INTRODUCTION

These magnetic resonance (MR) protocols were developed by an expert consensus panel for use on General Electric (GE) MR imaging machines, and were developed for high-end platform scanners with multichannel phased array coils and parallel reconstruction capabilities. The protocols are divided into 3 sections:

- Body MR imaging
- Body MR angiography
- Central nervous system (CNS) MR imaging

The protocol parameters can generally be adapted to work with other software platforms or releases and hardware configurations but may require small modifications that can be made by a knowledgeable and experienced MR technologist. Scan times may increase in some circumstances.

These protocols provide field strength–specific parameters for 1.5T and 3T. Attention has also been given to patient preparation, streamlining the exam, and making the best use of contrast material, whether it is a standard gadolinium-based extracellular fluid agent, a high-relaxivity gadolinium-based contrast agent (GBCA), such as MultiHance® (gadobenate dimeglumine [Gd-BOPTA]), or agents with hepatobiliary uptake such as Eovist® (gadoxetic acid) and MultiHance®.

Each protocol contains a brief description of patient preparation, special notes on coil choice and placement, suggestions for contrast dose and administration rate, and suggestions concerning timing of fluoroscopic triggering, if appropriate.

The consensus panel consisted of the following experts in radiology:

- Thomas Grist, MD – University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin
- Mark C. DeLano, MD – Michigan State University, Advanced Radiology Services, PC, Grand Rapids, Michigan
- Scott B. Reeder, MD, PhD – University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin
- Howard A. Rowley, MD – University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin
- Steffen Sammet, MD, PhD, DABR, DABMRS, FAMP – The University of Chicago Medical Center, Chicago, Illinois
- Megan E. Vadnais, BSRT, (R)(MR) – University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin

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MR Protocols for Body MR Imaging

Contrast timing is extremely important for abdominal MR imaging, particularly for high-quality liver imaging. We recommend the use of fluoro-triggering or “SmartPrep” methods rather than the use of a timing bolus.

All body MR imaging protocols presented here were developed by Scott B. Reeder, MD, PhD, Steffen Sammet, MD, PhD, DABR, DABMRS, FAMP, and Megan E. Vadnais, BSRT, (R)(MR) for 1.5T and 3T systems. Specific protocols include:

- **Abdomen**
  - Generic Abdomen Pelvis 1.5T and 3T
  - Appendicitis Noncontrast 1.5T and 3T
  - MR Enterography 1.5T and 3T

- **Liver**
  - Liver/Pancreas Extracellular Agent 1.5T and 3T
  - Liver/Pancreas Hepatobiliary Agent 1.5T and 3T
  - Magnetic Resonance Cholangiopancreatography (MRCP) Noncontrast 1.5T and 3T
  - Diffuse Liver Disease 1.5T and 3T

- **Pelvis**
  - Generic Pelvis 1.5T and 3T
  - Female Pelvis Malignant 1.5T and 3T
  - Female Pelvis Benign 1.5T and 3T
  - Uterine Anomaly 1.5T and 3T
  - Rectal Cancer 1.5T and 3T
  - Perianal Fistula 1.5T and 3T
  - Prostate 1.5T and 3T

- **Adrenal and Renal**
  - Adrenal 1.5T and 3T
  - Renal 1.5T and 3T

**General Notes**

- Intravenous access should be obtained with an 18- to 22-gauge needle
- We suggest the use of a contrast injector and a saline flush of a minimum of 20 to 30 mL at the same injection rate as the contrast injection (1.5-2.0 mL/sec)
- Breath-holding is essential for good image quality for thoracic or abdominal MR imaging. Precontrast scans should be used to ensure that the patient can both breath-hold adequately and understand the instructions. We recommend breath-holding at end-expiration (end tidal volume)
- When parallel imaging is used, care must be taken to increase the field of view sufficiently to avoid residual aliasing artifact. This is generally more often a problem for coronal imaging, which may require placing the arms over the head or elevating the arms by the patient’s side
- In patients with renal failure, consider using a half-dose (0.05 mmol/kg) of a high-relaxivity Group II contrast agent such as MultiHance® (gadobenate dimeglumine), particularly at 3T
MR Protocols for Body MR Angiography

All protocols should use Fluoro-Triggered (FT) magnetic resonance (MR) angiography fluoroscopic imaging for bolus detection. MR imaging protocols for MR angiography presented here include 1.5T and 3T systems, and were developed by Thomas Grist, MD, and Megan E. Vadnais, BSRT, (R)(MR) for the following procedures:

• **Cardiac MRA**
  – Cardiac Basic Anatomy and Function 1.5T and 3T
  – Pulmonary Artery 1.5T and 3T
  – Pulmonary Vein Mapping 1.5T and 3T

• **Thoracic MRA**
  – Thoracic Aorta MRA 1.5T and 3T
  – Gated Thoracic Aorta 1.5T and 3T

• **Abdominal MRA**
  – Contrast-enhanced MRA Abdomen 1.5T and 3T
  – Noncontrast-enhanced MRA Abdomen 1.5T and 3T
  – Thoracoabdominal Aortic Aneurysm MRA 1.5T and 3T

• **Peripheral MRA**
  – Lower Extremity Contrast-enhanced MR Venography (CE MRV) 1.5T and 3T
  – Runoff Abdomen to Lower Extremity MRA 1.5T and 3T
  – Peripheral Runoff Noncontrast 1.5T and 3T
  – Arteriovenous Malformation (AVM) Evaluation 1.5T and 3T

The rationale for the patient preparation for contrast-enhanced MR angiography is based on a hypothetical generic patient. Individual protocols may include important variations and will be delineated in the specific protocol.

**General Notes**

• Intravenous access should be obtained with an 18- to 22-gauge needle, inserted preferably in the antecubital fossa. Right side is preferred (when possible) for thoracic or carotid MR angiography

• Use respiratory bellows – gating parameters:
  – R-R intervals = 2-3
  – Trigger point = 40%
  – Trigger window = 30%
  – Delay = minimum

• The basic sequences recommended are intended to achieve both anatomic localization and high-quality anatomic imaging to complement the angiographic sequences that are performed. These include:
  – 3-plane localizer
  – Coronal single-shot fast spin-echo (FSE)
  – Axial T2 FSE (respiratory triggered)
  – 3D (three-dimensional) contrast-enhanced MR angiography FT (precontrast-practice breath-hold)
  – 3D contrast-enhanced MR angiography FT (postcontrast)
  – 3D contrast-enhanced MR angiography FT (2nd postcontrast)
  – Axial fast spoiled gradient-echo postcontrast fat-saturated
• A power injector is highly recommended with a minimum of 20- to 30-mL saline flush delivered at the same injection rate as the contrast injection.

• Breath-holding is critical to good image quality for thoracic or abdominal MR angiography. Precontrast or practice scans help ensure that the patient can both breath-hold adequately and understand the instructions.

• When parallel imaging is used, care must be taken to not have wraparound artifact on the vascular structures. This generally requires prescribing a large field of view beyond the body wall, and for abdominal imaging, it requires placing the arms over the head or elevating the arms at the patient’s side. When performing the calibration scan, overprescribe by one-fourth the area of interest in the superior and inferior directions to reduce scan cutoff. Calibration scans are performed in the axial plane.

MR Protocols for Central Nervous System (CNS) MR Imaging

Newer hardware and software platforms at both 1.5T and 3T allow efficient protocol options for a wide range of CNS indications. This section suggests multiple consensus methods for optimizing examination of patients undergoing MR imaging in the CNS. Core sequences in each protocol are identified, and their aggregate use constitutes a complete examination for each protocol. Alternative sequences of interest are included for emerging technologies, specific target anatomy, or subspecialty preference.

1.5T and 3T CNS MR imaging protocols presented here were developed by Howard A. Rowley, MD, Mark C. DeLano, MD, and Megan E. Vadnais, BSRT, (R)(MR) for the following procedures:

• **Brain**
  – Routine Adult Brain 1.5T and 3T
  – Brain Neck Magnetic Resonance Angiography (MRA)/Magnetic Resonance Venography (MRV) 1.5T and 3T
  – Motion Brain 1.5T and 3T
  – Routine Stroke Fast 1.5T and 3T
  – Hyperacute Stroke Brain 1.5T and 3T
  – Tumor Brain 1.5T and 3T
  – Multiple Sclerosis Brain 1.5T and 3T
  – Pediatric Brain 1.5T and 3T
  – Epilepsy Brain 1.5T and 3T

• **Specialty Brain**
  – Hydrocephalus Brain 1.5T and 3T
  – Cerebrospinal Fluid Flow 1.5T and 3T
  – Pituitary 1.5T and 3T
  – Cranial Nerves/Internal Auditory Canals 1.5T and 3T
  – Vessel Wall 1.5T and 3T

• **Head and Neck**
  – Orbits 1.5T and 3T
  – Soft Tissue Neck 1.5T and 3T
  – Sinuses/Face 1.5T and 3T
• Spine
  – Cervical Spine 1.5T and 3T
  – Lumbar Spine 1.5T and 3T
  – Thoracic Spine 1.5T and 3T
  – Routine Total Spine 1.5T and 3T
  – Focused Total Spine 1.5T and 3T
  – Specialty Spine 1.5T and 3T
  – Brachial Plexus 1.5T and 3T
  – Lumbar Plexus 1.5T and 3T

General CNS Protocol Notes

• **Standard brain.** There are multiple approaches to obtain various tissue parameter weightings at both 1.5T and 3T, such that “standard” imaging refers more to the general-purpose nature of the protocol rather than the core sequence choices. The core preferences of our consensus panel are indicated within each protocol

• **T1.** Six techniques for obtaining T1-weighting are included: spin echo (SE), fast spin echo (FSE), T1 fluid-attenuated inversion recovery (T1-FLAIR), 3D IR-prepared FSPGR (BRAVO), 3D T1 CUBE, and magnetization transfer (MT)
  – **SE** is the T1 reference standard for image contrast at 1.5T, although the other sequences have unique advantages and are included as options. Due to T1 prolongation at 3T and associated loss of gray-white contrast there is no consensus standard for T1-weighting, and many sites use inversion recovery preparation to restore tissue contrast
  – **FSE** with its intrinsic magnetization transfer effects results in decreased gray-white contrast but may depict contrast enhancement to better advantage
  – **T1-FLAIR and BRAVO** are inversion prepared, facilitating excellent gray-white differentiation but with the potential disadvantage of inconspicuous contrast enhancement due to the marked precontrast hypointensity of many lesions and subsequent isointensity to surrounding brain postcontrast
  – **BRAVO**, as a standard 3D sequence, has the key advantage of multiplanar reconstruction capability of the isotropic data sets, and excellent gray-white contrast desirable for most applications
  – **T1 CUBE.** This T1-weighted FSE-based volumetric sequence can be performed either before or after contrast. Beyond the usual 3D attributes (such as high resolution and multiplanar reconstructions), it has particular advantages postcontrast, where it provides black blood imaging, supports fat saturation, and shows outstanding tissue contrast for enhancing lesions. T1 CUBE is suitable for routine brain imaging and also orbital, cranial nerve, and vessel wall imaging exams. Many sites now use T1 CUBE as a supplement to postcontrast T1 BRAVO and other sequences
  – **MT** is an optional feature that can be added to increase contrast enhancement conspicuity on SE imaging, but at the cost of increased SAR and decreased gray-white distinction

• **T2.** Most sites use FSE sequences rather than SE. PROPELLER is effective for dealing with patient motion, and is the primary FSE sequence used at many sites. Some users add fat saturation to T2 imaging as an option
• **T2-FLAIR.** Improves lesion detection particularly at the brain-CSF interface. When done as the first sequence postinjection, postcontrast T2-FLAIR imaging effectively inserts a time delay for subsequent T1-weighted scans, which improves lesion detection on subsequent T1 imaging. The T2-FLAIR images also have some intrinsic T1 contrast that allows visualization of both edema and enhancement on one sequence for many lesions. Both 2D and 3D T2-FLAIR sequences are commonly performed, with the advantage of multiplanar reconstruction capability and fewer CSF pulsation artifacts of the 3D CUBE.

• **Susceptibility.** Due to the reduced susceptibility weighting of FSE methods, a T2*-GRE sequence can be added as an option to detect blood products and calcium. The SWAN sequence has been shown to more sensitively detect subtle areas of blood and calcium and has become a common protocol choice.

• **Diffusion.** Most brain protocols include a diffusion-weighted imaging sequence that is useful for stroke, infection, and tumor imaging. Apparent diffusion coefficient maps should be included to assess T2 shine-through. In areas near the skull base or orbits, PROPELLER DWI can be a good option to reduce signal pile-up and geometric distortion artifacts.

• **Perfusion.** Dynamic susceptibility contrast, perfusion-weighted imaging is becoming increasingly important and can provide clinically significant information regarding blood volume and/or transit time for both stroke and tumor imaging. Arterial spin labeling is also an option for assessing cerebral blood flow at 3T, but must be obtained precontrast.

• **Contrast.** The protocols presented here do not list separate imaging sequences for postcontrast imaging; rather, the T1-weighted sequence of choice is typically repeated after contrast agent administration. Most neurologic sequences with contrast are acquired with at least a 3- to 5-minute delay after injection to optimize visualization of disorders of the blood-brain barrier. Some protocols use more than one sequence “family” postcontrast, such as T2-FLAIR, T1-BRAVO, and T1-CUBE Fat Sat due to their complementary information. Many centers prefer routinely acquiring such volumetric series postcontrast to facilitate retrospective multiplanar reconstructions, treatment planning, and neuronavigation applications. T2-FLAIR is an excellent complement to T1 series, and may be done first postcontrast to intentionally provide a time delay before the T1 series are acquired. The method of injection is not important in these cases, and manual injection is typically used. However, power injectors are needed for contrast-enhanced MR angiography and perfusion imaging. Rates of injection vary, but 4 to 5 mL/sec is standard for perfusion, and 1.5 to 2 mL/sec is used for MR angiography. Dosing is weight based and at 0.1 mmol/kg for most protocols aimed at standard extracellular fluid distribution. The dose for an individual injection may be lower for first-pass MRA or perfusion exams, where a split-dose protocol can often be used, keeping overall dose within the standard 0.1 mmol/kg guideline. The ACR has recommended that the lowest dose feasible be used for diagnostic purposes. Because standard dosing recommendations are mostly influenced by lean body mass, and ECF volume in fatty tissues is low, some sites cap the upper limit of contrast for heavier adults at 20 mL total, especially when a high-relaxivity agent is being used.

A useful contrast dose calculator (“GadCalc”) is available at https://www.radiology.wisc.edu/contrastCorner/gadcalc.php and is also available for free download at the Apple and Droid App Stores.