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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 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.

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.

¹ *Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing*, ___ N.W.2d ___ (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 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 magnetic resonance angiography (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, it 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, referred to as body MRA. For information on assessment of vessels of the head and neck, 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 to 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, gadolinium-based contrast agents have been linked to the development of nephrogenic systemic fibrosis (NSF) in patients with severe renal insufficiency [8-11]. However, unenhanced MRA techniques are available for assessing the vasculature in patients who cannot or should not receive gadolinium-based contrast agents [12-15]. Compared to 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 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. In addition, CTA does not provide quantitative information about blood flow, which is possible with phase contrast MRA, and CTA does not assess oxygen saturation, which is possible with susceptibility-weighted MRA.

MRA is also useful in diagnosing vascular disease in children and is more advantageous for this patient population given the lack of radiation exposure. 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 to adults but 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 \(MRI\)](#) [16] and the [ACR–SIR Practice Parameter for Sedation/Analgesia](#) [17].

(For pediatric considerations, see sections III.B.4 and V.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 of the thoracic aorta and branch vessels
 - ii. Post-traumatic 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
 - ii. Atherosclerotic narrowing
 - 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. Pre-operative 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
 - c) Patients with previous interventions (postoperative)
 - i. Stent grafts
 - ii. Bypass grafts
 - d) Atheroembolism
 - ii. Congenital anomalies, including vascular malformations
 - iii. Vasculitides
 - iv. Arterial fibrodysplasias
 - 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 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 due to the risk (albeit low) related to catheter-based angiographic procedures, including the small potential risk of exposure to ionizing radiation [18]. 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 [1,19-21].

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, mid aortic 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 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 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 \(MRI\)](#) [22].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the [ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging \(MRI\)](#) [16].

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. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the [ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging \(MRI\)](#) [16], the [ACR Guidance Document on MR Safe Practices](#) [23], and the [ACR Manual on Contrast Media](#) [24].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [23,25,26].

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 body MRA 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 should have a good 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 shall 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](#) [27]).

When intravenous 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](#) [27]).

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](#) [17].

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. Patients with cardiovascular conditions may have additional considerations, and these can be found in the ACCF/ACR/AHA/NASCI/SCMR 2010 Expert Consensus Document on Cardiovascular Magnetic Resonance: A Report of the American College of Cardiology Foundation Task Force on Expert Consensus Documents [28].

C. Examination Technique

Magnetic resonance angiography 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 [12-15,29-31]. Time-of-flight (TOF) technique relies on inflow enhancement to generate images of blood flow [10]. 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 [33,34]. 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 [35-37]. 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 [38]. With this technique, angiographic images can be obtained by subtracting the systolic dataset from the diastolic dataset. CE-MRA methods rely on

enhancement of the blood signal by intravascular paramagnetic contrast agents, typically gadolinium-based, and use a rapid, 3-D T1-weighted gradient-echo acquisition [39-41]. Individuals using MRA must understand these concerns as well as those related to the artifacts and limitations of the 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 [42-44]. However, MRA performed on a high-field MR scanner presents concerns related to higher absorption rate (SAR) and artifacts related to metallic susceptibility.

1. Noncontrast MRA

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 three-dimensional 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 [45,46]. 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 undesirable signal along the entire course of the vessels of interest.

As with TOF, PC-MRA can be obtained as either a 2-D or 3-D dataset. Intravenous contrast enhancement may also be used to increase the signal obtained from 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.

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 SSFP 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. The abdominal aorta and visceral (eg, renal) arterial branches can be selectively imaged, however, through the use of an asymmetrically applied inversion prepulse that can effectively null the signal from venous blood [12].

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 [12,38,47]. During systole, intravascular signal is reduced due to flow-related signal void using a T2-weighted echo train spin-echo sequence. During diastole, the blood behaves as a relatively immobile fluid and demonstrates relatively high signal intensity. By timing the acquisition of datasets to the cardiac cycle, systolic and diastolic datasets 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.

2. Contrast-enhanced MRA

Contrast-enhanced 3-D MRA (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 contrast-enhanced MRA that may differ in terms of relaxivity, gadolinium

concentration, biodistribution, elimination, and various safety concerns [29,48-50]. 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 [51,52]. CE-MRA has documented efficacy in assessing the arterial and venous systems in the thorax, abdomen, pelvis, and extremities [2,5,30,39,51,53-65]. 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 [66,67]. Furthermore, breath-holding eliminates respiratory artifacts, and artifacts due to complex flow are minimized. 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 [68-70]. Novel k-space filling and parallel imaging techniques allow for high temporal resolution (time-resolved) imaging of vascular territories, [29,44,71-74] 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 [75-77]. 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 [78] and PC MRA [79] can often provide supplemental vascular information to CE-MRA.

3. Special Considerations

a. MR venography (MRV)

Venous illustration can be achieved using both noncontrast and CE-MRA methods. Indications for MR venography are listed above. Contrast-enhanced MR venography (CE-MRV) is implemented in much the same way as CE-MRA, whereby an intravenous gadolinium-based contrast agent injection is combined with the acquisition of a 3-D T1-weighted spoiled gradient-echo dataset [80]. 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, since it remains within the circulation for several hours after the initial injection [81]. 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.

Noncontrast MRV is desirable in patients with renal dysfunction, pregnancy, contrast allergy and in children. Noncontrast MRV is best achieved with SSFP or turbo spin-echo [82] 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. Time of flight imaging, which depends on 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 time-resolved MR angiography (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 antegrade or retrograde flow is present in the ovarian vein [83]. 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 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 child or possibly the complexity of the clinical questions being answered. In infants and young children, special attention must be paid to the appropriate dose of contrast media (See the [ACR-SPR Practice Parameter for the Use of Intravascular Contrast Media](#) [27]), taking into account the immature renal function, especially in infancy. Given the small body size of some pediatric patients, certain clinical applications of contrast-enhanced 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 if 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 datasets 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 with each display method [52,84-89]. Optimized pulse sequences and quantitative postprocessing tools for evaluating blood vessel caliber, flow velocity, volume, and direction should be used when indicated clinically.

VI. DOCUMENTATION

Reporting should be in accordance with the [ACR Practice Parameter for Communication of Diagnostic Imaging Findings](#) [90].

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.

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.

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

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

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 [23,25,26]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [91].

Equipment monitoring should be in accordance with the [ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging \(MRI\) Equipment](#) [92].

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 (<http://www.acr.org/guidelines>) by the Committee on Body Imaging (Cardiovascular) 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 NASCI and the SPR.

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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 6)

Amended 2006 (Resolution 35)

Revised 2010 (Resolution 22)

Amended 2012 (Resolution 8 – title)

Amended 2014 (Resolution 39)

Revised 2015 (Resolution 8)