

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 guidelines 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 guidelines and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice guideline 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, requiring the approval of the Commission on Quality and Safety as well as the ACR Board of Chancellors, the ACR Council Steering Committee, and the ACR Council. The practice guidelines 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 guideline and technical standard by those entities not providing these services is not authorized.

Revised 2010 (Resolution 16)\*

## **ACR PRACTICE GUIDELINE FOR THE PERFORMANCE OF MAGNETIC RESONANCE IMAGING (MRI) OF THE ABDOMEN (Excluding the Liver)**

### **PREAMBLE**

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

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

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

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

### **I. INTRODUCTION**

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 have been omitted here to avoid promoting obsolete methodology. This document pertains to the MRI assessment of the abdomen excluding the liver. For practice guidelines pertaining to the liver, see the [ACR Practice Guideline for the Performance of Magnetic Resonance Imaging \(MRI\) of the Liver](#).

The choice of MRI of the abdomen requires an analysis of the strengths of MRI as well as its suitability for the particular patient and particular clinical situation. For suspected lesions requiring a technique to detect subtle soft-tissue contrast (lesion characterization), to provide a three-dimensional depiction of a lesion, and to image other than with ionizing radiation or in a patient with an allergy to iodinated contrast and a need for intravenous contrast enhancement, MRI might be the procedure of

choice provided that the patient does not have a contraindication to MRI (see section IV below).

## II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

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

## III. INDICATIONS

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

### A. Pancreas

1. Detection of pancreatic tumors.
2. Characterization of indeterminate lesions and/or unexplained enlargement detected with other imaging modalities.
3. Evaluation of pancreatic duct obstruction or dilatation.
4. Detection of pancreatic duct anomalies.
5. Evaluation of pancreatic or peripancreatic fluid collections or fistulae.
6. Evaluation of chronic pancreatitis to include estimating pancreatic exocrine function.
7. Evaluation of complicated acute pancreatitis.
8. Preoperative assessment of pancreatic neoplasms.
9. Postoperative/treatment follow-up after pancreatic surgery.

### 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 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.

### D. Adrenal Glands

1. Detection of suspected pheochromocytoma and functioning adrenal adenoma.

2. Characterization of indeterminate lesions detected with other imaging modalities.

### E. Vascular (See the [ACR–ASNR–SNIS–SPR Practice Guideline for the Performance of Pediatric and Adult Cervicocerebral Magnetic Resonance Angiography \[MRA\]](#)).

### F. Bile Ducts and Gallbladder

1. Detection and post treatment follow-up of bile duct and gallbladder cancer.
2. Detection of bile duct or gallbladder stones.
3. Evaluation of dilated bile duct.
4. Preoperative staging of cholangiocarcinoma.
5. Evaluation of suspected congenital abnormalities of the gallbladder or bile ducts.

### G. Gastrointestinal Tract and Peritoneum

1. Preoperative assessment of gastric neoplasms.
2. Preoperative staging of rectal carcinoma.
3. Assessment of inflammatory disorders of the small or large bowel and mesenteries.
4. Assessment of acute abdominal pain (e.g., appendicitis) in pregnant patients.
5. Detection and evaluation of primary and metastatic peritoneal or mesenteric neoplasms.
6. Detection and characterization of intra-abdominal fluid collections.

### H. Other

1. Imaging follow-up of abnormalities of the abdomen deemed indeterminate on initial MRI and for which surgery is not advised.
2. Detection and characterization of extraperitoneal neoplasms other than above.
3. Evaluation of the abdomen as an alternative to computed tomography (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.

## IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

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

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [1,3].

## V. SPECIFICATIONS OF THE EXAMINATION

The supervising physician must have complete understanding of the indications, risks, and benefits of the

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

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

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

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

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 use. (See the [ACR Practice Guideline for the Use of Intravascular Contrast Media](#).)

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 Guideline for Sedation/Analgesia](#).

#### 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 unless precluded by patient body habitus or condition [4]. The field of view should be selected to provide the highest resolution possible that includes the entire region or organ of interest and allows for an adequate signal-to-noise ratio (SNR). Multiple acquisitions with repositioning of the surface coil may be necessary when the region of interest exceeds the potential field of view of the surface coil. For most applications, evaluation of the abdomen should include T1-weighted 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 1 cm with the interslice gap not exceeding 3 mm, although thinner slices and gaps are desirable.

T1-weighted imaging may be performed using a conventional spin echo, echo train spin echo (TSE) or fast spin echo (FSE), or gradient echo sequence. T2-weighted images may be accomplished using one of the fast spin echo sequences (TSE or FSE) or a hybrid gradient and spin echo (GRASE) technique [5]. Fat suppression is frequently beneficial during T2-weighted imaging 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 Dixon-based techniques.

While fast gradient echo T1-weighted images can usually be acquired during breath-holding, conventional and fast spin echo T2-weighted imaging is often complicated by motion. Breath-hold techniques can be used for T2-weighted imaging if the scan time is reduced by (a) long echo trains, (b) half-Fourier imaging, and/or (c) use of parallel imaging techniques. Other strategies include respiratory compensation (respiratory ordered phase encoding), respiratory triggering with respiratory bellows [6], or the use of navigator pulses [7,8] to correct for

motion during free breathing. A recent advance in motion correction is the acquisition of k-space data in concentric rectangular strips [9] rotated about central k-space, which has recently shown promise in reducing motion artifact in the abdomen [10,11].

Three-dimensional (3D) techniques are available for both T1-weighted and T2-weighted imaging. Numerous advantages over 2D sequences include higher inherent SNR, higher in-plane and through-plane resolution, and homogenous fat suppression [12], most of which are better realized in T1-weighted imaging. Isotropic voxel dimensions allow multiplanar reconstructions that may obviate the need for additional acquisition in other planes. Limited early data have shown varying degrees of diagnostic performance but have illustrated the value of T2 3D imaging for the depiction of complex anatomy [13-15].

Intravenous contrast enhancement with gadolinium chelates is beneficial to detect and characterize many intra-abdominal neoplasms, vascular abnormalities, and inflammatory processes. However, the use of gadolinium may be omitted when noncontrast images are sufficiently diagnostic if in the opinion of the supervising physician, the administration of intravenous contrast is unlikely to be of further benefit to the patient. Intravenous contrast may also be omitted when there is (a) no intravenous access, (b) a history of prior allergic-type reaction to gadolinium chelates and the patient has not been premedicated, (c) a relative contraindication to gadolinium chelates (such as pregnancy), (d) severe renal insufficiency estimated glomerular filtration rate ([eGFR] <30 mL/min) or acute renal insufficiency of any severity in the setting of hepatorenal syndrome or in the perioperative transplantation period [16], or (e) known or suspected diagnosis of nephrogenic systemic fibrosis. Contrast-enhanced images in dynamic fashion (including precontrast, arterial, venous, and equilibrium phase images) are beneficial for evaluating blood vessels and tumors of the solid organs [17-20]. Subtraction images may also be generated, which can be helpful in identifying tumor enhancement [21]. Postcontrast enhanced imaging may be performed with a 2D or 3D technique. 3D imaging allows isotropic or near isotropic resolution and facilitates multiplanar reconstructions [22]. The use of fat suppression during dynamic contrast-enhanced, T1-weighted imaging is encouraged, as it improves the conspicuity of enhancing structures and abnormalities. Fat suppression can be accomplished using chemically selective fat saturation techniques, water excitation, or Dixon technique. STIR should be avoided for gadolinium-enhanced T1-weighted imaging, as enhancement due to gadolinium can be suppressed with this technique.

Delayed postcontrast T1-weighted imaging can be useful in detecting pathology in the urinary tract (excretory MR

urography) [23-25]. Intravenous hydration and/or diuretic administration has been shown to improve visualization of the nondilated collecting system [26,27] and ureters [28] during excretory MR urography. Delayed imaging may also be useful in diagnosing cancer of the biliary system [29].

The use of an oral contrast agent for MRI of the abdomen is considered optional but may occasionally be beneficial for gastrointestinal imaging [30]. 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, pancreato biliary tree, or urinary system. When using oral contrast media for assessing the small bowel (MR enterography), an agent that produces a dark enteric lumen on T1-weighted images is recommended to allow detection of mural enhancement after intravenous administration of a gadolinium chelate. Administration of spasmolytic agents, such as glucagon [31] 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 (MR enterography) [32] or for evaluating the mesentery and peritoneal surfaces [33].

Inclusion of at least one in-phase and out-of-phase gradient echo sequence is useful for detecting intracellular lipid within certain adrenal (e.g., adenoma) and renal (e.g., clear cell carcinoma) tumors and to confirm fatty infiltration of organs such as the pancreas [4,34-40]. Either a single dual echo gradient echo sequence or separate gradient echo sequences that differ in echo times may be performed, although breath-held dual echo sequences are generally preferable.

The addition of a heavily T2-weighted magnetic resonance cholangiopancreatography (MRCP) sequence may be beneficial for evaluating the biliary and pancreatic ducts [41-44]. 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 [45-47], chronic pancreatitis [48,49], and side-branch intraductal papillary mucinous neoplasms [50], and in quantifying pancreatic exocrine function [51,52]. T2-weighted imaging is usually performed using a rapid acquisition relaxation enhance (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 spatial resolution [53]. Such heavily T2-weighted sequences may also serve to evaluate dilated renal collecting systems (static-fluid MR urography) [24,54]. The addition of an additional sequence, such as dynamic T1-weighted or FSE T2-weighted imaging, can

aid in the assessment of periductal tissues, in the evaluation for causes of extrinsic ductal compression, and in the staging of cholangiocarcinoma [55,56].

In recent years, 3 T imaging systems have become widely available. While experience in the abdomen remains relatively limited, potential advantages include increased SNR [57] and increased conspicuity of enhancement after administration of a gadolinium chelate [58]. Potential disadvantages include decreased image contrast on T1-weighted images, increased susceptibility artifact, increased chemical shift artifact, increased specific absorption rate (SAR), and signal inhomogeneity [59]. The latter can be partially compensated for by the use of radiofrequency cushions [60]. In short, 3 T 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.

Parallel imaging (PI) techniques take advantage of spatial sensitivity information from multiple independent receiver coil elements in order to reduce the number of phase encoding steps, therefore reducing scan times [61]. The two strategies currently used include sensitivity encoding (SENSE), which works in the “image” domain, and simultaneous acquisition of spatial harmonics (SMASH), which works in the “k-space” domain. Parallel imaging techniques can not only shorten overall examination duration, but they can also expand the options for breath-hold imaging and result in decreased blurring on echo train sequences such as single shot FSE. The primary penalty for this time savings is modestly reduced SNR [62]. 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 phase encoding steps [63].

Diffusion weighted imaging (DWI) has recently been investigated for abdominal application [64]. Most research to date has centered on oncologic applications, either for staging disease or monitoring response to therapy [65-71]. 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 [72,73]. PI can be used to decrease imaging time, and has been shown to result in accurate Apparent diffusion coefficient (ADC) values [74]. DWI has shown promising results in early research and at least appears to be a value-added adjunct sequence capable of revealing additional sites of disease in the abdomen [69]. ADC maps can be generated to help differentiate between restricted diffusion and T2 shine-through. At least two b-values are obtained, including  $b = 0 \text{ s/mm}^2$  and  $b = 500 \text{ to } 1,000 \text{ s/mm}^2$ .

## VI. DOCUMENTATION

Reporting should be in accordance with the [ACR Practice Guideline for Communication of Diagnostic Imaging Findings](#).

## VII. EQUIPMENT SPECIFICATIONS

The MRI equipment specifications and performance 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.

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

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing under the heading *Position Statement on QC & Improvement, Safety, Infection Control, and Patient Education* on the ACR web page (<http://www.acr.org/guidelines>).

Specific policies and procedures related to 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 examinations to the patient as well as to others in the immediate area [1,3-7]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [1,3,6,7].

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

## ACKNOWLEDGEMENTS

This guideline was revised according to the process described under the heading *The Process for Developing ACR Practice Guidelines and Technical Standards* on the ACR web page (<http://www.acr.org/guidelines>) by the Committee on Abdominal Imaging of the Commission on Body Imaging.

Principal Reviewers: John R. Leyendecker, MD  
David D. Childs, MD

### ACR Committee on Abdominal Imaging

Joel F. Platt, MD, Chair  
Barry D. Daly, MD, MB, BCh  
Amy K. Hara, MD  
Jay P. Heiken, MD, FACR  
Ramin Khorasani, MD  
Dean D. Maglinte, MD, FACR  
Donald G. Mitchell, MD, FACR  
Koenraad J. Mortele, MD  
Erick M. Remer, MD  
Stuart G. Silverman, MD, FACR  
Ruedi F. Thoeni, MD  
James A. Brink, MD, FACR, Chair, Commission

### Comments Reconciliation Committee

Paul J. Chang, MD, Co-Chair  
Cynthia S. Sherry, MD, FACR, Co-Chair  
Kimberly E. Applegate, MD, MS, FACR  
James A. Brink, MD, FACR  
David D. Childs, MD  
Howard B. Fleishon, MD, MMM, FACR  
Alan D. Kaye, MD, FACR  
Paul A. Larson, MD, FACR  
John R. Leyendecker, MD  
Lawrence A. Liebscher, MD, FACR  
Joel F. Platt, MD  
Nabeel E. Sarwani, MD  
Ruedi F. Thoeni, MD

### REFERENCES

1. Kanal E, Barkovich AJ, Bell C, et al. ACR guidance document for safe MR practices: 2007. *AJR Am J Roentgenol* 2007; 188:1447-1474.
2. American College of Radiology. Manual on Contrast Media. [http://www.acr.org/SecondaryMainMenuCategories/quality\\_safety/contrast\\_manual.aspx](http://www.acr.org/SecondaryMainMenuCategories/quality_safety/contrast_manual.aspx). Accessed September 11, 2009.
3. Shellock FG. *Reference Manual for Magnetic Resonance Safety, Implants, and Devices*. 2009 ed. Los Angeles, CA: Biomedical Research Publishing Group; 2008.
4. Mitchell DG. Chemical shift magnetic resonance imaging: applications in the abdomen and pelvis. *Top Magn Reson Imaging* 1992; 4:46-63.
5. Karantanas AH, Papanikolaou N. T2-weighted magnetic resonance imaging of the liver: comparison of fat-suppressed GRASE with conventional spin echo, fat-suppressed turbo spin echo, and gradient echo at 1.0 T. *Abdom Imaging* 2001; 26:139-145.
6. Low RN, Alzate GD, Shimakawa A. Motion suppression in MR imaging of the liver: comparison of respiratory-triggered and nontriggered fast spin-echo sequences. *AJR Am J Roentgenol* 1997; 168:225-231.
7. Kim BS, Kim JH, Choi GM, et al. Comparison of three free-breathing T2-weighted MRI sequences in the evaluation of focal liver lesions. *AJR Am J Roentgenol* 2008; 190:W19-27.
8. Lee SS, Byun JH, Hong HS, et al. Image quality and focal lesion detection on T2-weighted MR imaging of the liver: comparison of two high-resolution free-breathing imaging techniques with two breath-hold imaging techniques. *J Magn Reson Imaging* 2007; 26:323-330.
9. Pipe JG. Motion correction with PROPELLER MRI: application to head motion and free-breathing cardiac imaging. *Magn Reson Med* 1999; 42:963-969.
10. Hirokawa Y, Isoda H, Maetani YS, Arizono S, Shimada K, Togashi K. MRI artifact reduction and quality improvement in the upper abdomen with PROPELLER and prospective acquisition correction (PACE) technique. *AJR Am J Roentgenol* 2008; 191:1154-1158.
11. Hirokawa Y, Isoda H, Maetani YS, Arizono S, Shimada K, Togashi K. Evaluation of motion correction effect and image quality with the periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) (BLADE) and parallel imaging acquisition technique in the upper abdomen. *J Magn Reson Imaging* 2008; 28:957-962.
12. Hussain SM, Wielopolski PA, Martin DR. Abdominal magnetic resonance imaging at 3.0 T: problem or a promise for the future? *Top Magn Reson Imaging* 2005; 16:325-335.
13. Arizono S, Isoda H, Maetani YS, et al. High-spatial-resolution three-dimensional MR cholangiography using a high-sampling-efficiency technique (SPACE) at 3T: comparison with the conventional constant flip angle sequence in healthy volunteers. *J Magn Reson Imaging* 2008; 28:685-690.
14. Futterer JJ, Yakar D, Strijk SP, Barentsz JO. Preoperative 3T MR imaging of rectal cancer: local staging accuracy using a two-dimensional and three-dimensional T2-weighted turbo spin echo sequence. *Eur J Radiol* 2008; 65:66-71.
15. Lichy MP, Wietek BM, Mugler JP, 3rd, et al. Magnetic resonance imaging of the body trunk using a single-slab, 3-dimensional, T2-weighted turbo-spin-echo sequence with high sampling efficiency (SPACE) for high spatial resolution imaging: initial clinical experiences. *Invest Radiol* 2005; 40:754-760.
16. U.S. Food and Drug Administration. Information for healthcare professionals gadolinium-based contrast agents for magnetic resonance imaging. March 16, 2009; <http://www.fda.gov/Drugs/DrugSafety/PostmarketDrugSafetyInformationforPatientsandProviders/ucm142884.htm>.
17. Ho VB, Allen SF, Hood MN, Choyke PL. Renal masses: quantitative assessment of enhancement with dynamic MR imaging. *Radiology* 2002; 224:695-700.
18. Kanematsu M, Shiratori Y, Hoshi H, Kondo H, Matsuo M, Moriwaki H. Pancreas and peripancreatic vessels: effect of imaging delay on gadolinium enhancement at dynamic gradient-recalled-echo MR imaging. *Radiology* 2000; 215:95-102.

19. Scialpi M, Di Maggio A, Midiri M, Loperfido A, Angelelli G, Rotondo A. Small renal masses: assessment of lesion characterization and vascularity on dynamic contrast-enhanced MR imaging with fat suppression. *AJR Am J Roentgenol* 2000; 175:751-757.
20. Tajima Y, Kuroki T, Tsutsumi R, Isomoto I, Uetani M, Kanematsu T. Pancreatic carcinoma coexisting with chronic pancreatitis versus tumor-forming pancreatitis: diagnostic utility of the time-signal intensity curve from dynamic contrast-enhanced MR imaging. *World J Gastroenterol* 2007; 13:858-865.
21. Hecht EM, Israel GM, Krinsky GA, et al. Renal masses: quantitative analysis of enhancement with signal intensity measurements versus qualitative analysis of enhancement with image subtraction for diagnosing malignancy at MR imaging. *Radiology* 2004; 232:373-378.
22. Rofsky NM, Lee VS, Laub G, et al. Abdominal MR imaging with a volumetric interpolated breath-hold examination. *Radiology* 1999; 212:876-884.
23. Karabacakoglu A, Karakose S, Ince O, Cobankara OE, Karalezli G. Diagnostic value of diuretic-enhanced excretory MR urography in patients with obstructive uropathy. *Eur J Radiol* 2004; 52:320-327.
24. Leyendecker JR, Barnes CE, Zagoria RJ. MR urography: techniques and clinical applications. *Radiographics* 2008; 28:23-46; discussion 46-27.
25. Takahashi N, Kawashima A, Glockner JF, et al. Small (<2-cm) upper-tract urothelial carcinoma: evaluation with gadolinium-enhanced three-dimensional spoiled gradient-recalled echo MR urography. *Radiology* 2008; 247:451-457.
26. Di Girolamo M, Pirillo S, Laghi A, et al. [Urography with magnetic resonance: a new method for the study of the renal collecting system in patients without obstructive uropathy]. *Radiol Med* 1996; 92:758-764.
27. Ergen FB, Hussain HK, Carlos RC, et al. 3D excretory MR urography: improved image quality with intravenous saline and diuretic administration. *J Magn Reson Imaging* 2007; 25:783-789.
28. Nolte-Ernsting CC, Bucker A, Adam GB, et al. Gadolinium-enhanced excretory MR urography after low-dose diuretic injection: comparison with conventional excretory urography. *Radiology* 1998; 209:147-157.
29. Lacomis J, Baron RL, Oliver JH, 3rd., Nalesnik MA, Federle MP. Cholangiocarcinoma: delayed CT contrast enhancement patterns. *Radiology* 1997; 203:98-104.
30. Giovagnoni A, Fabbri A, Maccioni F. Oral contrast agents in MRI of the gastrointestinal tract. *Abdom Imaging* 2002; 27:367-375.
31. Marti-Bonmati L, Graells M, Ronchera-Oms CL. Reduction of peristaltic artifacts on magnetic resonance imaging of the abdomen: a comparative evaluation of three drugs. *Abdom Imaging* 1996; 21:309-313.
32. Fidler J. MR imaging of the small bowel. *Radiol Clin North Am* 2007; 45:317-331.
33. Low RN. MR imaging of the peritoneal spread of malignancy. *Abdom Imaging* 2007; 32:267-283.
34. Bilbey JH, McLoughlin RF, Kurkjian PS, et al. MR imaging of adrenal masses: value of chemical-shift imaging for distinguishing adenomas from other tumors. *AJR Am J Roentgenol* 1995; 164:637-642.
35. Haider MA, Ghai S, Jhaveri K, Lockwood G. Chemical shift MR imaging of hyperattenuating (>10 HU) adrenal masses: does it still have a role? *Radiology* 2004; 231:711-716.
36. Israel GM, Hindman N, Hecht E, Krinsky G. The use of opposed-phase chemical shift MRI in the diagnosis of renal angiomyolipomas. *AJR Am J Roentgenol* 2005; 184:1868-1872.
37. Korobkin M, Lombardi TJ, Aisen AM, et al. Characterization of adrenal masses with chemical shift and gadolinium-enhanced MR imaging. *Radiology* 1995; 197:411-418.
38. Mitchell DG, Crovello M, Matteucci T, Petersen RO, Miettinen MM. Benign adrenocortical masses: diagnosis with chemical shift MR imaging. *Radiology* 1992; 185:345-351.
39. Outwater EK, Bhatia M, Siegelman ES, Burke MA, Mitchell DG. Lipid in renal clear cell carcinoma: detection on opposed-phase gradient-echo MR images. *Radiology* 1997; 205:103-107.
40. Yoshimitsu K, Irie H, Tajima T, et al. MR imaging of renal cell carcinoma: its role in determining cell type. *Radiat Med* 2004; 22:371-376.
41. Fayad LM, Kowalski T, Mitchell DG. MR cholangiopancreatography: evaluation of common pancreatic diseases. *Radiol Clin North Am* 2003; 41:97-114.
42. Fulcher AS, Turner MA. MR pancreatography: a useful tool for evaluating pancreatic disorders. *Radiographics* 1999; 19:5-24; discussion 41-24; quiz 148-149.
43. Fulcher AS, Turner MA, Capps GW, Zfass AM, Baker KM. Half-Fourier RARE MR cholangiopancreatography: experience in 300 subjects. *Radiology* 1998; 207:21-32.
44. Leyendecker JR, Elsayes KM, Gratz BI, Brown JJ. MR cholangiopancreatography: spectrum of pancreatic duct abnormalities. *AJR Am J Roentgenol* 2002; 179:1465-1471.
45. Akisik MF, Sandrasegaran K, Aisen AA, Maglinte DD, Sherman S, Lehman GA. Dynamic secretin-enhanced MR cholangiopancreatography. *Radiographics* 2006; 26:665-677.
46. Kamisawa T, Tu Y, Egawa N, Tsuruta K, Okamoto A, Kamata N. MRCP of congenital pancreaticobiliary malformation. *Abdom Imaging* 2007; 32:129-133.
47. Lee NJ, Kim KW, Kim TK, et al. Secretin-stimulated MRCP. *Abdom Imaging* 2006; 31:575-581.
48. Sai JK, Suyama M, Kubokawa Y, Watanabe S. Diagnosis of mild chronic pancreatitis (Cambridge classification): comparative study using secretin injection-magnetic resonance cholangiopancreatography and endoscopic retrograde

- pancreatography. *World J Gastroenterol* 2008; 14:1218-1221.
49. Schlaudraff E, Wagner HJ, Klose KJ, Heverhagen JT. Prospective evaluation of the diagnostic accuracy of secretin-enhanced magnetic resonance cholangiopancreatography in suspected chronic pancreatitis. *Magn Reson Imaging* 2008; 26:1367-1373.
  50. Carbognin G, Pinali L, Girardi V, Casarin A, Mansueto G, Mucelli RP. Collateral branches IPMTs: secretin-enhanced MRCP. *Abdom Imaging* 2007; 32:374-380.
  51. Gillams AR, Lees WR. Quantitative secretin MRCP (MRCPQ): results in 215 patients with known or suspected pancreatic pathology. *Eur Radiol* 2007; 17:2984-2990.
  52. Schneider AR, Hammerstingl R, Heller M, et al. Does secretin-stimulated MRCP predict exocrine pancreatic insufficiency? A comparison with noninvasive exocrine pancreatic function tests. *J Clin Gastroenterol* 2006; 40:851-855.
  53. Nandalur KR, Hussain HK, Weadock WJ, et al. Possible biliary disease: diagnostic performance of high-spatial-resolution isotropic 3D T2-weighted MRCP. *Radiology* 2008; 249:883-890.
  54. Nolte-Ernsting CC, Staatz G, Tacke J, Gunther RW. MR urography today. *Abdom Imaging* 2003; 28:191-209.
  55. Hanninen EL, Ricke J, Amthauer H, et al. Magnetic resonance cholangiopancreatography: image quality, ductal morphology, and value of additional T2- and T1-weighted sequences for the assessment of suspected pancreatic cancer. *Acta Radiol* 2005; 46:117-125.
  56. Kim JY, Lee JM, Han JK, et al. Contrast-enhanced MRI combined with MR cholangiopancreatography for the evaluation of patients with biliary strictures: differentiation of malignant from benign bile duct strictures. *J Magn Reson Imaging* 2007; 26:304-312.
  57. Choi JY, Kim MJ, Chung YE, et al. Abdominal applications of 3.0-T MR imaging: comparative review versus a 1.5-T system. *Radiographics* 2008; 28:e30.
  58. Soher BJ, Dale BM, Merkle EM. A review of MR physics: 3T versus 1.5T. *Magn Reson Imaging Clin N Am* 2007; 15:277-290, v.
  59. Leyendecker JR, Childs DD. Kidneys and MR urography. *Magn Reson Imaging Clin N Am* 2007; 15:373-382, vii.
  60. Franklin KM, Dale BM, Merkle EM. Improvement in B1-inhomogeneity artifacts in the abdomen at 3T MR imaging using a radiofrequency cushion. *J Magn Reson Imaging* 2008; 27:1443-1447.
  61. Glockner JF, Hu HH, Stanley DW, Angelos L, King K. Parallel MR imaging: a user's guide. *Radiographics* 2005; 25:1279-1297.
  62. Larkman DJ, Nunes RG. Parallel magnetic resonance imaging. *Phys Med Biol* 2007; 52:R15-55.
  63. Pruessmann KP. Parallel imaging at high field strength: synergies and joint potential. *Top Magn Reson Imaging* 2004; 15:237-244.
  64. Koh DM, Collins DJ. Diffusion-weighted MRI in the body: applications and challenges in oncology. *AJR Am J Roentgenol* 2007; 188:1622-1635.
  65. Akduman EI, Momtahan AJ, Balci NC, Mahajann N, Havlioglu N, Wolverson MK. Comparison between malignant and benign abdominal lymph nodes on diffusion-weighted imaging. *Acad Radiol* 2008; 15:641-646.
  66. Cova M, Squillaci E, Stacul F, et al. Diffusion-weighted MRI in the evaluation of renal lesions: preliminary results. *Br J Radiol* 2004; 77:851-857.
  67. Fujii S, Matsusue E, Kanasaki Y, et al. Detection of peritoneal dissemination in gynecological malignancy: evaluation by diffusion-weighted MR imaging. *Eur Radiol* 2008; 18:18-23.
  68. Liapi E, Geschwind JF, Vossen JA, et al. Functional MRI evaluation of tumor response in patients with neuroendocrine hepatic metastasis treated with transcatheter arterial chemoembolization. *AJR Am J Roentgenol* 2008; 190:67-73.
  69. Low RN, Gurney J. Diffusion-weighted MRI (DWI) in the oncology patient: value of breathhold DWI compared to unenhanced and gadolinium-enhanced MRI. *J Magn Reson Imaging* 2007; 25:848-858.
  70. Shinya S, Sasaki T, Nakagawa Y, Guiking Z, Yamamoto F, Yamashita Y. Usefulness of diffusion-weighted imaging (DWI) for the detection of pancreatic cancer: 4 case reports. *Hepatogastroenterology* 2008; 55:282-285.
  71. Zhang J, Tehrani YM, Wang L, Ishill NM, Schwartz LH, Hricak H. Renal masses: characterization with diffusion-weighted MR imaging--a preliminary experience. *Radiology* 2008; 247:458-464.
  72. Gourtsoyianni S, Papanikolaou N, Yarmenitis S, Maris T, Karantanas A, Gourtsoyiannis N. Respiratory gated diffusion-weighted imaging of the liver: value of apparent diffusion coefficient measurements in the differentiation between most commonly encountered benign and malignant focal liver lesions. *Eur Radiol* 2008; 18:486-492.
  73. Koh DM, Takahara T, Imai Y, Collins DJ. Practical aspects of assessing tumors using clinical diffusion-weighted imaging in the body. *Magn Reson Med Sci* 2007; 6:211-224.
  74. Yoshikawa T, Kawamitsu H, Mitchell DG, et al. ADC measurement of abdominal organs and lesions using parallel imaging technique. *AJR Am J Roentgenol* 2006; 187:1521-1530.
- 
- \*Guidelines 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 guidelines and standards published before 1999, the effective date was January 1 following the year in which the guideline or standard was amended, revised, or approved by the ACR Council.
- Development Chronology for this Guideline**  
 2005 (Resolution 5)  
 Amended 2006 (Resolution 35)  
 Revised 2010 (Resolution 16)