PRACTICE GUIDELINE

Cervicocerebral MRA

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Revised 2015 (Resolution 10)*

ACR–ASNR–SNIS–SPR PRACTICE PARAMETER FOR THE PERFORMANCE OF CERVICOCEREBRAL MAGNETIC RESONANCE ANGIOGRAPHY (MRA)

PREAMBLE

This document is an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. Practice Parameters and Technical Standards are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care. For these reasons and those set forth below, the American College of Radiology and our collaborating medical specialty societies caution against the use of these documents in litigation in which the clinical decisions of a practitioner are called into question.

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

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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.
course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The sole purpose of this document is to assist practitioners in achieving this objective.

I. INTRODUCTION

This practice parameter was revised collaboratively by the American College of Radiology (ACR), the American Society of Neuroradiology (ASNR), the Society of NeuroInterventional Surgery (SNIS), and the Society for Pediatric Radiology (SPR).

Cervicocerebral magnetic resonance angiography (MRA) is a general term that refers to various MRA techniques used for the evaluation, assessment of severity, and follow-up of arterial and venous diseases of the cervicocerebral system. MRA is a rapidly evolving technology and, consequently, only general recommendations can be made regarding imaging techniques. Detailed imaging protocols have been omitted here to avoid promoting obsolete methodology. The practitioner should periodically review imaging protocols and update the protocols as needed using resources from the literature, major MR manufacturers and professional imaging society meetings and their websites (eg, American Society of Neuroradiology, International Society for Magnetic Resonance in Medicine, Society of Cardiovascular Magnetic Resonance, MR Angiography Club, and other similar resources).

Cervicocerebral MRA should be performed only for valid medical reasons. Additional or specialized pulse sequences are frequently required to optimize the examination. Although it is not possible to detect all abnormalities by using cervicocerebral MRA, adherence to the following practice parameter will enhance the probability of their detection.

MRA has important attributes that make it valuable in assessing a wide spectrum of vascular diseases [1,2]. Compared to radiographic catheter-based angiography, it is noninvasive with no risk of neurologic deficit, circulatory compromise due to vascular injury, or adverse effects of iodinated contrast material. Compared to vascular ultrasound, it is less operator-dependent, has greater freedom from interference by body habitus, and has greater 3-D capability. These benefits must be balanced against the limitations of MRA, which include artifacts generated by vascular flow, patient motion, and metal, which can lead to degraded imaging. The potential for nephrogenic systemic fibrosis (NSF) in at risk populations undergoing gadolinium contrast-enhanced (CE) MRA also needs to be considered [3-9]. The ACR Manual on Contrast Media provides detailed recommendations for the use of gadolinium contrast agents in at risk groups [10].

Children typically demonstrate a different spectrum of vascular conditions. Imaging protocols tailored for adult patients may not be optimal or even appropriate in the pediatric setting. Cervicocerebral MRA can provide valuable information regarding flow conditions, congenital/developmental vascular abnormalities, and acquired pathologic processes that may involve the pediatric brain and spine without the concern for radiation to the developing central nervous system. Performing successful MRA evaluation in pediatric patients is more complex and poses unique technical and safety issues [11]. In general, the fast intracranial flow in pediatric patients makes time-of-flight (TOF) MRA sequences a useful choice in most cases, reducing the need for the more technically challenging CE MRA. The smaller size of the pediatric patient requires higher resolution sequences. Finally, sedation is frequently necessary in order to obtain a diagnostic quality examination.

Application of this practice parameter should be in accordance with the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [12] and the ACR–SIR Practice Parameter for Sedation/Analgesia [13].
II. INDICATIONS

A. Pediatric Indications for Cervicocerebral MRA

MRI/MRA is typically the imaging modality of choice for the initial evaluation of the cervicocerebral vasculature in children [14]. It is a noninvasive and low-risk examination free of ionizing radiation, as compared to conventional endovascular or CT angiographic procedures. Studies of pediatric stroke that compared MRA to conventional angiography found MRA to be accurate in delineating stenosis and/or occlusion and able to demonstrate vascular anatomy in a variety of pathological conditions [15-22]. In some clinical instances, follow-up computed tomographic angiography (CTA) or catheter angiography may be necessary to fully characterize the abnormality.

Indications for cervicocerebral MRA in the pediatric population include, but are not limited to, the definition and evaluation of the following:

1. Evaluation of etiology of intracranial hemorrhage and intraspinal hemorrhage
2. Sickle cell vasculopathy [23]
3. Vasculitis and collagen vascular disease [24,25]
4. Moyamoya disease [26]
5. Detection and evaluation of aneurysms or pseudoaneurysms and venous varices [27,28]
6. Cerebral arteriovenous malformations (AVMs), arteriovenous fistulas, and venous and vascular malformations [29,30]
7. Vascular status following extracorporeal membrane oxygenation.
8. Blood supply to vascular neoplasms for operative planning
9. Acute ischemic stroke, vasospasm, and thromboembolism [31]
10. Traumatic injury to cervicocerebral vessels, including dissection [32]
11. Localization of arterial and venous structures for operative planning
12. Invasion, encasement, and constriction of blood vessels by neoplasm
13. Soft-tissue vascular anomalies in the head and neck region[33]
14. Dural sinus thrombosis and intracranial venous occlusive disease
15. Atherosclerotic steno-occlusive disease
16. Nonatherosclerotic, noninflammatory vasculopathy

B. Indications for cervicocerebral MRA for adults include, but are not limited to, the definition and evaluation of the following:

1. Presence and extent of atherosclerotic occlusive disease and thromboembolic phenomena in the setting of patients presenting with symptoms of cerebral ischemia and infarction [34-36]
2. Etiology of intracranial hemorrhage and intraspinal hemorrhage [37]
3. Relevant vascular anatomy for preprocedural evaluation and determining the effect of therapeutic measures, including the endovascular coil embolization treatment of aneurysms and AVM embolization [38,39]
4. Presence, location, and anatomy of extracranial and intracranial aneurysms and vascular malformations [40-42]
5. Presence, nature, and extent of traumatic injury to cervicocerebral vessels, including dissection [43,44]
6. Vascular supply to tumors and vessel encasement and narrowing by tumors
7. Dural sinus thrombosis and intracranial venous occlusive disease [45-47]
8. Nature and extent of other congenital or acquired AVM (soft tissue) vascular anomalies (eg, hemangioma, venous malformation, AVM, lymphatic malformation) [45-47]
9. Extend of disease in vasculitis and vasculopathy
10. Operative planning for tumor resection

C. Evaluation of the aortic arch and subclavian arteries in adults and children may require separate techniques and sequences. Indications include, but are not limited to, the following [48-50]:

1. Dissection of the aorta and great vessels to the brain
2. Aneurysm of the aorta and/or its branches
3. Presence and extent of atherosclerotic occlusive disease and subclavian steal
4. Differentiation of aneurysms and masses
5. Definition of the relationship of masses to nearby vascular structures
6. Identification of congenital abnormalities of the aorta, such as coarctation, double arch, and aberrant subclavian artery
7. Evaluation of superior vena cava syndrome or unilateral upper extremity edema
8. As a measuring tool for treatment of occlusive disease of the extracranial vessels (ie, subclavian, innominate, common carotid)

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [12].

IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the ACR Practice Parameter for Performing and Interpreting Magnetic Resonance Imaging (MRI) [12] and the ACR Guidance Document on MR Safe Practices: 2013 [51].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [1,21].

V. SPECIFICATIONS OF THE EXAMINATION

The supervising physician must have complete understanding of the indications, benefits, and risks of the examination, as well as alternative imaging procedures. The physician must be familiar with potential hazards associated with MRI, including incompatible devices and potential adverse reactions to contrast media. The physician should be familiar with relevant ancillary studies that the patient may have undergone (See the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [52].). 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 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 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 (e.g., incompatible metallic implants surgical devices, etc). See the ACR MR Guidance Document on MR Safe Practices: 2013 [51].

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 used. Patients receiving gadolinium contrast agents should be evaluated for potential risk of NSF according to the recommendations in the chapter on NSF in the ACR Manual on Contrast Media [10].

Patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of moderate sedation may enable achievement of a successful examination. If moderate sedation is necessary, refer to the ACR–SIR Practice Parameter for Sedation/Analgesia [13]. Additional considerations and equipment may be required in critically ill or intubated patients under general anesthesia.

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

Magnetic resonance angiography is a general term that refers to a diverse group of MR pulse sequences. Multiple methods can be used to generate signal from flowing blood and each method may be performed with a variety of coils, acquisitions and display techniques. Time of flight techniques rely on flow enhancement to generate images of blood flow within the vascular lumen. Flow images and quantitative measurements of flow velocity can be obtained using phase-contrast (PC) MRA techniques in which the image contrast is generated by velocity-induced phase shifts. Contrast enhanced MRA relies on enhancement of the blood signal by paramagnetic contrast agents and typically uses rapid, 3-D T1-weighted gradient-echo acquisitions. Contrast enhanced MRA can provide higher spatial resolution with the first-pass techniques or provide temporal resolution with time-resolved techniques [53-56]. Vascular images can also be generated by arterial spin labeling and blood can be directly imaged using methods such as inflow inversion recovery [57-59]. Individuals using MRA must understand the artifacts and limitations of each imaging technique. The most commonly used techniques are noncontrast TOF and CE 3-D and 4-D methods.

1. Noncontrast TOF MRA

   In two-dimensional (2-D) TOF MRA acquisitions, multiple thin slices are obtained and combined to form a 3D volume data set. Vascular structures are isolated from the surrounding tissue by projecting the pixels with maximum intensity into multiple views called maximum intensity projection (MIP) images. Three-dimensional TOF technique directly acquire a 3-D volume. Multiple 3-D volumes using short TE/TR sequences are typically obtained with overlapping edges to provide coverage of the region of interest. Focused assessment of the vascular structures from the 3-D volume set can also be displayed with MIP imaging [60-63].
MRA datasets can also be displayed as 2-D source images. The supervising physician should always review the source images in an effort to improve diagnostic accuracy. Review of the source images can reduce possible confusion of high signal material (eg, fat or thrombus) with flow signal, aid diagnosis by eliminating overlapping structures, and identify artifacts that can cause spurious increase or decrease in flow-related signal [64].

Rotating displays of 3-D MIP images allow separation of vessels that are superimposed on routine projections. The supervising physician should be familiar not only with MIP displays, but also with surface displays, volume displays, and multiplanar reformatting techniques including 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 [65].

2. Contrast-enhanced MRA

Contrast-enhanced 3-D MRA combines a fast T1-weighted gradient-echo acquisition with an intravenously administered paramagnetic contrast agent [66]. Such agents reduce the T1 relaxation time of blood and nearly eliminate the loss of signal related to saturation effects, thus leading to a more accurate assessment of vascular stenosis. Contrast-enhanced MRA has been evaluated for use in assessing the cervical carotid and vertebral arterial system, the intracranial arterial circulation, the dural venous sinuses, and the ascending and descending thoracic aorta. Contrast-enhanced MRA has been successful in demonstrating atherosclerotic occlusive disease of the aorta, aortic dissection, anomalies of the aortic arch, vascular malformations, and vascular involvement by tumor. It does not routinely require cardiac gating, which makes it a more widely applicable technique in patients with irregular cardiac rhythms. Furthermore, respiratory artifacts are reduced by breath-holding, and artifacts due to flow-related enhancement or in-plane dephasing encountered with vascular tortuosity are much reduced. These advantages make CE MRA extremely useful for imaging of the aortic arch, great vessels, and intracranial circulation.

Contrast enhanced cervicocerebral MRA is optimized when the center of k-space is sampled near the peak arterial concentration of the gadolinium chelate. Centric encoding is an example of a vascular imaging technique that improves capture of the arterial phase of the bolus and reduces venous contamination of the image. Many other CE MRA techniques have been developed in order to better evaluate vascular pathology [36,67-71].

A contrast medium injection rate of 2 to 4 mL/sec generates a bolus profile with a 5 second to 7 second arterial phase. This is desirable because most techniques require several seconds to sample the center of k-space. The contrast injection volume may vary based on the size and condition of the patient [69]. For example, very large patients or those with known poor cardiac output may require a timing bolus and a larger volume of contrast in order to offset the effects of contrast dilution in the blood pool. The use of a power injector facilitates control of the injection rate and helps to standardize the protocol. Following injection of the contrast material, the power injector can rapidly switch to inject the saline flush. The dose and injection rate of contrast material will need to be adjusted accordingly for pediatric patients who typically have a faster circulation time. The size and location of the IV also needs special consideration in young children.

Rapid intracranial circulation, typically on the order of 8 to 10 seconds, makes CE MRA of the cervicocerebral vascular system particularly challenging. Arch and carotid cervicocerebral MRA studies require very accurate timing of the acquisition in relation to the contrast medium injection. If the images are obtained too early, the arterial structures may not be visualized. Late acquisition will result in reduced arterial signal, venous opacification, and soft-tissue enhancement. Ideally, the center of k-space is scanned during the first pass of the bolus [72].
A limitation of CE MRA is that the extracellular gadolinium chelates are nonspecific MR contrast agents. Many normal and pathologic tissues will enhance. This makes repeat imaging more problematic. Subtraction techniques may help, but often there is incomplete subtraction of the background, and artifacts generated by misregistration of the datasets can occur. Increased signal intensity of the enhanced adjacent soft tissues can obscure vessels on the MIP images and may simulate flow-related signal or degrade vascular detail. Blood-pool contrast agents (eg, gadofosveset trisodium) are available and may be of utility in dynamic CE MRA studies.

Saturation (SAT) bands are less effective when the T1 of blood is significantly reduced. In CE MRA, a poorly timed contrast bolus can result in undesirable venous enhancement, which cannot be eliminated by the selective placement of SAT bands, and relevant arterial anatomy may be obscured. Similarly, arterial structures cannot be selectively eliminated by saturation techniques when contrast material is administered. The type and frequency of artifacts will vary with the technique; thus, the supervising physician must understand the potential limitations of each acquisition method [73-75].

3. Phase contrast (PC) MRA
Phase contrast MRA 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 obtained with the TOF technique, although direction of flow can also be indicated. Contrast enhancement may also be used to increase the signal obtained from blood. In some instances, it is necessary to gate the PC acquisition to the cardiac cycle. When the proper velocity encoding is selected, the image data can be used to measure flow velocity or flow volume. When phase contrast MRA is used in this manner, it is frequently called 4-D flow MRA [76-80].

4. Initial results from recently developed clinically feasible MRA techniques such as continuous and pseudocontinuous arterial spin labeling (ASL) and inflow inversion recovery have shown clinical utility [57-59].

5. Vessel wall imaging
The previously described MRA techniques display images of the vessel lumen. Black-blood T1-weighted techniques are emerging that permit imaging of the cervical/intracranial arterial wall and may be of clinical value in the setting of subintimal and intramural dissections and atherosclerotic disease. For example, the detection of a thin fibrous cap, lipid/necrotic core, intraplaque hemorrhage, and neovascularity have been reported to be associated with a higher risk of ischemic events [81-86]. Detection and characterization of vessel wall enhancement can suggest the diagnosis of vasculitis, vasoconstriction, or symptomatic atherosclerotic disease [87].

6. MR angiography of the venous system, also called MR venography (MRV), can be performed using TOF, PC, and CE imaging techniques. Display protocols should be modified to focus on the venous structures as clinically indicated.

VI. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [52].

In addition to examining the vascular structures of interest, the MRA 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. When MRA techniques are used for determining carotid stenosis, the report
should reflect the methodology and reference the criteria for percent stenosis outlined in the NASCET or based on methods validated against NASCET measurement [88-91]. Also, the percent stenosis must be calculated using the distal cervical ICA (internal carotid artery) diameter, where the walls are parallel, for the denominator. Similar to CTA, MRA with attention to the acquisition parameters and postprocessing techniques can provide cross-sectional measurements of stenosis that correlate with properly performed NASCET estimates of percent stenosis obtained with catheter angiography [92]. In the setting of near occlusion, it may not be accurate to calculate percent stenosis ratios in the presence of poststenotic arterial diameter decrease. Some MRA techniques may not be amenable to quantitative measurements, in which case qualitative assessment of stenosis should be provided.

VII. EQUIPMENT SPECIFICATIONS

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

A workstation capable of creating multiplanar reformations, MIP images, and 3-D volume renderings or shaded surface displays is required for MR angiograms. The workstation should also allow the direct measurement of vascular diameters and, when appropriate, path lengths and branch angles, either from source images or from reformatted images.

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. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [93-95].

Equipment performance monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging (MRI) Equipment [96].

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