echo in-phase images (longer TE images) [168]. MR shows inflammation as enhancement on T1-W contrast-enhanced scans (especially if subtraction is performed following a 3-D acquisition) and edema as fluid signal on fat-suppressed T2-W images [51]. In the acute setting, DWI may show high signal on the high b-value image and restricted diffusion on the ADC map in an abscess [169]. Abscesses may be treated by percutaneous drainage; however, imaging guidance is usually accomplished using US or CT.

Pelvic hematomas can be caused by trauma, surgery, and/or coagulopathy. Although seromas and lymphoceles have the appearance of simple fluid on all MR sequences without and do not enhancement, the MR appearance of hematoma varies with the age of the blood but is commonly hyperintense on T1-W images [170,171].

Urinomas can usually result from obstructive uropathy, but may also occur after trauma, or surgery, or may occur iatrogenically after instrumentation [170]. MRI does not play a role in acute urinary tract injuries [172], but resultant findings may be seen in MRI scans that were requested for other reasons. Urinomas have fluid signal on MR, with
low signal on T1-W and high signal on T2-W images. Extravasation of urine can be directly demonstrated in the excretory phase after IV contrast administration from the genitourinary system. Management of urinomas differs from that of other postoperative collections in that it usually involves treatment of the primary cause of urine extravasation—such as stent or nephrostomy tube placement, or operative repair of tears or damage—in addition to percutaneous drainage of the collection.

Lymphoceles, usually a complication of lymphadenectomy, are managed differently than other postoperative fluid collections if refractory to medical therapy, as the former may undergo may be managed by catheter drainage with or without sclerotherapy [169]. Uncomplicated lymphoceles are unilocular with fluid signal on all MR sequences and are located in the distribution of previous lymph node dissection [173]. DWI and ADC maps may help identify active disease.

Acute radiation enteritis occurs within days to weeks of exposure and is manifested by mucosal hyperenhancement and bowel wall thickening of bowel wall, usually affecting the small bowel as it is more sensitive to injury. Chronic radiation enteropathy usually presents with bowel obstruction due to stricture formation. MR also shows wall thickening, scarring, tethering, and abnormal or absence of peristalsis. T2-W sequences and contrast enhancement are used to differentiate active inflammation (bright signal) from fibrosis with stenotic disease (dark signal with luminal narrowing). Fistulas may form secondary to radiation injury with tissue breakdown [174].

MR enterography using ultrafast or turbo spin-echo sequences to reduce artifacts from peristalsis with IV contrast enhancement can demonstrate radiation changes, such as bowel-wall thickening and dilation, submucosal edema, fatty stranding in the adjacent mesentery, and an abrupt transition point from adhesions. These studies involve administration of IV or IM glucagon to reduce peristalsis and ingestion of up to 1.5 L of biphasic negative endoluminal contrast agents. Balanced gradient-echo sequences (such as FIESTA or true FISP) in axial and coronal planes with breath-holding best show mural abnormalities and findings surrounding the bowel loops. 3-D spoiled gradient-echo fat-saturated T1-W sequences are acquired before and serially after IV contrast administration in the coronal and axial planes [175]. For more information, see the ACR–SAR–SPR Practice Parameter for the Performance of Magnetic Resonance (MR) Enterography [176].

Imaging along with physical examination can identify the site of a fistula and map its course and extent. Fistulas may be caused by surgery, radiation, trauma, childbirth, infection, inflammatory bowel disease, and malignancies. In patients with a malignancy, fistulas may occur as a result of a primary or recurrent tumor or as a consequence of surgery or radiation therapy. On T2-W images, fistulas typically have high signal due to fluid. Short inversion time inversion-recovery (STIR) images may show a fistulous tract to advantage. Air-filled tracts produce low SI on all MR pulse sequences [177]. On DCE T1-W imaging, the fistulous tract often enhances.

The sagittal plane usually best delineates vaginal fistulas. For vesicovaginal fistulas, CT or MR with excretory phase imaging shows contrast material outlining the fistulous communication between the bladder and the vagina, and vaginal air–fluid levels. In patients with contraindications to iodinated IV contrast material, MR is preferred to noncontrast CT [177].

REFERENCES


Section 7. Identification of Source of Lower Abdominal Pain in Pregnant Women: Appendicitis, Ovarian and Uterine Masses, and Urologic Conditions

V. SPECIFICATIONS OF THE EXAMINATION (general specifications were discussed earlier in the document)

C. Technical Advances:

DWI reflects water mobility and tissue cellularity. ADCs can be calculated from images with different b-values.

D. Examination Technique: (Please also refer to the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging [1]).

The etiology of acute pelvic pain in pregnant patients falls into one of 3 categories: gastrointestinal disease, gynecologic disease, or urologic disease. The most common cause is acute appendicitis [178]. Other common pelvic etiologies include degenerating fibroid and significant hydronephrosis [179].

The goal of imaging a pregnant patient with pelvic pain is to promptly identify the source of the pain. This information guides surgical and medical management. US remains the initial imaging modality for evaluating pelvic pain. However, the advent of widespread motion-insensitive MR sequences, coupled with the absence of ionizing radiation, has led to an increase of MR examinations in pregnant patients, especially when US is equivocal or limited [3,180-187].

Patients should fast between 4–6 hours prior to imaging to decrease bowel peristalsis. A 1.5T magnet strength (or lower) is suggested in pregnant patients to decrease specific absorption rates. Patients can be imaged in the supine or left lateral decubitus position using a multicoil array and a large FOV (38-44 cm).

Suggested imaging sequences include the following:

i. Three-plane orthogonal T2-W SSFSE images

ii. Axial fat-suppressed T2-W SSFSE images or STIR

iii. Axial T1-W in-phase and out-of-phase gradient-echo images

iv. Optional: Coronal T1-W

v. Optional: 2-D time-of-flight (TOF)

vi. Optional: Orthogonal T2-W fast imaging with steady-state free precession images

vii. Optional: DWI with ADC maps

viii. Optional: 2-D or 3-D balanced-steady-state-free-precession (b-SSFP) noncontrast MRA/MRV

(See the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation [8])

1. Gastrointestinal Disease

The MRI features of acute appendicitis parallel those of CT: a fluid-filled, dilated appendix >6 mm with a thickened wall and periappendiceal inflammation and fluid. A diameter between 6 and 9 mm without secondary finding is indeterminate [187]. It is important to have an adequate imaging FOV to ensure identification of the entire appendix, which is displaced superiorly and medially by the enlarging uterus [182]. 2-D TOF imaging can help distinguish the appendix from adjacent engorged gonadal vessels.

Bowel-wall edema is common to many gastrointestinal diseases: inflammatory bowel disease, enteritis, colitis, enteropathies, and ischemia [188]. On T2-W and DWI, edema manifests images as high SI [189]. Noting the
segment of bowel affected and any ancillary imaging features (eg, fibrofatty proliferation) aids in arriving at the correct differential diagnosis.

2. Gynecologic Disease

Fibroids may be a source of acute pain during pregnancy owing to rapid growth, torsion, and/or hemorrhagic infarction. Of these, hemorrhagic infarction may have characteristic imaging features: diffuse or peripheral high SI on T1-W images, central high SI on T2-W images, and restricted diffusion [182,188].

Pelvic mass origin and characterization can be challenging in pregnant patients, and MRI can be used as a problem-solving tool. MR can be used to delineate whether a mass is uterine or adnexal or to differentiate conditions such as mature cystic teratomas dermoids and endometriomas with confidence. Acute torsion may occur in pregnancy as the ovaries are lifted out of the true pelvis by the enlarging uterus. The enlargement and edema that accompanies torsion is readily apparent on fat-suppressed T2-W images and include afollicular stroma with peripherally displaced follicles [56]. Hemorrhage within the stroma is a later finding, and T1-W and T2-W SI reflects the age of the blood products [182]. A twisted pedicle, though specific, is not commonly identified.

3. Urologic Disease

Cystitis has bladder wall thickening with or without air and/or filling defects. Nondependent signal voids in the urinary tract in the absence of instrumentation suggest air, whereas dependent filling defects may be blood clots, and/or calculi, and/or fungus balls. Pelviocaliectasis and ureterectasis are common in late pregnancy and are differentiated from obstruction by noting ureteral tapering to the point where there is extrinsic compression by the gravid uterus anteriorly and the sacral promontory posteriorly. Ureteral calculi, in contrast, result in abrupt caliber change of the ureter and may have associated high SI on T2-W images due to inflammatory changes [182]. Pyelonephritis results in lower ADC values compared with normal renal cortex [190].

REFERENCES


Section 8. Identification and Classification of Perianal Fistulas

(For parameters on performance of MRI for abscess, please refer to the section Evaluation of Complications Following Pelvic Surgery, Including Abscess, Urinoma, Lymphocele, Radiation Enteritis, and Fistula Formation)

V. SPECIFICATIONS OF THE EXAMINATION (general specifications were discussed earlier in the document)

C. Technical Advances:

Digital subtraction MR-fistulography and high-resolution precontrast and postcontrast fat-suppressed 3-D T1-W gradient-echo sequence with subtraction postprocessing have been reported to be an important complement to surgical exploration [191]. DCE 2-D T1-W images with time-SI curves provide information on fistula activity [192]. This technique may be useful to identify a subgroup of patients with perianal Crohn’s disease at increased risk for complications. These patients may benefit from more frequent monitoring. DWI reflects water mobility and tissue cellularity and can improve diagnostic confidence.

D. Examination Technique:

Imaging with a pelvic phased array coil is standard practice that results in high accuracy for detecting perianal fistulas [193-196]. This is especially true for patients with Crohn’s disease who are prone to distant fistulous extensions and abscesses. Some centers rely on an have utilized an endoluminal coil alone or in combination with an external coil and report good imaging results, but endoluminal coils are not routinely used [197].

Suggested sequences include [198] the following:

i. Sagittal T2-W SSFSE (localizer) to prescribe true axial and coronal images of the anal canal (oblique axial and oblique coronal)

ii. Oblique axial T2-W FSE

iii. **Oblique coronal T2-W FSE**

iv. Oblique axial fat-suppressed T2-W FSE

v. Oblique axial fat-suppressed T1-W fat

vi. Oblique axial and oblique coronal postcontrast fat-suppressed 3-D T1-W gradient echo

vii. Optional: oblique coronal fat-suppressed T2-W FSE

viii. Optional: STIR images

ix. Optional: DWI with ADC maps

x. Optional: digital subtraction MR-fistulography

xi. Optional: DCE 2-D T1-W images with time-SI curves

The majority of perianal fistulas are not associated with an underlying condition. They result from impaired drainage of the anal glands, leading to abscesses that subsequently fistulize. However, perianal fistulas frequently complicate Crohn’s disease and can be seen in up to a quarter of patients with longstanding (20 years) disease [199,200].

MRI is superior to digital rectal examination and anal endosonography in classifying fistulous tracts and identifying their internal opening [201,202]. The objectives in performing and interpreting MRI for perianal fistulas are 3-fold:

1) to determine the relationship of the fistula to the sphincter complex; 2) to identify any secondary fistulae and/or abscesses; and 3) to monitor medical therapy for perianal fistulizing Crohn’s disease [203,204]. The most accepted MRI fistula classification system is the St. James University Hospital classification [205], which is a modification of the Parks classification [206].
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There are 5 grades:

i. Grade 1: Simple linear intersphincteric fistula

ii. Grade 2: Intersphincteric fistula with intersphincteric abscess or secondary fistulous tract

iii. Grade 3: Transspincteric fistula

iv. Grade 4: Transspincteric fistula with abscess or secondary tract within the ischioanal or ischiorectal fossa

v. Grade 5: Supralevator and translevator disease

On unenhanced T1-W images, fistulous tracts, inflammation, and abscesses have low to intermediate SI and may be difficult to distinguish from spincters and normal muscles. On T2-W and STIR images, linear fistulas and their complications (secondary tracts and/or abscesses) have high in SI compared to surrounding structures. The use of contrast increases the conspicuity of the fistulous tracts and abscess cavity walls. Contrast-enhanced T1-W images can also help distinguish fluid from inflammatory tissue, common in Crohn’s disease patients. Time-SI curves following dynamic contrast administration provide information about disease activity. Additionally, DWI improves diagnostic confidence and may be especially helpful as an adjunct to T2-W images in patients with a contraindication to IV contrast [207].

REFERENCES


Section 9. Identification and Characterization of Congenital Anomalies of the Female and Male Pelvis, Including the Anatomic Evaluation of Ambiguous Genitalia and Disorders of Sexual Development (DSD)

V. SPECIFICATIONS OF THE EXAMINATION (general specifications were discussed earlier in the document)

C. Technical Advances:

3-D T2-W MRI allows volumetric acquisition of the male and female pelvis, providing submillimeter sections with multiplanar reformating capability. There is a tradeoff between volume imaged, acquisition time, and T2 characteristics [41]. When evaluating nonpalpable undescended testes, DWI is complementary to conventional imaging [208]. High-resolution images of the seminal vesicles can be obtained with endorectal MR and/or by acquiring images on a 3T system.

D. Examination Technique:

1. Müllerian Duct Anomalies

The workup of suspected Müllerian duct anomaly (MDA) is often undertaken in the setting of infertility, obstetric complications, primary amenorrhea, and/or endometriosis. Although US, especially 3-D US, is often the initial imaging examination and performs well in experienced hands [209,210], MRI is the most accurate modality to characterize and classify MDAs [211]. In young females who are not sexually active, MRI may be performed rather than transvaginal US [212]. Hysterosalpingography and hysterosalpingo contrast sonography are best suited to evaluate synechiae and fallopian tube patency.

The original 1979 Buttram and Gibbons classification of MDAs [213] was modified in 1988 by the American Society of Reproductive Medicine [214]. Accurate classification is critical as treatments vary by subtype, thus underscoring the role of diagnostic imaging. A comprehensive MRI examination evaluates the uterine corpus, uterine cervix, vagina, and adnexa [215]. Vaginal gel insertion may aid in evaluating cervical and/or vaginal involvement, such as by a vaginal septum [216]. The kidneys must also be assessed because there is a 30–50% prevalence of associated renal anomalies. Imaging is performed with a pelvic phased array coil. Fasting 4–6 hours prior to imaging decreases artifacts from bowel peristalsis; alternatively, SQ or IM glucagon may be administered if not contraindicated. Patients are asked to void before the examination.

Suggested sequences include the following:

i. Orthogonal high-resolution (long and short axis) T2-W FSE of the uterus and upper vagina. This should include a T2-W FSE coronal oblique view, oriented parallel to the long axis of the uterus, in order to assess the uterine fundal contour. Alternatively, and/or a 3-D volumetric T2-W acquisition may be obtained

ii. Axial T1-W with and without fat suppression

iii. Coronal large FOV T2-W SSFSE that includes the renal fossae

iv. If a patient is unable to cooperate, orthogonal T2-W SSFSE of the uterine corpus, uterine cervix, and vagina may be performed, recognizing the more limited spatial resolution

v. Optional: T2-W FSE with vaginal gel to define the vaginal canal and/or cervix

vi. Optional: T2-W FSE that includes the abdomen in patients with disorders of sex development for presurgical planning of prophylactic gonadectomy or surveillance in those who choose gonad preservation

vii. Optional: DWI can help identify and characterize the gonads in patients with disorders of sexual development

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IV contrast is not indicated.

During organogenesis, the paired Müllerian ducts undergo a 3-stage process: 1) development (elongation and descent); 2) fusion; and 3) reabsorption of the uterovaginal septum. The goal of high-resolution T2-W imaging is to identify abnormalities that may occur from the time the paired Müllerian ducts descend, elongate, and fuse to the time of reabsorption of the intervening tissue, the uterovaginal septum. The short-axis T2-W images provide information on the number of endometrial, endocervical, and/or endovaginal cavities, whereas the long-axis T2-W images provide information on the true fundal contour of the uterus. T2-W sequences also provide information on whether or not any 2 cavities communicate. T1-W images allow diagnosis of concomitant hematometra and/or endometriosis that may accompany certain MDAs. Finally, a large FOV coronal image assesses renal abnormalities that often accompany MDAs.

2. Male: Congenital Pelvis Anomalies Seminal Vesicle Anomalies

Congenital anomalies of the male pelvis includes a variety of cystic lesions such as ejaculatory duct cysts, Cowper gland duct cysts and syringoceles, prostatic utricle, and Müllerian duct cysts and seminal vesicle cysts [217]. Other anomalies include abnormalities of the seminal vesicle, cryptorchidism, and congenital absence of the vas deferens. US is often the initial imaging modality for evaluating the seminal vesicles, prostate gland, and/or cryptorchidism. CT and MRI are typically reserved for problem solving (eg, investigation of intra-abdominal undescended testes).

The seminal vesicles are extraperitoneal secretory glands that lie posterior to the bladder and cephalad to the prostate. They originate from the lower mesonephric ducts. Congenital anomalies include agenesis, hypoplasia, and cysts. Seminal vesicle agenesis and hypoplasia may be associated with cryptorchidism. Likewise, seminal vesicle cysts may be associated with renal anomalies, ectopic insertion of ureters, and/or agenesis of the vas deferens. Multiplanar MRI allows comprehensive evaluation of the seminal vesicles and their surrounding structures.

Suggested sequences include [218] the following:

i. Orthogonal T2-W
ii. Axial T1-W
iii. Contrast-enhanced T1-W images may be performed in complicated cases (eg, proteinaceous cyst)
iv. Optional coronal large FOV T2-W SSFSE that includes renal fossae

3. Male: Cryptorchidism

Imaging may help identify a nonpalpable testis by serving as a surgical roadmap in an effort to preserve testicular function and/or detect early malignant tumors [219]. US is often the initial modality in the workup of a nonpalpable testis and has moderate success [220]; however, a meta-analysis found that US rarely impacts treatment while at the same time increases health care costs [221]. MRI is usually reserved for patients with nondiagnostic US.

Sequences include the following:

i. Axial and coronal T1-W images
ii. Axial and coronal T2-W fat-suppressed images to include the abdomen.
iii. Optional: Orthogonal contrast-enhanced T1-W images may increase conspicuity of the nonpalpable testis
iv. Optional: Axial high b-value single-shot spin-echo echoplanar images with chemical shift selective fat suppression
The nonpalpable testis is typically hypointense to muscle on T1-W images, hyperintense to muscle on T2-W, and enhances following IV contrast. Although conventional imaging performs well in locating a nonpalpable testis, a high b-value DWI can increase the preoperative sensitivity and accuracy of detection of nonpalpable testes. A nonpalpable testis is markedly hyperintense to muscle on high b-value DWI.

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2245 *Practice parameters and technical standards are published annually with an effective date of October 1 in the year 
2246 in which amended, revised, or approved by the ACR Council. For practice parameters and technical standards 
2247 published before 1999, the effective date was January 1 following the year in which the practice parameter or 
2248 technical standard was amended, revised, or approved by the ACR Council. 
2249 2250 Development Chronology for this Practice Parameter 
2251 2005 (Resolution 4) 
2252 Amended 2006 (Resolution 35) 
2253 Revised 2010 (Resolution 15) 
2254 Amended 2014 (Resolution 39) 
2255 Revised 2015 (Resolution 4)
BE IT RESOLVED,
that the American College of Radiology adopt the ACR–NASCI–SPR Practice Parameter for the Performance of Body Magnetic Resonance Angiography (MRA)

Sponsored By: ACR Council Steering Committee

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

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Revised 2015 (Resolution 8) *

ACR–NASCI–SPR PRACTICE PARAMETER FOR THE PERFORMANCE OF BODY MAGNETIC RESONANCE ANGIOGRAPHY (MRA)

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. 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 in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication.

1 Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing, 813 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.

PRACTICE PARAMETER

1

Body MRA

2020 Resolution No. 29
I. INTRODUCTION

This practice parameter was revised collaboratively by the American College of Radiology (ACR), the North American Society for Cardiovascular Imaging (NASCI), and the Society for Pediatric Radiology (SPR).

Magnetic resonance angiography (MRA) is a proven and useful tool for the evaluation, assessment of severity, and follow-up of diseases of the vascular system. Contrast-enhanced MRA (CE-MRA) has been shown to be equivalent to conventional angiography in the evaluation of diseases of many portions of the vascular system and for pretreatment planning [1-5]. In addition, as compared with conventional angiography, MRA is less expensive, less invasive, and lacks ionizing radiation exposure. Despite its proven efficacy, MRA remains an evolving amalgam of different techniques. Consequently, only general recommendations can be made regarding imaging protocols. Detailed protocols have been omitted to avoid promoting obsolete methodology. This document pertains to the assessment of vessels below the thoracic inlet, which are referred to as body MRA. For information on assessment of vessels of the head and neck or assessment of the heart, see the ACR–ASNR–SNIS–SPR Practice Parameter for the Performance of Cervicocerebral Magnetic Resonance Angiography (MRA) [6] and the ACR–NASCI–SPR Practice Parameter for the Performance and Interpretation of Cardiac Magnetic Resonance Imaging (MRI) [7].

Body MRA should be performed only for a valid medical reason. Most MRI systems have available specialized sequences that have been optimized for performing MRA. Although it is not possible to detect all vascular abnormalities by using MRA, adherence to the following practice parameters will enhance the probability of their detection.

MRA has important attributes that make it valuable in assessing vascular disease. Compared with radiographic catheter-based invasive angiography, it is considerably less invasive with no significant risk of vascular injury. Although MRA techniques are free of adverse effects from iodinated contrast media, some gadolinium-based contrast agents have been linked to the development of nephrogenic systemic fibrosis (NSF) in patients with severe renal insufficiency (see the ACR Manual on Contrast Media) [8-12]. More recently, Ferumoxytol, an ultra-small superparamagnetic iron oxide (USPIO) contrast agent and not a gadolinium-based contrast agent, has been reported as a suitable alternative to gadolinium-based contrast agents and as capable of yielding high-quality CE-MRA [13-18]; however, this is an off-label indication. However, unenhanced Noncontrast MRA techniques are also available for assessing the vasculature in patients who cannot or should not receive gadolinium-based contrast agents [19-22]. Compared with vascular ultrasound, MRA is less operator dependent, yields images of the vascular system in a format familiar to most referring physicians, is less limited by body habitus and overlying bowel gas, and has greater 3-D capability. Contrast-enhanced CT angiography (CTA) can also provide excellent vascular illustration but is associated with increased patient concerns related to exposure to ionizing radiation and the use of iodinated contrast media—concerns not borne by utilization of MRA. MRA has the ability also to provide time-resolved vascular imaging without the additional ionizing radiation exposure concerns related to multiphase CTA. In addition, CTA does not provide quantitative information about blood flow, which is
possible with phase contrast MRA (PC-MRA), and CTA does not assess oxygen saturation, which is possible with susceptibility-weighted MRA. MRA has also shown promising results for atherosclerotic plaque characterization, notably for detection of high-risk features (eg, intraplaque hemorrhage, lipid-rich necrotic core, or fibrous cap thinning/rupture) of carotid atherosclerotic plaque [23-25].

MRA is also useful in diagnosing vascular disease in children and is more advantageous for this patient population given the lack of radiation exposure and ability to include time-resolved scans. Pediatric MRA may require specialized imaging approaches to accommodate the different spectrum of disease, physiology, smaller vessel caliber, typically faster blood flow, larger motion concerns, and varying body size as compared with adults and may require sedation or general anesthesia.

Application of this practice parameter should be in accordance with the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [26] and the ACR–SIR Practice Parameter for Sedation/Analgesia [27].

(For pediatric considerations, see sections II.B.4 and IV.C.)

II. INDICATIONS

A. General Considerations

Adult indications for body MRA include, but are not limited to, the definition and evaluation of the following:

1. Presence and extent of vascular stenosis or occlusion due to atherosclerosis, vasculitis, or thromboembolic phenomena
2. Etiology of thoracic, abdominal, or pelvic hemorrhage
3. Mapping vascular anatomy for preprocedural planning and postprocedural surveillance of treatment
4. Presence, location, and anatomy of aneurysms and vascular malformations
5. Presence, nature, and extent of injury to vessels, including dissection
6. Vascular supply to, or involvement by, tumors
7. Presence and extent of venous disease, including occlusion, thrombosis, and tumor invasion
8. Venous anatomy, including congenital abnormalities, extrinsic compression, or causes of intrinsic stenosis or obstruction
9. Presurgical assessment of vascularity that may be involved by or affected by disorders in proximity
10. Nature and extent of other congenital or acquired vascular abnormality
11. Quantitative measurements of blood flow

B. Specific Considerations

1. Thoracic vasculature
   MRA is useful for assessing the aorta, and its branch vessels, and can be used to assess the pulmonary vasculature. Indications for thoracic MRA include, but are not limited to, the definition and evaluation of the following:
   a. Thoracic aorta
      i. Aneurysm and/or atherosclerosis of the thoracic aorta and branch vessels
      ii. Posttraumatic pseudoaneurysm
      iii. Acute aortic syndrome evaluation
         a) Dissection
         b) Intramural hematoma
         c) Penetrating atherosclerotic ulcer
iv. Atheroembolic disease—identification of aortic thrombi
v. Vasculitis
vi. Neoplasia, both primary and secondary
vii. Postoperative evaluations
   a) Perianastomotic leaks
   b) Infection
   c) Pseudoaneurysm
viii. Endovascular stent graft, including endoleaks
ix. Congenital disorders, including vascular malformations, arch anomalies, and aortic coarctation
b. Coronary arteries
   i. Aberrant arterial anatomy
      Coronary artery anomaly
   ii. Atherosclerotic narrowing
      Atherosclerosis
   iii. Vasculitis
   iv. Aneurysmal disease (including Kawasaki disease)
   v. Coronary artery bypass graft
c. Pulmonary veins
   i. Venous mapping prior to and following radiofrequency ablation for atrial fibrillation
   ii. Pulmonary vein anomalies, including anomalous return and stenosis
d. Pulmonary arteries
   i. Thromboembolism
   ii. Pulmonary artery hypertension
   iii. Stenosis
   iv. Vascular malformations
      a) Pulmonary sequestration
      b) Pulmonary arteriovenous malformations
   v. Neoplastic disease
   vi. Preoperative and postoperative assessment of lung transplantation
e. Internal mammary and intercostal vessel evaluations
f. Bronchial arteries and aortopulmonary collateral vessels
g. Congenital or acquired thoracic venous disorders
h. Assessment of preoperative and postoperative status, including known or suspected complications following repair or palliation of congenital cardiovascular disorders in adults and children

2. Extremity evaluations
a. Arteries
   i. Atherosclerotic occlusive disease
      a) Intermittent claudication
      b) Acute and chronic critical limb ischemia
   ii. Patients with previous interventions (postoperative)
      i. Stent grafts
      ii. Bypass grafts
   iii. Atheroembolism
   ii. Congenital anomalies, including vascular malformations
   iii. Vasculitide
   iv. Arterial fibrodysplasia
   v. Postinterventional intimal hyperplasia
   vi. Arterial entrapment syndromes
   vii. Adventitial cystic disease
   viii. Vascular malformations and fistulae
   ix. Aneurysmal disease
   x. Assessment of complications of arterial bypass grafts
xi. Assessment of surgically created dialysis fistulas and grafts with unenhanced MRA
xii. Preoperative mapping of vascular anatomy for plastic surgery graft procedures
b. Assessment for vascular involvement with musculoskeletal tumors
c. Venous evaluations
   i. Thrombus
      a) Central
      b) Peripheral
      c) Effort thrombosis of the upper extremity
      d) Venous compression
   ii. Venous malformations
   iii. Varicose veins/venous mapping
   iv. Assessment for vascular involvement with musculoskeletal tumors
   v. Assessment of causes of peripheral edema
      a) Thrombus
      b) Venous compression
      c) Assessment of strictures from indwelling catheters
   vi. Assessment of patent vessels for venous access and mapping for surgical creation of native dialysis fistulas and grafts with unenhanced MRA
   vii. Assessment of vein suitability as bypass conduits

3. Abdominal and pelvic vasculature MRA
   a. Diagnosis and/or assessment of the following vascular abnormalities:
      i. Aneurysm of the aorta and major branch vessels
      ii. Stenosis or occlusion of the aorta and major branch vessels resulting from atherosclerotic disease, thromboembolic disease, or large-vessel vasculitis
      iii. Dissection of the aorta
      iv. Vascular malformation and arteriovenous fistula
      v. Portal, mesenteric, or splenic vein thrombosis
      vi. Inferior vena cava (IVC), pelvic vein, gonadal vein, renal vein, or hepatic vein thrombosis
   b. Vascular evaluation in one of the following clinical scenarios:
      i. Lower-extremity claudication
      ii. Known or suspected renovascular hypertension
      iii. Known or suspected chronic mesenteric ischemia
      iv. Hemorrhagic hereditary telangiectasia
      v. Known or suspected Budd-Chiari syndrome
      vi. Portal hypertension
      vii. Known or suspected gonadal vein reflux
   c. Preprocedure assessment for the following:
      i. Vascular mapping prior to living organ donation
         a) Liver
         b) Kidney
         c) Pancreas
         d) Combined organ transplant
      ii. Assessment of renal vein and IVC patency in the setting of renal malignancy or neoplasm
      iii. Vascular mapping prior to placement of or surgery on a transjugular intrahepatic portosystemic shunt (TIPS).
      iv. Vascular mapping prior to resection of abdominal and pelvic neoplasms
      v. Vascular mapping prior to uterine fibroid embolization
      vi. Vascular mapping prior to hepatic bland embolization, chemoembolization, and radioembolization procedures
      vii. Vascular mapping prior to tissue grafting
d. Postprocedure assessment for the following:
   i. Evaluation of organ transplant vascular anastomoses (hepatic, renal, and pancreatic)
   ii. Detection of suspected leak following aortic aneurysm surgery or MR-compatible aortic stent graft placement
   iii. Evaluation of ovarian artery collateral flow following uterine fibroid embolization

4. Pediatric indications for body MRA

MRA is particularly applicable in children because of the risk (albeit low) related to catheter-based angiographic procedures, including the small potential risk of exposure to ionizing radiation [28]. The need and potential risk of sedation should be considered. Various studies of children have shown MRA to be useful for assessing vascular abnormalities of the chest, abdomen, and extremities [1,29-31].

Indications for body MRA for children include, but are not limited to, the definition and evaluation of the following:

a. Congenital anomalies of the aorta, coronary arteries, pulmonary vasculature, and associated branch vessels
b. Aortic, pulmonary arterial, and branch vessel vasculopathies in the setting of a known or suspected syndrome (eg, Marfan syndrome and other connective tissue disorders, midaortic syndrome, neurofibromatosis type 1, and William syndrome)
c. Vasculitis
d. Arterial dissection
e. Aneurysmal disease
f. Renovascular hypertension
g. Vascular malformations of the trunk and extremities
h. Central and peripheral venous occlusive disease
   i. Congenital venous/portovenous anomalies
   j. Presence of thrombosis, including caval, portal, mesenteric, or splenic vein
   k. Blood supply to vascular neoplasms for operative planning
   l. Vascular anastomoses and complications of organ transplants
   m. Postoperative anatomy following vascular surgery
   n. Evaluation of surgically created dialysis fistulas and grafts with unenhanced MRA
   o. Evaluation of extremity peripheral vasculature in congenital anomalies (eg, Klippel-Trenaunay syndrome)
p. Portal hypertension
   q. Thoracic Arterial and venous thoracic outlet syndrome

Detailed discussion for additional imaging of the coronary arteries can be found in the ACR–NASCI–SPR Practice Parameter for the Performance and Interpretation of Cardiac Magnetic Resonance Imaging (MRI) [7].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [26].

The physician responsible for performing body MRA must fully appreciate the benefits, alternatives, and risks of the procedure. He/she must have a thorough understanding of thoracic, abdominal, and extremity anatomy (including congenital or developmental variants and common collateral pathways) as well as the indications, pertinent vascular considerations, and complications associated with common vascular procedures and surgeries.
IV. SPECIFICATIONS OF THE EXAMINATION

The supervising physician must have complete understanding of the indications, risks, and benefits of the examination as well as the 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 Body MRA 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 practice requirements. (ACR Resolution 35 adopted in 2006 – revised in 2016, Resolution 12-b)

The supervising physician should have an adequate understanding of both the clinical indications for body MRA as well as 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 and Preparation

The physician responsible for the examination should supervise patient selection and preparation, protocol the examination, and be available in person or by phone for consultation. Patients should be screened and interviewed prior to the examination to exclude individuals who may be at risk by exposure to the MR environment or, in the case of CE-MRA, by exposure to gadolinium-based contrast media (see the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [32]).

When intravenous (IV) gadolinium-based contrast media are required for successful performance of MRA, 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 [32]).

Patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of moderate sedation may be needed to achieve a successful examination. General anesthesia may be required for certain patients, particularly young children. If moderate sedation is necessary, refer to the ACR–SIR Practice Parameter for Sedation/Analgesia [27]. Although in some age groups (generally less than 6 years) some form of sedation may be needed, the need for sedation may be mitigated with the use of an alternative [33,34], such as use of an audiovisual systems during MRI [35] or the “feed-and-sleep” technique in neonates and infants [36].

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

PRACTICE PARAMETER

Body MRA

2020 Resolution No. 29
C. Examination Technique

MRA is a general term that refers to a diverse group of MR pulse sequences. Different mechanisms can be used to generate signal from flowing blood without gadolinium [19-22,38-40]. Time of flight (TOF) technique relies on inflow enhancement to generate images of blood flow [10]. [41][41][41][41][40][39][38][37][37][37][37]Flow images and quantitative measurements of flow velocity can be obtained using phase contrast (PC) MRA methods in which the image contrast is generated by velocity-induced phase shifts [42,43]. A third method relies on a steady-state free precession (SSFP) sequence that captures the intrinsic T1 and T2 features of blood as bright signal [44-46].

A fourth technique requires some form of cardiac gating and exploits the different signal intensities of blood using a T2-weighted echo train spin-echo sequence between systole, at which time flow void predominates, and diastole, at which time the relatively static blood has high signal intensity [47]. With this technique, angiographic images can be obtained by subtracting the systolic dataset from the diastolic dataset. The use of contrast media for CE-MRA has the benefit of speed of acquisition and reliable vascular signal for detection of intraluminal defects, such as an intimal tear, as well as the ability to provide time-resolved MRA (TR-MRA). CE-MRA relies on enhancement of the blood signal by an intravascular paramagnetic contrast agents, typically gadolinium-based, and uses a rapid, 3-D T1-weighted gradient-echo acquisition [48-50]. Individuals using MRA must understand these concerns as well as those related to the artifacts and limitations of the various MRA techniques available at their sites. There are also benefits and technical concerns for MRA based on the field strength of the MR scanner. MRA performed on a high-field MR scanner (eg, 3T), for instance, offers the advantages of speed and higher vascular signal-to-noise relative to that performed on a low-field 0.5T MR scanner [51-53]. However, MRA performed on a high-field MR scanner presents concerns related to higher absorption rate (specific absorption rate [SAR]) and artifacts related to metallic susceptibility.

1. Noncontrast MRA

Time-of-flight (TOF) technique relies on inflow enhancement to generate images of blood flow [10]. The most commonly used inflow techniques are 2-D TOF and 3-D TOF. In 2-D TOF acquisitions, multiple contiguous thin slices are obtained and combined to form a 3-D data set. The 3-D technique inherently acquires a volume of data. The region of coverage of a 3-D TOF sequence is limited by radiofrequency saturation within the acquisition volume. When using a 2-D TOF technique to image the aorta and arteries of the lower extremities, cardiac or peripheral gating can minimize artifacts related to vascular pulsation and improve image quality at the expense of a greatly lengthened examination [54,55]. Blood flow in a particular direction can be selectively imaged through the use of saturation bands. With a 2-D acquisition, these saturation bands can be prescribed to travel with the imaging slice, ensuring adequate elimination of undesired signal along the entire course of the vessels of interest.

Quiescent inflow slice-selective (QISS) MRA is a variant of TOF that relies on radiofrequency saturation of stationary in-plane spins followed by a delay time to allow for inflow enhancement [56-59]. Initial experience with this technique for the noncontrast evaluation of the lower-extremity peripheral arteries shows promising results.

Flow images and quantitative measurements of flow velocity can be obtained using PC-MRA methods in which the image contrast is generated by velocity-induced phase shifts [42,43]. As with TOF, PC-MRA can be obtained as either a 2-D or 3-D data set (ie, 4-D flow MRI). IV contrast enhancement may also be used to increase the signal obtained from the blood. PC techniques are based on the physical properties of moving spins. As protons move through a magnetic field, they acquire a phase shift directly.
proportional to their velocity. The magnitude of the phase shift can be measured, and an image of the flowing blood can be generated. Display of the vessels is similar to that of the TOF technique, although direction of flow can also be indicated without the need for saturation bands. PC-MRA can be obtained without or with electrocardiogram (ECG) triggering. The application of ECG triggering will typically lengthen the acquisition time. It is essential to trigger the PC acquisition to the cardiac cycle if measurements of flow velocity or flow volume are desired. Therefore, peripheral or cardiac gating should be available.

A third method relies on a steady state free-precession (SSFP) sequence that captures the intrinsic T1 and T2 features of blood as bright signal [44-46]. Because of balanced SSFP’s (bSSFP) reliance on T2/T1 signal, intraluminal thrombus may be masked on bSSFP MRA (Nota bene, use of PC-MRA, a flow-based technique, is often helpful to confirm luminal patency in these cases). Two-dimensional and 3-D SSFP MRA techniques use a type of unspoiled gradient-echo sequence in which the gradients are balanced and the signal is a composite signal from free-induction decay and stimulated echoes. The typical bSSFP sequence does not depend on flow and, therefore, does not distinguish flow direction or velocity. Flow-related artifacts are also dramatically reduced with this type of sequence, but it is sensitive to artifacts from static magnetic field inhomogeneity (off-resonance artifacts). The abdominal aorta and visceral (eg, renal) arterial branches can be selectively imaged, however, through the use of an asymmetrically applied inversion prepuise that can effectively null the signal from venous blood [19].

A fourth technique requires some form of cardiac gating and exploits the different signal intensities of blood using a T2-weighted echo train spin-echo sequence between systole, at which time flow void predominates, and diastole, at which time the relatively static blood has high signal intensity. A form of echo train spin-echo MRA exists that depends on the different signal intensities between rapidly flowing blood during systole and relatively static blood during diastole. During systole, intravascular signal is reduced because of the flow-related signal void using a T2-weighted echo train spin-echo or bSSFP sequence. During diastole, the blood behaves as a relatively immobile fluid and demonstrates relatively high signal intensity. By timing the acquisition of data sets to the cardiac cycle, systolic and diastolic data sets can be acquired and subtracted, eliminating background signal. The remaining intravascular signal can be displayed in a similar manner to other MRA techniques. This technique is best suited for imaging vessels that exhibit pulsatile flow and therefore may be limited in evaluation of distal extremity circulation when severe inflow disease diminishes distal pulsatility.

A fifth technique is the two-point Dixon water-fat separation technique noncontrast MRA of the whole heart and vasculature that has shown promising results on 1.5T and 3T scanners compared with spectral presaturation inversion recovery (SPIR) fat-suppressed balanced fast field echo (BFSE) coronary MRA in coronary imaging and vascular studies [60,61]. A novel 3-D respiratory-triggered gradient-recalled echo Dixon-based MRA/MR venography (MRV) technique that provides high-resolution anatomical imaging of the vasculature of the neck, body, and extremities without the need for IV contrast material or breath-holding has also recently been described [62].

2. CE-MRA

3-D CE-MRA combines a fast T1-weighted gradient-echo acquisition with an intravenously administered paramagnetic contrast agent. There are now a variety of contrast agents available for performance of CE-MRA that may differ in terms of relaxivity, gadolinium concentration, biodistribution, elimination, and various safety concerns (see the ACR Manual on Contrast Media) [12,38,63-67]. For example, higher-relaxivity gadolinium-chelate extracellular contrast agents can provide improved vascular signal-to-noise and contrast-to-noise ratios for an equimolar dose of a lower-relaxivity gadolinium-chelate extracellular contrast agent. Such agents reduce T1 relaxation time of blood and nearly eliminate the loss of signal related to saturation effects and flow-related artifacts due to intravoxel dephasing, thus leading to a more accurate assessment of stenosis [68,69]. CE-MRA has documented efficacy in assessing the arterial and venous...
systems in the thorax, abdomen, pelvis, and extremities [2,5,39,48,68,70-82]. In most cases, CE-MRA does not require cardiac gating and is, therefore, easily applicable in patients with irregular cardiac rhythms. The coronary arteries and aortic root, however, move quite significantly during each cardiac cycle, and CE-MRA of these vessels typically benefits from proper cardiac gating [83,84]. Using breath-holding during MRA often minimizes imaging artifacts related to motion artifacts, and artifacts due to complex flow are minimized. Respiratory-gated MRA using navigator echoes that synchronize image acquisition with the respiratory cycle in real time can often achieve higher-resolution 3-D MRA, notably in patients with limited breath-holding ability. These advantages make CE-MRA extremely useful for imaging of the vasculature in the thorax, abdomen, pelvis, and extremities. CE-MRA techniques can be combined with a moving table to allow large areas of coverage [85-87]. Novel contemporary k-space filling and parallel imaging techniques allow for high-temporal-resolution (time-resolved) imaging of vascular territories, [38,53,88-91], potentially eliminating the need for precise acquisition timing. Alternatively, accurate timing of acquisition can be enhanced through the use of a timing bolus, “fluoroscopic triggering,” or automatic bolus detection techniques [92-94]. It is important for non–TR-MRA that the contrast bolus duration matches the image acquisition duration in order to avoid either edge enhancement or blurring secondary to the changing contrast concentration in the vessels of interest throughout the scan. This can be done by adjusting the injection rate. CE-MRA is typically performed during the first pass of the bolus but often includes equilibrium phase acquisitions, which provide time-resolved vascular information. Postcontrast imaging using SSFP MRA [95] and PC-MRA [93] can often provide supplemental vascular information to CE-MRA even when performed well after the first pass of the bolus.

More recently, Ferumoxytol, an USPIO contrast agent, has been reported to successfully yield high-quality CE-MRA [13-18]; however, this is an off-label indication. Ferumoxytol is not a gadolinium-based contrast agent, and unlike gadolinium-based contrast agents, it does not pose a risk of NSF. Although recent studies suggest an excellent safety profile, careful consideration to relative risk and benefit is nonetheless required, given that the agent has a “black box” warning from the FDA and anaphylactic reactions resulting in death have been reported. Ferumoxytol has a prolonged intravascular half-life of several hours, which is much longer than that of traditional extracellular gadolinium-based contrast agents, which provides a prolonged window of opportunity for MRA.

3. Special Considerations
   a. MRV

   Venous illustration can be achieved using both noncontrast and CE-MRA methods. Indications for MRV are listed above. Contrast-enhanced MRV (CE-MRV) is implemented in much the same way as CE-MRA, whereby an IV gadolinium-based contrast agent injection is combined with the acquisition of a 3-D T1-weighted spoiled gradient-echo data set [96]. Digital subtraction of a precontrast mask from a postcontrast acquisition may improve depiction of venous structures, but this is not considered essential. Exact timing of the contrast bolus is less critical for venous imaging. Selection of an empiric delay time of 40–60 seconds following the contrast injection, which allows time for the contrast agent to fully equilibrate in the venous system, is usually adequate. The use of a blood pool contrast agent is particularly advantageous when imaging venous structures because it remains within the circulation for several hours after the initial injection [97]. Blood pool contrast agents ensure prolonged increase in vascular signal for high spatial resolution steady state CE-MRV. Respiratory gating can be used for equilibrium phase imaging in the thorax to allow free-breathing image acquisition. Ferumoxytol, which has a prolonged vascular half-life and does not have the same patient safety concerns (eg, NSF) as gadolinium-based contrast agents, may be particularly appropriate for MRV.

   Noncontrast MRV is another option for MRV desirable in patients with renal dysfunction, pregnancy, gadolinium-based contrast agent allergy, and in children [62]. Noncontrast MRV is best achieved with SSFP or turbo spin-echo [98] imaging approaches. ECG or respiratory gating can be employed in the
chest to offset motion artifact, and inversion recovery may be utilized to improve contrast and background suppression. TOF imaging, which depends on the generation of signal from flowing blood, may also be used for imaging the venous system and is best suited to the portal and intracranial circulations.

There are some specific clinical disorders of the venous system where additional maneuvers or techniques may be helpful for further disease characterization. Venous imaging using TR-MRA, which allows direct visualization of the physiologic blood flow dynamics, is helpful for the diagnosis of pelvic congestion syndrome because of its ability to determine temporal filling and whether anterograde or retrograde flow is present in the ovarian vein [99]. Provocative positioning of the patient may be required in some instances for final diagnosis. In Paget-Schroetter syndrome (ie, effort-induced thrombosis), for example, MRV, either during first pass or steady state, may need to be performed during both arm adduction and arm abduction to demonstrate dynamic compression of the subclavian vein between clavicle and rib.

b. Pediatric Patients
In infancy and childhood, MRA can provide valuable information about the vascular system, particularly for assessing various types of vascular malformations and syndromes, congenital lesions, such as coarctation of the aorta, or anomalous pulmonary venous return. However, technical and safety issues are more complex in pediatric patients. The smaller size of vasculature increases the demand for higher spatial resolution, and more rapid circulation time requires higher temporal resolution. In addition, sedation and/or general anesthesia may be necessary to successfully complete the examination, depending on the age of the child or possibly the complexity of the clinical questions being answered. Many of these concerns have been discussed earlier in this document by suggesting noncontrast, free-breathing high-resolution MRA imaging or using the “feed-and-sleep” method without need for sedation. Regarding the safety of using gadolinium-based contrast agents in neonates, readers are referred to the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [32]. Infants and young children, special attention must be paid to the appropriate dose of contrast media taking into account the immature renal function, especially in infancy. Given the small body size of some pediatric patients, certain clinical applications of CE-MRA may necessitate dilution of contrast media to increase the volume of the administered contrast.

c. MRA Interpretation
The supervising physician should review all MRA 2-D source images to reduce possible confusion of high-signal material (eg, fat or thrombus) with flow signal. Review of the source images also aids diagnosis by eliminating overlapping structures and determining whether artifacts are the cause of spurious signal or signal loss.

MRA data are routinely postprocessed using a multiplanar reformation (MPR), maximum intensity projection (MIP) reconstruction, and volume-rendering techniques. Rotating displays of 3-D data sets allow separation of vessels that are superimposed on a single projection. Additionally, multiple views are needed to fully depict altered vascular anatomy. Targeted MIP renderings can be made to clarify areas of tortuosity and vessel overlap. The supervising physician must be familiar with MPR, MIP, and volume-rendering techniques and with the limitations and strengths of each method. The type and frequency of artifacts will vary with the display technique; thus, the supervising physician must understand the potential errors associated with each display method [69,100-105]. Optimized pulse sequences and quantitative postprocessing tools for evaluating blood vessel caliber, flow velocity, volume, and direction should be used when indicated clinically.
V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [106].

In addition to examining the vascular structures of interest, the MR source images should be examined for extravascular abnormalities that may have clinical relevance. These abnormalities should be described in the formal report of the examination.

In addition, if contrast agents are used for MRA, the dose, method of injection, and type of contrast agent administered must be documented in the report.

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 that deal with potential hazards associated with the MRI examination of the patient as well as to others in the immediate area should be provided [107-109]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [110].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [107-109].

For additional safety considerations, see the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [26], the ACR Guidance Document on MR Safe Practices: 2013 [107], and the ACR Manual on Contrast Media [12].

VI. 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 [111].

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

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

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BE IT RESOLVED,

that the American College of Radiology adopt the ACR–SPR–SSR Practice Parameter for the Performance and Interpretation of Magnetic Resonance Imaging (MRI) of Bone and Soft Tissue Tumors

Sponsored By: ACR Council Steering Committee

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

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Revised 2015 (Resolution 5) *

ACR–SPR–SSR PRACTICE PARAMETER FOR THE PERFORMANCE AND INTERPRETATION OF MAGNETIC RESONANCE IMAGING (MRI) OF BONE AND SOFT-TISSUE TUMORS

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. 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 in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication.

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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.
of this document. However, a practitioner who employs an approach substantially different from the guidance in this document 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 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 sole purpose of this document is to assist practitioners in achieving this objective.

I. INTRODUCTION

This 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).

Magnetic resonance imaging (MRI) is a proven and well-established imaging modality in the detection, evaluation, assessment, staging, and follow-up of tumors of the musculoskeletal system. Properly performed and interpreted, MRI not only contributes to initial diagnosis and identification of local recurrence but is also useful to serve as an important guide to biopsy, and inform treatment planning, as well as and assess response to therapy. However, MRI of a tumor or suspected mass should be performed only for a valid medical reason and after careful consideration of alternative imaging modalities. An analysis of the strengths of MRI and other modalities should be weighed against their suitability for particular patients and particular clinical conditions. Radiographs should be the initial imaging study obtained for clinical suspicion of bone tumors used for the initial diagnosis of primary bone tumors. In addition, radiographs are usually the first imaging test performed for most suspected soft-tissue masses and are particularly valuable for identifying showing the presence and character of calcification, fat, or other radiopaque material. For superficial palpable soft-tissue masses, ultrasound may be useful to characterize lesion location, detect internal vascularity, and differentiate solid from cystic lesions [1-3]. Technetium-99m-labeled diphosphonates Radionuclide bone scintigraphy scanning and single-photon emission computed tomography (SPECT), with or without CT co-registration, is often used when occult bone disease is suspected or and to screen the entire skeleton for polyostotic disease conditions such as metastasis metastases. Other nuclear medicine examinations have a role for specific clinical scenarios (eg, Indium-111 oxine, a labeled white blood cell (WBC) scan study for suspected osteomyelitis). CT shows detailed bone anatomy and aids in identifying osteoid and chondroid matrix. CT can also be useful to demonstrate the presence of fat within both bone and soft-tissue lesions. Sonography may aid in examination of soft-tissue masses (eg, cystic versus solid, assessment of vascularity) [1,2]. Conventional, MR, or CT angiography remains useful for evaluating tumor vascularity, identifying the relationship of the lesion to adjacent major blood vessels, planning resection and reconstruction, and providing a road map access for presurgical embolization [4]. Positron emission tomography (PET) with or without CT or MR co-registration can help stage and grade tumors [5-10], assess response to therapy [11-14], and detect tumor recurrence [8,15], but it may not reliably discriminate between benign and malignant tumors [6,16].

Although MRI is one of the most sensitive, noninvasive diagnostic tests for detecting anatomic abnormalities of the musculoskeletal system, findings may be misleading if not closely correlated with radiographs, clinical history, clinical physical examination, and physiologic tests [17,18]. Adherence to the following guidelines will enhance the probability of detecting such abnormalities.

II. INDICATIONS

Indications for MRI of soft-tissue and bone tumors include, but are not limited to, the following:
1. Initial characterization, detection, or exclusion of tumors [19-34]
2. Local staging of tumors [35-39]
3. Evaluation of tumors prior to biopsy, surgery, chemotherapy, and/or radiotherapy [27,35,40-44]
4. Evaluation of the response of tumors to treatment, including neoadjuvant chemotherapy, postresection chemotherapy, and radiotherapy [45-56]
5. Detection and evaluation of complications related to tumors or their treatment, including hemorrhage, infection, and neurologic and vascular conditions [27,52,55-65]
6. Posttreatment and long-term surveillance and characterization of local, regional, and distant tumor recurrences [53,54]

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [66].

IV. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for MRI of bone and soft-tissue tumors 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’s scope of practice requirements. (ACR Resolution 35 adopted in 2006 – revised in 2016, Resolution 12-b)

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 prior ancillary studies that the patient may have undergone. The physician performing MRI interpretation must have a clear understanding and knowledge of the relevant 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 should be available in person or by phone for consultation by direct communication. Patients must be screened and interviewed prior to the examination to exclude individuals who may have contraindications to MRI, in which the risks may outweigh the benefits 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...
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utilization (See the ACR-SPR Practice Parameter for the Use of Intravascular Contrast Media [67] and the ACR Manual on Contrast Media [68]).

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 minimal or moderate sedation is necessary, refer to the ACR-SIR Practice Parameter for Sedation/Analgesia [69]. Young children may require sedation or general anesthesia in order to prevent patient motion during the MR examination. Strategies should be employed to mitigate the use of sedation whenever possible and should include motion-insensitive imaging acquisitions and the use of a child life specialist support [70].

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 MRI of suspected bone and soft-tissue masses can be performed using a variety of magnetic designs (closed-bore whole body, open whole body) and a variety of field strengths [21,23,26,29]. Regardless of system design, efforts should be made to maximize signal-to-noise ratios (SNR). Field of view (FOV) should be tailored to the size of the patient and the size of the suspected mass [23,63,71,72]. For example, a 48-cm FOV would be appropriate for an extremely large tumor of the pelvis or thigh, whereas a 12-cm FOV may be appropriate for a small mass in the foot. At times, additional sequences with a larger FOV will be necessary to evaluate proximal or distal spread of disease. It is important to obtain as many transverse, sagittal, or coronal images through the lesion as is reasonable. Slice thicknesses will also vary depending on the size of the lesion [23]. For example, a 1-cm mass might require 3-mm-thick slices, whereas a tumor greater than 30 cm in size may be appropriately imaged with 1-cm slice thickness [23]. An interslice gap may be chosen to decrease signal loss due to cross talk [71] but in general should be no more than one-half of the slice width and should not impair complete visualization of the mass. The imaging matrix should balance the intravoxel SNR with desired in-plane spatial resolution.

The size and location of the lesion will often dictate the most appropriate coil to use for imaging. Small lesions or lesions located in the extremities will often be best imaged using a local surface coil, a cylindrical coil, or a dedicated joint coil. For extremely large lesions or lesions involving the torso, the body or torso coil may be a more appropriate choice [23,39,43]. Every attempt should be made to include The entire soft-tissue or bone tumor and associated marrow signal abnormality edema in association with the possible tumor should be captured within the imaged volume. Additionally, For some tumors, two separate but overlapping volumes might be necessary high-grade sarcomas of bone, The entire bone, including the adjacent joints, should be imaged to evaluate for skip lesions and regional metastases. The use of a multiple-channel receiver coil unit may allow the use of parallel imaging and compressed sensing imaging techniques to reduce overall scan time or improve SNR and may be useful in reducing motion-related artifacts [73-75].

For patients with more than one suspected bone or soft-tissue mass, it may be necessary to perform separate MR examinations. For example, a patient with a mass involving both the pelvis and leg may require two separate studies.

When imaging bone and soft-tissue tumors at an MR imager of field strengths less than 1.5T, it is used to image bone and soft-tissue tumors, then other imaging parameters, such as the receiver bandwidth and number of acquisitions, will require modification to ensure adequate spatial and contrast resolution for confident diagnosis. This is often at the expense of longer examination times [63,76]. It may also be more difficult to achieve uniform
fat suppression on low-field systems using spectrally selective radiofrequency (RF) presaturation pulses, potentially necessitating the use of Dixon or short tau inversion recovery (STIR) techniques [77-80]. Other systems may be more prone to imaging artifacts (eg, chemical shift artifact on high-field magnets), again necessitating modification of imaging parameters, such as receiver bandwidth, to ensure that these artifacts do not detract from the diagnostic quality of the resultant images. Some MRI systems may not be appropriate for specific indications. For example, high-resolution evaluation of a small mass may not be feasible with a low-field, open magnet, regardless of the chosen imaging parameters [81].

MRI of bone and soft-tissue tumors usually includes images in at least two orthogonal planes (transverse, sagittal, and coronal) [21,23,24,30,63]. The long axis images may be oriented orthogonal to the magnetic bore or may be angled to better identify specific anatomic structures. Coverage of the tumor must ideally include all of the anterior, posterior, medial, lateral, superior, and inferior margins of the mass, unless clinically/radiographically impractical [21,23,44].

MRI of suspected bone and soft-tissue tumors can be performed with a variety of pulse sequences. The choice of sequences can be tailored to optimize the examination for specific clinical questions and according to local preferences. An imaging protocol would usually be composed of at least one T1-weighted pulse sequence image and one fluid-sensitive T2-weighted sequence with or without fat suppression.

Short echo time (TE) images with a relatively short repetition time (TR) (T1-weighted) are commonly used to evaluate tumors [21,23,71,76]. Because of the Properly optimized, most institutions use fast spin-echo sequences for T1-weighted imaging. If image blurring inherent in a with fast spin-echo imaging occurs image made with a short effective TE, conventional spin-echo imaging can may be utilized preferred [21,23,71,76]. Properly optimized, however, some investigators have used fast spin echo imaging for T1 weighted images. To demonstrate pathologic tissues, T2-weighted (fluid-sensitive) imaging using conventional spin-echo or fast spin-echo sequences are most commonly used [77-80,82]. T1-weighted spoiled gradient-echo chemical shift imaging (ie, water-fat in-phase/opposed-phase imaging) can be used to demonstrate the presence of lipid components in tissues and may help discriminate benign from malignant disease processes, such as in evaluation of fractures and bone marrow infiltration [83,84]. Gradient-recalled sequences may also be valuable, in particular in evaluating for internal areas of hemorrhage, gas, ossification, or calcification. Diffusion-weighted imaging (DWI) may also be useful to quantitatively and qualitatively assess bone and soft-tissue masses [85-87]. DWI uses the variability of Brownian motion of water to characterize lesions as having restricted or unrestricted motion of water, which correlates with lesion cellularity [88].

T1-weighted sequences are routinely done without fat suppression to depict anatomic relationships; however, the addition of fat suppression may be helpful to detect hemorrhage or fat within a mass and enhancement when IV contrast is given [89]. Fluid-sensitive images, obtained with long TR using conventional or fast spin-echo sequences, can be used to characterize bone and soft-tissue tumors, providing complementary information to the T1-weighted images. Therefore, a combination of both T1-weighted and T2-weighted images is typically performed in each imaging plane [21,78-80,82]. Lesion conspicuity may be increased with the addition of fat suppression to fluid-sensitive images; however, fat-suppressed imaging decreases the variation in tumor signal intensities that may be useful in tissue characterization. T2-weighted sequences can be performed with or without fat suppression, or Short Tau Inversion Recovery (STIR) sequences can be used [78,79,82]. A combination of techniques may prove advantageous. For example, the transverse images may be obtained without fat suppression and the long axis planes (sagittal and/or coronal images) performed with fat suppression or STIR sequences. The exact TR, TE, and flip angle chosen will depend on the field strength of the magnet and the relative contrast weighting desired [90-92].

Various techniques may be used to minimize the MR artifacts that can reduce imaging quality. Wraparound artifact, including that originating from signal received from other parts of the body, can be reduced by phase using oversampling, by switching the phase and frequency readout directions, by presaturation pulses, or by using RF shielding. Truncation (Gibbs) artifacts may obscure or mimic intralesional detail and can be reduced by changing

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the phase-encoding direction. Involuntary patient motion is best controlled by ensuring patient comfort combined
with gentle immobilization or sedation when necessary and often requires sedation or general anesthesia for young
children [63,93]. Desensitizing “practice runs” orchestrated by a child life specialist may also be effective for
children [70] as well as the use of MR video goggles. Use of MR systems and coils that provide a high SNR, such
as high-field (3T) MR systems and multichannel coils, with or without parallel imaging and/or compressed
sensing, can reduce overall scan duration and individual sequence scan times and may help reduce bulk motion
artifacts and patient discomfort [73,74]. Motion artifact can also be reduced by sampling k-space in a rotating
fashion, utilizing radially directed imaging planes [94]. Flowing blood can produce ghosting artifacts, which can
be reduced with presaturation pulses or the use of gradient moment nulling [63,93].

In many cases, it may be advantageous to administer a gadolinium-based IV contrast agent [95-101]. IV contrast
may be helpful to differentiate cysts from solid masses and may provide additional details of the imaging features
of bone and soft-tissue masses [82,96,97]. Subtracting the precontrast images from the postcontrast images may be
beneficial to show subtle areas of enhancement and to distinguish enhancement from adjacent fat or hemorrhage
[102]. Fast, multiphase dynamic contrast-enhanced imaging can provide analysis of tumor perfusion kinetics,
including parametric perfusion data, that may help to distinguish malignant from benign tumors [103-105], to stage
tumors and response to therapy [49,106-108], to determine an optimal site for biopsy [108] improve tumor detection,
or evaluate potential extension of tumor cells along related fascial planes [109]. The decision to use IV contrast
should be based on medical appropriateness.

Follow-up MR imaging of musculoskeletal tumors is generally performed using sequences similar to those used for
initial diagnosis, including T1-weighted and T2-weighted images [53,54]. Because local recurrence may often
appear similar to the original tumor, MRI following treatment or surgery should ideally be interpreted with
comparison to prior MRI examinations, including the preoperative or pretreatment MRI, if available. Follow-up MR examinations of patients with previously treated soft-tissue tumors often benefit from the addition
of IV contrast agents gadolinium chelates [52,53]. Protocols for follow-up and interpretation of MRI findings vary
depending on the type of tumor, the therapeutic methods used, and the aggressiveness of the tumor (see the ACR
Appropriateness Criteria®, Follow-up of Malignant or Aggressive Musculoskeletal Tumors [110]).

MR spectroscopy may be useful in gauging therapy response and tumor staging [111-116]. It may also be used to
detect certain metabolites in tumors to help in lesion characterization [113,117-122], but caution should be used in
interpretation because some metabolites that were thought to be specific may not be (eg, choline for malignant
tumors [123]). Newer imaging sequences employing isotropic or near-isotropic 3-D sequences (eg, IDEAL,
SPACE, CUBEm, etc) can produce images with shorter scan duration but have not been thoroughly evaluated for
imaging of musculoskeletal tumors at this time. Whole-body MR screening examinations can be useful both for
staging of disseminated or hematologic tumors, such as multiple myeloma, and to limit radiation dose to pediatric
and pregnant patients [124-129].

For interpretation, the images are most commonly viewed electronically on a workstation but may also be printed
on film or viewed on a workstation. If hard copy viewing is used, some practices may film the images with
magnified or narrowed window settings, but this can be left to local preferences. MR examinations in patients with
suspected tumors should be read cautiously and preferably in conjunction with available radiographs. Since local
recurrence may often appear similar to the original tumor, MR imaging following treatment or surgery should
ideally be interpreted with comparison to prior MRI exams, including the preoperative or pretreatment MRI, if
available. There are many pitfalls and artifacts that can suggest that a nonneoplastic mass is an aggressive tumor or
that a malignant tumor appears to be a benign lesion based on the MR appearance alone [82,130,131]. Furthermore,
imaging artifacts can also contribute to incorrect staging of tumors [82,130,131].
V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [132].

The report should address the presence or absence of a mass, the size of the lesion and description of anatomic extent, its composition (hemorrhage, necrosis, etc), signal intensity, and enhancement characteristics. When imaging is sufficiently characteristic, a diagnosis or differential diagnosis should be provided. A description of the anatomic location of a tumor, including its intracompartmental and extracompartmental extent, as well as its relationships to adjacent major muscles, vessels, and nerves, will contribute to the tumor’s grading and staging. The presence or absence of fascial extension of tumor should be described, which will contribute to the surgical resection planning. The presence or absence of any regional lymphadenopathy or skip lesions should be noted.

VI. EQUIPMENT SPECIFICATIONS

Equipment monitoring should be in accordance with the ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment [133].

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 and/or MR safety officer. Guidelines should be provided that deal with potential hazards associated with MRI examination to the patient as well as to others in the immediate area [134-136]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [134-137].

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 RF power deposition (specific absorption rate), and maximum acoustic noise levels.

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

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

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [66], the ACR Guidance Document on MR Safe Practices: 2013 [138], and the ACR Manual on Contrast Media [68].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [135,136].
ACKNOWLEDGEMENTS

This practice parameter was revised according to the process described under the heading The Process for Developing ACR Practice Parameters and Technical Standards on the ACR website (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) by the Committee on Body Imaging (Musculoskeletal) of the Commission on Body Imaging and by the Committee on Practice Parameters – Pediatric Radiology of the Commission on Pediatric Radiology, in collaboration with the SPR and the SSR.

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*Parameters and standards are published annually with an effective date of October 1 in the year in which amended, revised, or approved by the ACR Council. For parameters and standards published before 1999, the effective date was January 1 following the year in which the parameter or standard was amended, revised, or approved by the ACR Council.

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Amended 2006 (Resolution 35)

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Amended 2014 (Resolution 39)

Revised 2015 (Resolution 5)
NOT FOR PUBLICATION, QUOTATION, OR CITATION

RESOLUTION NO. 31

BE IT RESOLVED,
that the American College of Radiology adopt the ACR–SPR–SSR Practice Parameter for the Performance and Interpretation of Magnetic Resonance Imaging (MRI) of the Knee

Sponsored By: ACR Council Steering Committee

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

The American College of Radiology will periodically define new practice 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.

Revised 2015 (Resolution 6) *

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

PREAMBLE

These practice parameters are 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. For these reasons and those set forth below, the American College of Radiology cautions 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 physician or medical physicist in light of all the circumstances presented. Thus, an approach that differs from the practice parameters, 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 practice parameters when, in the reasonable judgment of the practitioner, such course of action is indicated by the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of the practice parameters. However, a practitioner who employs an approach

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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 of Pediatric Radiology (SPR), and the Society of Skeletal Radiology (SSR).

Magnetic resonance imaging (MRI) is a proven imaging modality for the detection, evaluation, assessment, staging, and follow-up of disorders of the knee. Properly performed and interpreted, MRI not only contributes to diagnosis but also serves as an important guide to treatment planning and prognostication. However, it should be performed only for a valid medical reason and after careful consideration of alternative imaging modalities. Radiographs will be the first imaging test performed for most suspected suspicious bone and soft-tissue abnormalities of the knee and will often suffice to diagnose or exclude an abnormality or direct further imaging workup. Computed Tomography (CT) provides better details of bone trabeculae, cortex, and periosteal new bone formation compared to the radiographs. With multiplanar reformatting capabilities, CT can be helpful to demonstrate radiographically occult fracture or osseous loose body within the joint [1]. Ultrasound can evaluate the extra-articular soft tissues around the knee, including tendons and bursae, assess for joint effusion, and document synovitis [1]. In children, who often have an abundance of unossified epiphyseal cartilage and perarticular soft tissues that can limit the clinical assessment, ultrasound is particularly helpful to confirm or exclude a clinically suspected joint effusion. Bone scintigraphy is often used when radiographically occult bone disease is suspected or to screen the entire skeleton for conditions such as metastases. Other nuclear medicine (NM) examinations have a role for specific clinical scenarios (eg, a labeled white blood cell study or Positron Emission Tomography (PET)/CT for suspected osteomyelitis). Dual-energy CT techniques have also been used in evaluation of crystalline arthropathy, such as gout [2]. Computed tomography can show detailed bone trabecular and cortical anatomy, whereas sonography may be appropriate to examine superficial soft tissue structures around the knee, such as tendons, bursae, and joint effusion. Lastly, arthroscopy provides a detailed examination of the internal structures of the knee joint, allowing the surgeon to treat as well as to diagnose many internal derangements.

Although MRI is a sensitive, noninvasive diagnostic test for detecting anatomic abnormalities of the knee, its findings may be misleading if not closely correlated with radiographs, clinical history, symptomatology, physical examination, and radiographs physiologic tests. Adherence to the following practice parameters will enhance the probability of detecting such abnormalities.

II. INDICATIONS

A. Primary indications for MRI of the knee include, but are not limited to, the diagnosis, exclusion, and grading of suspected:

1. Meniscal disorders: nondisplaced and displaced tears, discoid menisci, parameniscal cysts; complications of meniscal surgery \[3-11\]
2. Ligament abnormalities: cruciate and collateral sprains and tears; complications following ligament repair or reconstruction † [12-17]
3. Extensor mechanism abnormalities: quadriceps and patellar tendon degeneration, partial and complete tears; patellar fractures and sleeve avulsions; and retinacular sprains and tears [18-22]
4. Osteochondral abnormalities: osteochondral fractures, osteochondritis dissecans, and treated osteochondral defects † [23-25]
5. Articular cartilage abnormalities: degeneration, chondromalacia, chondral fissures, fractures, flaps, and separations; complications following chondral surgery † [26-33]
6. Loose bodies and impinging structures: Hoffa syndrome, patellar and quadriceps impingement [34]
7. Evaluation of prefemoral fat pad in appropriate clinical scenarios [35]
8. Synovial-based disorders: synovitis, bursitis, symptomatic plicae³, and popliteal cysts* [36-39]
9. Osseous abnormalities: osteonecrosis, marrow edema syndromes, stress fractures, radiographically occult fractures, physeal and transphyseal injuries, and transphyseal bar evaluation, osseous and nonosseous and tethering mapping for growth disturbance and limb-length discrepancy* [40-43]
10. Muscle and tendon disorders: strains, partial and complete tears, tendonitis, tendinopathy, inflammation, and ischemia [44,45]
11. Iliotibial band friction syndrome [46,47]
12. Neoplasms of bone, joint, or soft tissue* [48,49]
13. Infections of bone, joint, or soft tissue* [50,51]
14. Congenital and developmental conditions: Blount disease, dysplasia, normal variants* [52,53]
15. Vascular conditions: popliteal artery entrapment, aneurysm, stenosis, occlusion, cystic adventitial disease* [54-56]
16. Neurologic conditions: common peroneal or tibial nerve traumatic injury, entrapment, compression injury, denervation, and peripheral neuropathy* [57]

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

1. Arthritides: inflammatory, infectious, neuropathic, degenerative, crystal-induced, posttraumatic* [58-62]
2. Primary and secondary bone and soft-tissue tumors* [48,49]
3. Fractures and dislocations [63-65]

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

1. Prolonged, refractory, or unexplained knee pain [66]
2. Acute knee trauma [67]
3. Mechanical knee symptoms: catching, locking, differentiating a stiff versus a locked knee (fixed extension block), limited or painful range of motion, snapping, crepitus† [68,69]
4. Tibiofemoral and/or patellofemoral instability: chronic, recurrent, subacute, acute dislocation, and subluxation* [64,65,70-72]
5. Tibiofemoral malalignment and/or patellofemoral malalignment or maltracking [73-75]
6. Swelling, enlargement, mass, or atrophy*
7. Patients for whom diagnostic or therapeutic arthroscopy is planned † [66,76-81]
8. Patients with recurrent, residual, or new symptoms following knee surgery† [10,13,14,27,82-86]
9. Patients with selected complications following knee arthroplasty [87,88] using appropriate metal artifact reduction strategies [89]

* Conditions in which intravenous contrast may be useful.
† Conditions in which intra-articular contrast (performed by direct intra-articular injection or indirect joint opacification following intravenous administration) may be useful.
III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [90].

IV. SPECIFICATIONS OF THE EXAMINATION

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

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

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

The supervising physician must have 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 the 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 phone for consultation. Patients must be screened and interviewed by qualified personnel 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–SPR Practice Parameter for the Use of Intravascular Contrast Media [91]).

Patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of conscious sedation may be needed to achieve a successful examination. If moderate sedation is necessary, refer to the ACR–SIR Practice Parameter for Sedation/Analgesia [92].

B. Facility Requirements

Appropriate emergency equipment and medications must be immediately available to treat adverse reactions associated with administered medications. The equipment and medications should be monitored for inventory and
drug expiration dates on a regular basis. The equipment, medications, and other emergency support must also be appropriate for the range of ages and sizes in the patient population.

C. Examination Technique

Diagnostic-quality knee MRI is possible using a variety of magnet designs (closed-bore whole-body, open whole-body, dedicated extremity) and field strengths [5, 7, 93-94]. Regardless of magnet design, a local coil is mandatory to maximize signal-to-noise ratio (SNR). Typically, a cylindrical coil (often called an “extremity” or “knee” coil) surrounds the knee. Newer multichannel knee coils or flexible surface coils containing 8 or more coil elements will further increase SNRs and are required when using techniques like parallel imaging, which can be used to increase spatial resolution and/or decrease the time of the scan [95]. Occasionally, a very large extremity may require a slightly larger coil (a posterior neck coil, for example), but every attempt should be made to ensure that the size of the coil closely matches that of the knee circumference [96]. In children with smaller knee joints, a multichannel flexible surface coil may provide superior SNR than a one-size-fits-all dedicated knee coil. The coil’s placement should allow imaging of the major structures in and around the knee; at times, repositioning the coil and/or extremity will be necessary to demonstrate additional pertinent anatomy.

Certain MR systems (eg, those using low-field-strength magnets) have inherently lower SNRs than others. When using such a system to perform knee MRI, other imaging parameters, such as the receiver bandwidth and number of acquisitions, will require modification to ensure adequate spatial and contrast resolution for confident diagnosis, often at the expense of longer examination times [97-99]. It may also be more difficult to achieve uniform chemical fat suppression on low-field-strength systems, necessitating the use of Dixon [100] or short tau inversion recovery (STIR) techniques. Other systems may be more prone to imaging artifacts (eg, chemical shift artifact on high-field magnets), again necessitating that imaging parameters, such as readout bandwidth, be modified to ensure that these artifacts do not detract from the diagnostic quality of the resultant images [5]. For some indications, like high-resolution imaging of articular cartilage, images obtained with a low-field system will be of lower quality compared with those acquired on a high-field system [94, 100-104]. Detection of other conditions, such as cruciate ligament tears, is less dependent on magnet strength and design.

Typically, the patient is positioned supine with the affected knee completely or nearly completely extended in the coil. Mild external rotation of the leg is often comfortable for the patient. Gentle immobilization of the extremity and use of comfort measures for the entire body will help to reduce involuntary patient motion and resultant artifacts.

Knee MRI examinations usually include images acquired in appropriate transverse (axial), sagittal, and coronal imaging planes [105, 106]. Multiplanar images can be acquired directly or reconstructed electronically from volumetric data acquired in one imaging plane. Some practices obtain standard sagittal and coronal images orthogonal to the anatomic planes of the knee, whereas others may angle the planes to better identify specific anatomic structures, such as the posterolateral corner ligaments [107, 108]. The coverage should include all the anterior, posterior, medial, and lateral supporting structures of the knee, though not all structures need to be included in every imaging plane. Superiorly, the distal aspects of the quadriceps tendon and suprapatellar joint recess should be included. The distal insertions of the patellar tendon and pes anserinus tendons should be included inferiorly [109].

The field of view (FOV) should be tailored to the size of the knee and the structures being examined, but for the standard sequences, the FOV should be 16 cm or smaller. Occasionally, additional sequences with a larger FOV will be appropriate to completely evaluate a detected or suspected abnormality completely, for example, in the extensor mechanism or bone marrow. Slice thickness in the sagittal and coronal planes of 4 mm or less is necessary to demonstrate subtle meniscal pathology, but even thinner sections may be advantageous for detailed analysis of other structures, such as the articular cartilage. An interslice gap can decrease signal loss due to cross talk [110] but should typically be no more than 33% to 50% of the slice width and should not impair complete visualization of the intra-articular structures. In younger children, the imaged structures are often smaller in size; thus, smaller...
FOV (<14 cm), thinner slice thickness (2.5-3.5 mm), and lower interslice gap (<20%) are often preferred. The imaging matrix should balance intravoxel SNR with desired in-plane spatial resolution and reduction of truncation artifacts but should be at least 192 x 196 steps in the phase direction and 256 steps in the frequency direction for 2-D imaging. Three-dimensional sequences with near isotropic voxels allow for multiplanar reconstructions from a single acquisition [111-113].

Knee MRI uses a wide variety of pulse sequences [96]. Many practices tailor the specifics of each study to optimize the examination for specific clinical questions. The choice of sequences will vary because of local preferences and/or available equipment or software limitations. Spin-echo, fast (turbo) spin-echo (FSE), and gradient-recalled sequences each may have a role for knee MRI. A typical imaging protocol will be composed of one or more of these pulse sequence types. The exact repetition time (TR), echo time (TE), and flip angle chosen will depend on the field strength of the magnet and the relative contrast weighting desired.

Fast (turbo) spin-echo images with a relatively short effective TE are most frequently used to examine the menisci. A short-echo train short-interecho spacing, and/or tailored radiofrequency pulses can reduce potential blurring. The literature supports that, for FSE and meniscal tears, a short effective TE, short echo train length, and narrow echo spacing reduces blurring and is “equivalent” to conventional spin echo (CSE). Two-dimensional and 3-D gradient-recalled images can also demonstrate meniscal disorders [109,111,113]. To show ligament pathology, water-sensitive images obtained using conventional or FSE long-TE sequences [114,115] or T2*-weighted gradient-recalled sequences [113] may be used. Including at least one plane of T1-weighted sequences is useful for characterizing marrow abnormalities [116], various stages of hemorrhage [117], and muscle pathology [44,45]. Additionally, T1-weighted images (often with fat suppression) are used after IV administration of gadolinium-based contrast agents to show tissue enhancement [118].

Imaging of articular cartilage disorders can be accomplished with a variety of pulse sequences [27,29], including FSE proton density–weighted, intermediate-weighted, T2-weighted sequences with or without fat suppression [26-28,119,120], or 3-D gradient-recalled sequences, or 3-D FSE sequences [113,121-123]. Newer sequences that may be advantageous to assess articular cartilage include modified steady-state free precession or spoiled gradient-recalled sequences that create separate water and lipid images [124-126] that selectively excite water protons [127,128] or that average 2 separate echoes to increase T2 weighting [129,130]. In contrast to these traditional pulse sequences that are optimized to detect sites of morphologic change, quantitative cartilage imaging tools such as T1-rho or T2 relaxation time mapping can detect microstructural changes within the cartilage matrix, which occur prior to irreversible damage [32,33].

In skeletally immature children with a history of knee trauma with that involved the transphyseal physis, development of physeal bar is a complication that can lead to growth disturbances, angular deformities, and limb length discrepancies. Extension resulting ingrowth disturbance and limb length discrepancy The resulting deformity depends on several factors: the nature and severity of the initial insult, residual growth potential, location and extent of physeal involvement. The latter can be “mapped” and better quantified using a 3-D fat-suppressed spoiled gradient-recalled echo sequence physeal bar evaluation and mapping can be performed by using 3-D fat-suppressed spoiled gradient-recalled echo sequence. Additional specialty sequences have been advocated for cartilage imaging and may require product licenses and postprocessing specialized equipment and software. In addition, MR artrography may be useful for evaluating articular surfaces in the knee [87], especially following articular cartilage transplantation [128], or on low-field systems where many of the newer sequences are not available [131]. IV contrast-enhanced MRI administration is typically recommended for the diagnosis of cartilage involvement in infants and young children because infection manifests differently than in older children. In infants and young children, skeletal infection particularly (S. aureus) has a propensity for involvement of the unossified cartilage, which may be occult on unenhanced MRI sequences.[123].

Suppressing the signal from fat may enhance the diagnostic yield of some pulse sequences [96]. Fat suppression techniques include spectral suppression of water protons, a phase-dependent method, such as the Dixon method or
The latter 2 techniques may be necessary on low-field systems. Methods also exist for generating separate water and lipid images [124-126] or for selectively exciting water protons, which essentially nulls the contribution of fat in the final images [127,128]. Fat suppression is useful for identifying marrow abnormalities [132,133] and may be a useful adjunct when performing MR arthrography [14,84] or when FSE sequences are used to examine the menisci, ligaments, and articular surfaces of the knee [26,119,135]. It may be possible to shorten the time required for a knee MR examination without compromising diagnostic yield when using high field-strength systems and multichannel surface coils [137]. Reduced sampling of k-space using parallel imaging, Multichannel local coils allow the use of parallel imaging compressed sensing, and machine-learning acceleration techniques can which decrease acquisition times for individual pulse sequences [95,112,125,138,139]. Additionally, high-resolution 3-D near-isotropic imaging with near-isotropic voxels is possible using with newer gradient-recalled and FSE sequences on the latest generation MR systems [111,112,126]. Using these methods, a single volumetric acquisition obtained and reconstructed into multiple imaging planes will decrease can eliminate the need to obtain multiplanar 2-D sequences and thereby decrease the total number of pulse sequences needed. Synthetic MRI of the knee may allow a single sequence to provide T1-, proton density-, and T2-weighted images to also shorten the overall scan times [140].

Additional imaging techniques may have a role for specific knee disorders. Direct and indirect MR arthrography may be beneficial for various internal knee derangements and for imaging postoperative conditions [14,24,34,83,84,87,141]. In cases in which the etiology of a focal marrow lesion is uncertain, comparing the lesion signal intensity on a pair of gradient-recalled images with TE values chosen so that fat and water protons are in phase and out of phase, respectively, may help show fat within the lesion, thus supporting benignity [142]. Various techniques are useful to reduce artifacts that can degrade imaging quality. Wraparound artifact, including that originating from signal received from the contralateral knee, can be reduced by phase oversampling, by swapping the phase and frequency orientations, or by using radiofrequency shielding between the knees [143,144]. Truncation (Gibbs) artifacts may obscure or mimic meniscal tears; changing the phase-encoding direction or increasing the imaging matrix will reduce this artifact [143,145]. Ensuring patient comfort combined with gentle immobilization when necessary may reduce involuntary patient motion [96]. Presaturation pulses or the use of gradient moment nulling will reduce ghosting artifacts from flowing blood [143,146]. Chemical shift artifact is more severe at higher field strengths and may necessitate an increase in the receiver bandwidth [5,147]. Susceptibility artifacts, which originate from local field heterogeneity, are also more severe at higher field strengths and when using gradient-recalled pulse sequences. Avoiding gradient-echo imaging and reducing the voxel size by increasing the imaging matrix and/or decreasing the slice thickness and FOV will help reduce the magnitude of susceptibility artifacts [143].

In knees containing large metallic implants, a combination of longer echo trains, increased receiver bandwidth, decreased FOV, increased matrix size in the frequency-encoding direction, and control of the phase and frequency encoding directions will reduce, but typically not completely eliminate, metal artifacts [83,88]. Vendor specific pulse sequences have been developed which can further reduce metal artifacts [148-150]. The term “metal artifact reduction sequences” (MARS) has been applied to such strategies. Lower magnet strength (1.5T rather than 3T) and use of nonfat-suppressed pulse sequences is preferred. In the presence of metal hardware, STIR imaging is often preferred over spectral fat suppression techniques, and gradient echo (GRE) techniques should be avoided [151,152]. 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 (FDA), such as the intra-articular injection of gadolinium chelates (direct MR arthrography) [153-155], can be considered when they are judged to be medically appropriate.
V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [156].

The report should address the condition of the menisci, major ligaments, articular cartilage, osseous structures, and extensor mechanism. In selected cases, a description of findings in the neurovascular structures, muscles and tendons, synovium, and cortical bone would be appropriate.

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 [157-160]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [157-160].

VI. 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 [139].

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

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

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [90], the ACR Guidance Document on MR Safe Practices: 2003 [161], and the ACR Manual on Contrast Media [162].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [158,159].

ACKNOWLEDGEMENTS

This practice parameter was revised according to the process described under the heading The Process for Developing ACR Practice Parameters and Technical Standards on the ACR website (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) by the Committee on Body Imaging (Musculoskeletal) of the Commission on Body Imaging and by the Committee on Practice Parameters – Pediatric Radiology of the Commission on Pediatric Radiology, in collaboration with the SPR and the SSR.
Collaborative Committee
Members represent their societies in the initial and final revision of this practice parameter.

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PRACTICE PARAMETER 9 MRI Knee
2020 Resolution No. 31
REFERENCES


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*Practice parameters and technical standards are published annually with an effective date of October 1 in the year in which amended, revised, or approved by the ACR Council. For practice parameters and technical standards published before 1999, the effective date was January 1 following the year in which the practice parameter or technical standard was amended, revised, or approved by the ACR Council.

Development Chronology for this Practice Parameter

2005 (Resolution 9)
Amended 2006 (Resolution 35)
Revised 2010 (Resolution 19)
Amended 2014 (Resolution 39)
Revised 2015 (Resolution 6)
BE IT RESOLVED,
that the American College of Radiology adopt the ACR–SPR–SSR Practice Parameter for the Performance and Interpretation of Magnetic Resonance Imaging (MRI) of the Shoulder

Sponsored By: ACR Council Steering Committee

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

The American College of Radiology will periodically define new practice 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.

Revised 2015 (Resolution 7) *

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

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. 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 in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication.

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.
of this document. However, a practitioner who employs an approach substantially different from the guidance in this document 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 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 sole purpose of this document is to assist practitioners in achieving this objective.

I. INTRODUCTION

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

Magnetic resonance imaging (MRI) is an established and proven imaging modality for the detection, evaluation, assessment, staging, and follow-up of disorders of the shoulder. Properly performed and interpreted, MRI contributes not only to diagnosis but also to treatment planning and prognostication. However, it should be performed only for a valid medical reason and after careful consideration of alternative diagnostic modalities. MRI of the shoulder may be performed without contrast, following intra-articular contrast injection (“direct” MR arthrography) to increase conspicuity of intra-articular abnormalities, or with intravenous (IV) contrast to identify hyperemic lesions or to create “indirect” arthrographic images by enhancing synovial-lined structures and their contents.

An analysis of the strengths and potential risks of MRI and other diagnostic modalities should be weighed against their suitability for specific patients and particular clinical conditions. **Computed tomography (CT) is used to evaluate the bone integrity of the glenoid fossa and humerus and the alignment and congruence of the glenohumeral joint [1]. When combined with arthrography, CT can also be used for evaluating the labrum, articular cartilage, and loose bodies [2].** **Sonography can be used to evaluate the rotator cuff and biceps tendon and has the advantage of imaging during physiologic motion [3-7].** Radiographs are usually the first imaging test performed for most suspected abnormalities in the shoulder and will often suffice to diagnose or exclude an abnormality or to direct further imaging evaluation. Radionuclide bone scanning can screen the entire skeleton in addition to the shoulder for radiographically occult bone disease, such as metastases. Other nuclear medicine examinations have a role for specific clinical scenarios (eg, a labeled white blood cell study for suspected osteomyelitis). Conventional single-contrast or double-contrast arthrography can accurately depict most articular-surface and full-thickness tears of the rotator cuff [8,9]. Sonography can be used to evaluate the rotator cuff and biceps tendon and has the advantage of imaging during physiologic motion [3-7]. **Ultrasound and fluoroscopy can be used to guide arthrographic injection [10,11].** **Computed tomography (CT) is used to evaluate the bone integrity of the glenoid fossa and humerus and the alignment and congruence of the glenohumeral joint [1]. When combined with arthrography, CT can also be used for evaluating the labrum, articular cartilage, and loose bodies [2].** Lastly, arthroscopy provides a detailed examination of the internal structures of the shoulder, allowing the surgeon to treat as well as diagnose many internal derangements.

Although MRI is one of the most sensitive diagnostic tests for detecting anatomic abnormalities of the extremities, findings may be misleading if not closely correlated with other imaging studies, clinical history, clinical examination, and physiologic tests. Adherence to the following practice parameter will enhance the probability of accurately diagnosing such abnormalities.
II. INDICATIONS

A. Primary indications for MRI of the shoulder include, but are not limited to, diagnosis, exclusion, and grading of suspected:

1. Rotator cuff tendon abnormalities: massive, full-thickness, partial-thickness, and recurrent (postoperative) tears, tendinopathy, calcific tendinitis, and cuff tear arthropathy† [12-22]
2. Disorders of the long head of the biceps brachii: full-thickness, partial-thickness, and recurrent (postoperative) tears, tendinopathy, calcific tendinitis, subluxation, and dislocation† [10,11,20,23-25]
3. Conditions affecting the supraspinatus outlet: acromial shape, os acromiale, subacromial spurs, acromioclavicular joint disorders, coracoacromial ligament integrity, subacromial bursitis† [15,26-29]
4. Labral abnormalities: tears, cysts, and degeneration, and tears, including superior labrum anterior posterior (SLAP) lesions, Bankart lesions and their variants, and recurrent (postoperative) labral tears† [2,20,30-44]
5. Abnormalities of the rotator interval and biceps pulley† [23,45,46]
6. Muscle disorders affecting the shoulder girdle: atrophy, hypertrophy, denervation, masses, and injuries [18,22,47-53]
7. Glenohumeral chondral and osteochondral abnormalities: osteochondral fractures and osteochondritis dissecans, articular cartilage degeneration, fissures, fractures, flaps, and separations† [54-56]
8. Intra-articular bodies†
9. Synovial-based disorders: synovitis, bursitis, metaplasia, and neoplasia* [57,58]
10. Marrow abnormalities: osteonecrosis, marrow replacement and edema syndromes, and osseous contusion and stress fractures* [59]
11. Neoplasms, masses, and cysts of bone, joint, or soft tissue* [29,39,60]
12. Infections of bone, joint, or soft tissue* [61-63]
13. Congenital and developmental conditions, including dysplasia and normal variants* [64-67]
14. Vascular conditions: entrapment, aneurysm, stenosis, and occlusion* [68]
15. Neurologic conditions: entrapment, compression, masses, and peripheral neuritis* [37,42,69]

16. Pathology in the shoulder following arthroplasty [70]

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

1. Arthritides: inflammatory, infectious, neuropathic, degenerative, crystal-induced, posttraumatic* [29,71,72]
2. Frozen shoulder (adhesive capsulitis)* [45]
3. Primary and secondary bone and soft-tissue tumors* [60]
4. Fractures and dislocations [26,73,74]

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

1. Prolonged, refractory, or unexplained shoulder pain*†
2. Acute shoulder trauma [26,74]
3. Impingement syndromes: subacromial, subcoracoid, internal† [15,27,28,75-78]
4. Glenohumeral instability: chronic, recurrent, subacute, and acute dislocation and subluxation† [43,64,74,79-81]
5. Shoulder symptoms in the overhead motion or throwing-athlete† [82-84]

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2 * Conditions in which IV contrast may be useful.
3 †Conditions in which intra-articular contrast (performed by direct intra-articular injection or indirect joint opacification following IV administration) may be useful.
6. Mechanical shoulder symptoms: catching, locking, snapping, crepitus†
7. Limited or painful range of motion
8. Swelling, enlargement, mass, or atrophy* [39]
9. Patients for whom diagnostic or therapeutic arthroscopy is planned†
10. Patients with recurrent, residual, or new symptoms following shoulder surgery† [14,18,20,22,51,85,86]

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [87].

The interpreting physician needs a thorough knowledge and understanding of the anatomy of the shoulder, including the numerous normal variations in the glenohumeral capsular and labral configurations and their corresponding MRI appearances.

IV. SPECIFICATIONS OF THE EXAMINATION

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

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

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

The supervising physician must have complete understanding of the indications, risks, and benefits of the examination as well as alternative imaging procedures. The physician must be familiar with the 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 phone 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.

Certain indications require administration of IV contrast media. IV contrast enhancement should be performed using appropriate injection protocols and in accordance with the institution’s policy on IV contrast utilization. (See the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [88].)
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 Sedation/Analgesia [89].

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

Shoulder MRI can be performed using a variety of magnet designs (closed or open) and field strengths (low, medium, or high) [16,38,90-94]. Because the inherent signal-to-noise ratio (SNR) is reduced with lower field strength MR systems, imaging practice parameters may require modifications. With lower field strength systems, for example, the number of acquisitions can be increased at the expense of longer imaging times and increased risk of involuntary patient motion [90,92,95,96]. Alternatively, the voxel size can be increased (by a combination of larger field of view (FOV), thicker slices, and/or decreased matrix) at the expense of spatial resolution [92,93,96,97]. Fat-suppression techniques that rely on the difference between fat and water frequencies (chemical shifts) are unreliable at low field strength, and substituting short tau inversion recovery (STIR) images may be necessary [90]. Even when the imaging protocol is optimized for shoulder imaging on a low-field open system, subjective image quality will likely be inferior to that obtained with a high-field system [93,96]. Various investigators using different equipment and scanning protocols have reached contradictory conclusions regarding the diagnostic performance of low field strength MR scanners for shoulder disorders. Some studies have found that the accuracy for complete and partial rotator cuff tears and for labral abnormalities is not significantly different for open, low-field and closed, high-field systems, with careful attention to technique [91,93,94,98]. MR arthrography can further enhance the diagnostic yield for shoulder MRI performed on low field strength systems [90,96]. Other investigators have found lower accuracy for evaluating disorders like SLAP tears, capsular abnormalities, and small rotator cuff tears with specific low-field systems compared with high-field ones [97-99].

Regardless of system design, a local coil is mandatory to maximize the SNR. Commercially available coils appropriate for shoulder imaging include single-loop contoured or flat-surface coils [100,101], paired coils in a Helmholtz configuration [36,102], circularly polarized flexible coils [97], solenoid coils [92], and phased array designs [31,41].

Patients are positioned supine with the affected arm at the side. For evaluation of the rotator cuff and anterior labrum, internal rotation of the arm should be avoided [81,101,103]. When MR arthrography is performed, repositioning the affected arm into the abduction external rotation (ABER) position may increase sensitivity for anterior inferior labral tears [2,32,104,105] and may increase accuracy for rotator cuff tears, especially partial-thickness undersurface tears [106-108]. Images with the patient’s arm in this position are obtained parallel to the humeral shaft prescribed from a coronal localizer image [32].

Shoulder MR examinations usually include images acquired in the transverse (axial), oblique sagittal, and oblique coronal planes. The oblique sagittal and oblique coronal planes sections are prescribed orthogonal to each other using either the glenoid fossa or the supraspinatus tendon as reference anatomic landmarks. Evaluation of the rotator cuff is performed using both oblique coronal and oblique sagittal images [109]. Prescribing the oblique sagittal images in the frontal plane so that they are perpendicular to the distal supraspinatus tendon may be useful for identifying subtle partial-thickness rotator cuff tears [110]. The oblique coronal and oblique sagittal images can be used to evaluate the labrum, biceps tendon, acromial anatomy, supraspinatus outlet, acromioclavicular joint, and rotator interval [23,27,46]. The transverse images best display the subscapularis tendon, the long head of the biceps
tendon in the intertubercular groove, glenohumeral articulation, and the glenoid labrum [2,24,33,36]. Transverse images may aid in detecting anterior rotator cuff tears. The use of multiple imaging planes increases the accuracy of detecting subscapularis tendon tears [111]. Radial imaging can be used to evaluate the rotator cuff, especially the subscapularis tendon, long head biceps tendon, rotator interval, and for the glenoid labrum has been reported [112-114], but it is not widely used.

FOV should be tailored to the size of the patient and the structures being examined, but for the standard sequences, the FOV should be 16 cm or smaller on medium-field and high-field units. Larger FOVs and smaller imaging matrices may be necessary on lower field systems but will result in lower spatial resolution, limiting the sensitivity of the examination [93,96]. Occasionally, additional sequences with a larger FOV will be appropriate to more fully evaluate a specific suspected or detected abnormality, for example, in the scapulothoracic bursitis articulation or in the anterior chest wall, ie, the pectoralis major tear in the anterior chest wall muscle. Slice thickness in the oblique sagittal and oblique coronal planes of 4 mm or less is needed to demonstrate subtle tendon pathology, but thinner sections may be advantageous for detailed analysis of other structures, such as the labrum and articular cartilage. An interslice gap may be selected to decrease signal loss due to cross talk [115] but should be no more than 33% of the slice width. Two interleaved scans may allow imaging without gaps at the expense of an increase in scan time. The imaging matrix should balance intravoxel SNR with desired in-plane spatial resolution and reduction of truncation artifacts but should be at least 160 steps in the phase direction and 256 steps in the frequency direction for 2-D imaging, other than when imaging a large tumor. Some practices may use higher imaging matrices (up to 512 steps) to increase spatial resolution for diagnosing labral lesions, including SLAP tears [31,33].

Shoulder MRI can be performed with a wide variety of pulse sequences [116]. The choice of sequences can be tailored to optimize the examination for specific clinical questions and may vary because of local preferences. Conventional spin-echo, fast (turbo) spin-echo, and gradient-recalled sequences have all been used successfully for shoulder MRI. A typical imaging protocol will be composed of one or more of these pulse sequence types. The prescribed repetition time (TR), echo time (TE), and flip angle will depend on the field strength of the magnet and the relative contrast weighting desired.

Fluid-sensitive sequences, such as long-TR/moderate-to-long TE (proton-density weighted or T2-weighted) images with or without fat suppression or STIR images, are typically used for evaluating the rotator cuff, with either conventional spin-echo or fast (turbo) spin-echo technique [21,117-119]. T2*-weighted gradient-echo recalled sequences can also be used for diagnosing rotator cuff abnormalities but probably with lower accuracy compared with conventional spin-echo or fast spin-echo sequences [120,121]. To show labral abnormalities, long-TR (proton-density weighted or T2-weighted) spin-echo or fast spin-echo images or T2*-weighted gradient-recalled images are typically performed [33,36,122], although gradient-echo imaging may be less accurate when used in isolation for anterior labrum abnormalities compared with conventional spin-echo or fast spin-echo imaging [101]. Lesions of the superior labrum such as SLAP tears can be visualized on fast spin-echo, long-TR images [31,41,114], or with MR arthrography [30,34]. T1-weighted sequences (short TR/short TE) have a role in characterizing marrow abnormalities [73], various stages of hemorrhage [123,124], and muscle pathology [22,47,48,51,52]. T1-weighted sequences have been used to characterize the degree of rotator cuff muscle atrophy in patients with tendon tears, which can be used to predict patient outcomes after surgery [125-129]. Additional imaging methods, such as spectroscopic MRI, T2-mapping, and 3-D Volume-interpolated Breathhold Examination (VIBE) with 2-point Dixon, have been used to provide a more quantitative measure of muscle atrophy [130-135]. 3-D T1-weighted fast field-echo and 3-D MR reconstruction using axial Dixon 3-D–T1-weighted–Fast low angle shot (FLASH) sequences as well as 3-D VIBE MR arthrography have proven accurate in quantifying glenoid bone loss when compared with CT and surgical measurements [136-139]. T2 relaxation maps of glenoid articular cartilage are possible and provide quantitative measures that reflect early structural change in articular cartilage.

MR arthrography using direct intra-articular injection of saline [81] or dilute gadolinium-containing contrast [79] may improve diagnostic accuracy in unstable shoulders [44]. Additionally, MR arthrography may improve diagnostic performance for some rotator cuff tendon tears, particularly partial-thickness tears, postoperative
Vacuum phenomena in the shoulder joint can also be accomplished indirectly by allowing IV-injected contrast to diffuse across the synovial membrane; MRI in this circumstance is performed after a short delay (during which time the patient may be asked to move or exercise the shoulder) following IV injection of a gadolinium-containing agent [106,143]. T1-weighted images either without (valuable to assess presence and degree of muscle fatty infiltration and/or volume loss) [79,140] or with fat suppression [30,32,141] are most frequently used when direct or indirect MR arthrography is performed with gadolinium-containing contrast. At least one fluid-sensitive sequence with fat suppression is still necessary when performing MR arthrography to detect pathology that does not communicate with the joint as well as to identify altered bone marrow signal intensity.

Suppressing the signal from fat may enhance the diagnostic yield of some pulse sequences [116]. Fat suppression can be performed using spectrally selective radiofrequency (RF) pulses, selective water excitation, a STIR sequence, or a phase-dependent method (eg, the Dixon method) [90,93,144,145]. The latter two techniques may be necessary on low-field systems [93,108]. Fat suppression is useful for identifying marrow abnormalities and may be a useful adjunct when performing MR arthrography [146]. The addition of fat suppression may increase diagnostic accuracy for rotator cuff tendon tears [118,144], especially partial-thickness tears [21]. Fat suppression is a useful adjunct to T1-weighted images when MR arthrography is performed using gadolinium-containing contrast [30,32,141].

Recent advances have demonstrated the ability to shorten MRI shoulder acquisition time without decreasing diagnostic yield, using the combination of high field strength systems and parallel imaging [147].

Additional imaging techniques have specific roles for certain shoulder disorders. Both shoulders are imaged together for evaluation of glenohumeral dysplasia related to brachial plexus birth injury allowing evaluation of associated rotator cuff muscle atrophy, glenohumeral alignment, and glenoid version [148]. Applying axial traction to the affected arm via a weight attached to the wrist may aid in the visualization of SLAP lesions [149]. The ABER position may help with the MR arthographic diagnosis of instability lesions and partial-thickness, articular-surface rotator cuff tears [2,32,104-108]. Flexion-adduction and internal rotation of the shoulder can increase conspicuity of posterior labral tears if they are suspected and not seen on routine positioning [150].

Various techniques are used to minimize artifacts that can reduce imaging quality. Wraparound artifact should be reduced by phase oversampling [151]. Involuntary patient motion is best controlled by ensuring patient comfort combined with gentle immobilization when necessary [116]. Securing the affected arm against the thigh may further reduce motion artifacts [81]. When available, software that compensates for motion by the use of navigator echoes can be useful [152]. Flowing blood and other periodic motions produce ghosting artifacts, which can be reduced with presaturation pulses or gradient moment nulling [151,153]. Chemical shift artifact is more severe at higher field strengths and may necessitate an increase in the receiver bandwidth [16,95,151]. Susceptibility artifacts, which originate from heterogeneity of the local field, are also more severe at higher field strengths and when using gradient-recalled pulse sequences. In clinical practice, patients with known metallic implants should be scheduled for MRI using 1.5T rather than 3T units. Avoiding gradient-echo imaging and reducing the voxel size will help reduce the magnitude of susceptibility artifacts [151,152]. Other techniques to reduce susceptibility artifact include the avoidance of spectral fat suppression and the use of a STIR sequence as well as the use of a fast spin-echo (FSE) technique rather than spin-echo (SE) imaging keeping the echo train length low and increasing bandwidth [154,155]. Newer techniques include the use of view angle tilting (VAT) to correct the in-plane distortions, slice encoding for metal artifact correction (SEMAC), and multiacquisition variable-resonance image combination (MAVRIC), which correct both the in-plane and through-slice distortions [156]. Vacuum phenomena in the shoulder joint can also result in artifact generation, especially when gradient-recalled pulse sequences are used [157]. Lastly, magic angle artifact can produce apparent increased signal intensity on short-TE images within the supraspinatus tendon as it curves over the humeral head, mimicking intratendinous pathology particularly on short-TE images [158,159]. This pitfall is best avoided by confirming abnormal signal intensity in the tendon on long-TR images and correlating apparent signal intensity abnormalities with changes in tendon thickness.
It is the responsibility of the supervising physician to determine whether additional 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 (FDA), such as the intra-articular injection of gadolinium chelates (direct MR arthrography) [160], can be considered when they are judged to be medically appropriate.

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [161].

At a minimum, the report should address the condition of the rotator cuff muscles and tendons, supraspinatus outlet, biceps tendon, and labrum. In selected cases, a description of findings in the major ligaments and capsule, articular cartilage, bone marrow, synovium, and cortical bone would be appropriate. An effort should be made to adopt a standardized lexicon of terms, and the report should use precise anatomic descriptions of identified abnormalities whenever possible [162].

VI. 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 RF 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 [89].

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

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

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 [163-165]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [163-166].

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [87], the ACR Guidance Document on MR Safe Practices 2003 [167], and the ACR Manual on Contrast Media [168].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [164,165].
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RESOLUTION NO. 33

BE IT RESOLVED,
that the American College of Radiology adopt the ACR–STR Practice Parameter for the Performance of High-Resolution Computed Tomography (HRCT) of the Lungs in Adults

Sponsored By: ACR Council Steering Committee

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

The American College of Radiology will periodically define new practice 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.

Revised 2015 (Resolution 17)*

ACR–STR PRACTICE PARAMETER FOR THE PERFORMANCE OF HIGH-RESOLUTION COMPUTED TOMOGRAPHY (HRCT) OF THE LUNGS IN ADULTS

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 care¹. 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 in light of 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 the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document is advised to document in the patient record information sufficient to explain the approach taken.

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.
NOT FOR PUBLICATION, QUOTATION, OR CITATION

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 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 sole purpose of this document is to assist practitioners in achieving this objective.

I. INTRODUCTION

High-resolution computed tomography (HRCT) imaging of the lungs is well established for diagnosing and managing many pulmonary diseases [1-7]. Optimal methods of acquisition and interpretation of HRCT images require knowledge of anatomy and pathophysiology [8] as well as familiarity with the basic physics and techniques of CT. This parameter outlines the principles for performing high-quality HRCT of the lungs.

The main objective of HRCT is to detect, characterize, and determine the extent of diseases that involve the lung parenchyma and airways.

HRCT is the use of thin-section CT images (0.625-mm to ≤1.5-mm slice thickness) with a high spatial frequency reconstruction algorithm to detect and characterize diseases that affect the pulmonary parenchyma and small airways [9]. Following the development and widespread availability of multidetector CT (MDCT) scanners capable of acquiring near-isotropic data throughout the entire thorax in a single breath-hold, HRCT is generally performed using MDCT [10-14]. Two general approaches are available for acquiring HRCT images. The first and more traditional method entails obtaining axial HRCT images spaced at 10-mm to 20-mm intervals throughout the lungs. The second method uses the ability of MDCT scanners to provide This permits the acquisition of volumetric single breath-hold data sets, allowing spaced, contiguous, and/or overlapping HRCT images to be reconstructed. With MDCT, the volumetric data enables multiplanar (MPR) thin-section HRCT reconstruction, which facilitating evaluation of the distribution of diffuse lung disease [12] evaluation of coexisting focal lung disease and the application of postprocessing techniques, such as maximum intensity projection (MIP), minimum intensity projection (minIP), and software that uses volumetric data for quantification of features in the lungs and airways [11]. Quantitative CT is emerging as an important technique for determining the extent of fibrotic and obstructive lung diseases and requires specific standardized protocols that will not be addressed here [15].

An older approach to HRCT used noncontiguous inspiratory thin-section images acquired at 10-20mm intervals through the lungs. Although this method substantially reduces the radiation dose, its diagnostic value is more limited; it may have a limited role in screening individuals at risk for diffuse lung disease.

Optimal performance of HRCT studies requires familiarity with the advantages and disadvantages of each HRCT method, with the choice between these approaches reflecting available equipment, clinical indication(s), and radiation dose considerations.

With both methods, image data HRCT images are routinely acquired at suspended full inspiration with patients in the supine position. Additional options, useful in many cases, include obtaining inspiratory prone images to differentiate posterior lung disease from dependent atelectasis and end-expiratory images to evaluate for air trapping [16].

II. INDICATIONS AND CONTRAINDICATIONS

A. Indications

The indications for the use of HRCT of the lungs include, but are not limited to, the following [5,8,17-25]:
1. Evaluation of known or clinically suspected diffuse lung disease that is incompletely evaluated on standard chest (CT) or chest x-ray or that which is chest x-ray occult

2. Evaluation of suspected small airway disease

3. Visual estimation Quantification of the extent of diffuse lung disease for evaluating effectiveness of treatment

4. Guidance in selection of the most appropriate site for biopsy of diffuse lung disease

B. Contraindications

There are no absolute contraindications to HRCT of the lungs. As with any imaging procedure, the benefits and risks should be considered prior to thoracic CT performance.

For the pregnant or potentially pregnant patient, see the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation [26].

For imaging of diffuse lung disease in the pediatric patient, please refer to the ACR–ASER–SCBT–MR-SPR Practice Parameter for the Performance of Pediatric Computed Tomography (CT) [27].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [28].

The physician is responsible for reviewing all indications for the examination, specifying the precise technical factors to be used for the HRCT study, generating a final report, and monitoring and maintaining the quality of images and interpretation.

The physician should be thoroughly acquainted with the many anatomic and physiologic manifestations of thoracic disease. Additionally, supervising physicians should have appropriate knowledge of alternative modalities for imaging of the thorax, including chest radiography and standard thoracic CT as well as angiography, ultrasonography, magnetic resonance imaging (MRI), and nuclear medicine studies.

The CT technologist must be familiar with optimal techniques for acquiring an HRCT examination, and in particular, need to communicate breathing instructions with the patient to ensure high-quality, motion-free inspiratory and expiratory images.

IV. SPECIFICATIONS AND PERFORMANCE OF THE EXAMINATION

A. Written Request for the Examination

The written or electronic request for HRCT of the Lungs should provide sufficient information to demonstrate the medical necessity of the examination and allow for the proper performance and interpretation of the examination.

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

The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient’s clinical problem or question and consistent with the state scope of practice requirements. (ACR Resolution 17 adopted in 2006 – revised in 2009, 2013, Resolution 52)
B. Technical Parameters

Although many of the operations of a CT scanner are automated, a number of technical parameters remain operator dependent. Because these factors can significantly affect the diagnostic value of the HRCT examination [32-31], it is necessary for the supervising physician to be familiar with the following:

1. Radiation exposure factors (mAs, kVp)
2. Collimation
3. Display section thickness for multidetector systems
4. Table increment or pitch and gantry rotation time and table speed
5. Matrix size, scan field of view, and reconstruction field of view
6. Window settings (width and center)
7. Reconstruction algorithm, filter or (kernel) and iterative reconstruction techniques
8. Display section thickness for multidetector systems and image reconstruction interval or increment
9. Detector configuration for multidetector systems
10. Automatic exposure control (angular and longitudinal tube current modulation) and image quality reference parameter
11. Radiation dose report
12. Reformatted images (MPR, curvilinear, MIP, and minIP) and 3-D surface or volume rendered (VR) and image plane (axial, coronal, sagittal)
13. Reconstruction techniques such as filtered back projection or iterative reconstruction
14. Axial or helical acquisition mode of the CT scanner

C. Optimal HRCT Protocol

Optimization of the CT examination requires the supervising physician to develop an appropriate HRCT protocol based on careful review of relevant patient history and clinical indications as well as all prior available imaging studies that are relevant.

1. Protocols should be prepared according to the specific medical indication. Techniques that provide image quality consistent with the diagnostic needs of the examination at acceptably low radiation dose levels to the patient should be selected. When volumetric HRCT data are acquired, utilization of the MPR capabilities is encouraged to facilitate assessment of disease distribution and morphology. For each indication, the protocol should include at least the following:
   a. Tube potential and tube current appropriate to patient size. For the lowest dose to provide diagnostic quality, see the ACR–AAPM–SPR Practice Parameter for Diagnostic Reference Levels and Achievable Doses in Medical X-Ray Imaging [32]. Typically, this entails use of 120 (kVp) and approximately ≤240 mAs. Use of lower tube potentials (eg, 100 kVp) and tube current settings is encouraged, especially for younger patients or those who may need serial imaging. In this case, Using similar technical parameters for each study facilitates direct comparison between studies and is of particular value if quantitative CT measurements are employed.
   b. Techniques available to minimize dose (eg, tube current modulation) should be utilized. Imaging using lower radiation settings is subject to image noise, which can be offset with iterative reconstruction techniques [33]. However, special caution should be taken when utilizing iterative techniques because high degrees of iterative reconstruction weighting may obscure subtle interstitial pulmonary findings and lead to an inaccurate characterization of the patient's underlying lung disease.
   c. Proper supine and/or prone patient positioning with optimal breathing instructions.
   d. State of respiration (inspiration and/or expiration) with appropriate breathing instructions; it is critical to obtain inspiratory scans on full inspiration. Expiratory images are typically acquired at end-maximal expiration.
   e. Table speed for volumetric HRCT to enable single breath-hold acquisition, when possible.
f. Axial (incremental HRCT) or helical (volumetric HRCT) modes of data acquisition. As mentioned above, helical, volumetric acquisition is generally recommended for the inspiratory acquisition. For exploratory and prone acquisitions, acquiring exploratory and/or prone sequence images in a helical fashion is discouraged. For those sequences, axial acquisition with nonirradiated increments of 10–20 mm or more is preferable to reduce radiation dose.

g. Gantry rotation: ≤1 s.

h. Reconstructed image thickness (≤1.5 mm for axial CT, ≤1.5-mm nominal slice thickness for helical CT).

i. Moderately high spatial-frequency reconstruction algorithm, such as a bone algorithm for lung images. Avoid use of an overly sharp reconstruction algorithm, which would create excessive image noise and high degrees of iterative reconstruction, which can decrease spatial resolution [33,34].

j. Proper patient positioning (positioning the patient at isocenter to minimize radiation dose and optimize image quality).

k. Superior and inferior extent of the region of interest to be imaged, typically from the lung apices to the costophrenic sulci. For additional series, such as prone or expiratory HRCT imaging, shorter z-axis coverage and/or greater increment between imaging locations is encouraged to decrease patient radiation exposure.

l. When possible, scan field of view should be selected appropriate to patient size at time of imaging.

m. Reconstructed field of view limited to the lungs, adjusted for small, medium, and large patients to optimizing spatial resolution for each patient.

n. Plane, thickness, and interval for reconstructions or reformats (eg, coronal, sagittal, oblique MPRs and MIPs) from volumetric HRCT data to be sent to the picture archiving and communications system (PACS) or reconstruction directly at the PACS workstation.

o. Retention of the radiation dose report in the radiological record, in alignment with the ACR–SCBT–MR–SPR Practice Parameter for the Performance of Thoracic Computed Tomography (CT) [35].

2. Attention should be directed toward the following:

a. Radiation dose to the degree indicated in the ACR–SCBT–MR–SPR Practice Parameter for the Performance of Thoracic Computed Tomography (CT) [35], considering factors influencing radiation dose, particularly for small adults, and techniques such as increasing pitch, lowering tube current or kV, and limiting the z-axis coverage to the region of clinical question. Other factors that can decrease radiation dose are the use of sequential acquisition and larger interscan gap, which can be employed when expiratory and prone HRCT imaging is performed to supplement an inspiratory examination. The necessity appropriateness of prone imaging should be considered determined in all patients, particularly on subsequent HRCT scans; omitting unnecessary sequences provides an opportunity to reduce dose. Alternatives to breast shielding need to be carefully considered and utilized. Please refer to the AAPM Position Statement on the Use of Bismuth Shielding for the Purpose of Dose Reduction in CT Scanning at (http://www.aapm.org/publicgeneral/BismuthShielding.pdf).

b. Producing motion-free images at the appropriate inspiratory and expiratory level.

3. Use of Intravenous (IV) iodinated contrast should not be used when performing an HRCT to evaluate the lung parenchyma and small airways primarily because subtle pulmonary findings may be obscured by intrapulmonary contrast. In addition, IV contrast adds little value to the interpretation of diffuse lung disease yet exposes patients to the risks associated with the administration of iodinated contrast.

4. Periodic update and review of the HRCT protocol.

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [36,37].

PRACTICE PARAMETER 5 HRCT Lungs 2020 Resolution No. 33
VI. EQUIPMENT SPECIFICATIONS

Equipment performance monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [38].

To achieve acceptable clinical HRCT scans of the lungs, a CT scanner should meet or exceed the following capabilities as specified in the ACR–SCBT-MR–SPR Practice Parameter for the Performance of Thoracic Computed Tomography (CT) [35]:

1. Scan times: ≤1 s per image; a scan time of <1 s per image may apply to direct axial acquisition but may not apply to helical CT acquisition of HRCT images
2. Image thickness: ≤ 1.5 mm
3. Algorithm available: bone or moderately high spatial frequency
4. Axial mode available on CT scanner

Review capability of a PACS workstation should be available to the radiologist; authorized health care providers should be able to review images remotely. A method for digitally transmitting the image data should be available.

VII. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, registered radiologist assistants, radiologic technologists, and all supervising physicians have a responsibility for safety in the workplace by keeping radiation exposure to staff, and to society as a whole, “as low as reasonably achievable” (ALARA) and to assure that radiation doses to individual patients are appropriate, taking into account the possible risk from radiation exposure and the diagnostic image quality necessary to achieve the clinical objective. All personnel that work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection and application of dose limits) and the principles of proper management of radiation dose to patients (justification, optimization and the use of dose reference levels) http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1578_web-57265295.pdf.

Nationally developed guidelines, such as the ACR’s Appropriateness Criteria®, should be used to help choose the most appropriate imaging procedures to prevent unwarranted radiation exposure.

Facilities should have and adhere to policies and procedures that require varying ionizing radiation examination protocols (plain radiography, fluoroscopy, interventional radiology, CT) to take into account patient body habitus (such as patient dimensions, weight, or body mass index) to optimize the relationship between minimal radiation dose and adequate image quality. Automated dose reduction technologies available on imaging equipment should be used whenever appropriate. If such technology is not available, appropriate manual techniques should be used.

Additional information regarding patient radiation safety in imaging is available at the Image Gently® for children (www.imagegently.org) and Image Wisely® for adults (www.imagewisely.org) websites. These advocacy and awareness campaigns provide free educational materials for all stakeholders involved in imaging (patients, technologists, referring providers, medical physicists, and radiologists).

Radiation exposures or other dose indices should be measured and patient radiation dose estimated for representative examinations and types of patients by a Qualified Medical Physicist in accordance with the applicable ACR technical standards. Regular auditing of patient dose indices should be performed by comparing the facility’s dose information with national benchmarks, such as the ACR Dose Index Registry, the NCRP Report No. 172, Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States
or the Conference of Radiation Control Program Director’s National Evaluation of X-ray Trends. (ACR Resolution 17 adopted in 2006 – revised in 2009, 2013, Resolution 52)

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 and Improvement, Safety, Infection Control and Patient Education on the ACR website (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).

ACKNOWLEDGEMENTS

This parameter was revised according to the process described under the heading The Process for Developing ACR Practice Parameters and Technical Standards on the ACR website (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) by the Committee on Body Imaging (Thoracic) of the Commission on Body Imaging and the Committee on Practice Parameters – General, Small and Rural Practice of the Commission on General, Small, and Rural Practice, in collaboration with the STR.

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OLD REFERENCES


*Practice parameters and technical standards are published annually with an effective date of October 1 in the year in which amended, revised, or approved by the ACR Council. For practice parameters and technical standards published before 1999, the effective date was January 1 following the year in which the practice parameter or technical standard was amended, revised, or approved by the ACR Council.

Development Chronology for this Practice Parameter

2000 (Resolution 10)
Revised 2005 (Resolution 28)
Amended 2006 (Resolution 17, 35)
Revised 2010 (Resolution 43)
Amended 2014 (Resolution 39)
Revised 2015 (Resolution 17)
RESOLUTION NO. 34

Mandatory Early Radiology Education for Medical Students by Radiologists

WHEREAS, radiology is central to most medical specialties for diagnostic evaluation and patient management; and

WHEREAS, the importance of radiology is recognized by other medical specialties - as evidenced by the integration of radiology which may not be taught by radiologists into medical school curricula; and

WHEREAS, medical students may have pocket ultrasound tools to complement physical exam, their knowledge of other imaging resources and radiologists’ importance to timely diagnoses and patient care is lacking; and

WHEREAS, radiology is not a mandatory course in the core curriculum of many medical schools, and may not be available as an elective until the fourth year after students have chosen a specialty; and

WHEREAS, the ACR has developed the Radiology-TEACHES program: https://www.acr.org/Clinical-Resources/Radiology-TEACHES directed toward appropriateness criteria, and this program’s principal investigator received the Teaching Value Award in 2017 from the ABIM Foundation Creating Value Challenge for his team’s work; therefore,

BE IT RESOLVED, that the ACR form a taskforce to investigate avenues for introducing medical students to mandatory radiology clerkships taught by radiologists during their second or third years, and/or a longitudinal radiology curriculum, to allow medical students the opportunity to select radiology early enough as their career preference and be able to match successfully into a diagnostic radiology/interventional radiology residency program and to allow those seeking a career in other areas of medicine to have an appreciation of radiology's central role. The taskforce will report to the Council at its 2021 meeting.

Sponsored by: Illinois Radiological Society
To support the resolution for Mandatory Early Radiology Education for Medical Students by Radiologists, the ACR would incur the following estimated costs:

**Costs:**

- De minimis (< $10,000)
RESOLUTION NO. 35

RFS and YPS Standing to Submit ACR Resolutions

WHEREAS,

the American College of Radiology (ACR) has robust participation in its Resident and Fellow (RFS) and Young and Early Career Physician Sections (YPS), with both sections coordinating and participating in dedicated educational programming for the annual ACR meetings.

WHEREAS,

the American College of Radiology encourages chapter resident and fellow sections and will continue to assist in their formation; adopted 1985, amended 1995, 2005 (Res. 12). The chapters should provide residents and fellows the opportunity for membership and access to policy program development and implementation through the development of chapter resident and fellow sections; adopted 1984, 1994, amended 2004, 2014 (Res. 1-a ). [1]

WHEREAS,

the ACR encourages state chapters to facilitate greater involvement by young and early career professionals. The YPS shall work in coordination with the Commission on Membership and Communications to increase membership and volunteerism in the ACR by young and early career professionals, and ACR Commissions and Committees will be encouraged to have representation from this important and unique demographic group. [1]

WHEREAS,

the popularity of radiology, and more specifically, attendance and membership in the ACR has expanded beyond these sections, now welcoming and including medical students [2]

WHEREAS,

currently resolutions may only be submitted and/or sponsored by one of the following: a chapter, an individual councilor, the Council Steering Committee, or the Board of Chancellors. [3]

WHEREAS,

other organized medical societies allow the submission of resolutions to their societies, oftentimes first through their medical student/resident-fellow/young physician sections prior to consideration on the floor of major societal meetings. [4]
WHEREAS,

the submission of resolutions to the ACR meetings encourages participation and can be used to fulfill ACGME core competency requirements such as Systems Based Practice and Professionalism [5]; therefore,

BE IT RESOLVED,

that the ACR Bylaws Committee draft a resolution for the ACR 2021 annual meeting to amend the bylaws to allow submission of resolutions by the RFS or YPS.

Sponsored by: Taj Kattapuram, MD, Councilor, Colorado Radiological Society
J.Paul Nielsen, MD, Councilor, Colorado Radiological Society
Andrew Moriarty, MD, Councilor, YPS
Fiscal Note

RFS and YPS Standing to Submit ACR Resolutions

To support the resolution for RFS and YPS Standing to Submit ACR Resolutions, the ACR would incur the following estimated costs:

**Costs:**
- De minimis (< $10,000)

**REFERENCES**