Revised 2010 (Resolution 21)*

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

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

This guideline 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 several MRA techniques that are used for the evaluation, assessment of severity, and follow-up of vascular 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.

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

MRA has important attributes that make it valuable in assessing a wide spectrum of vascular disease [1]. 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 three-dimensional capability. These benefits must be balanced against the potential of flow and motion artifacts to degrade MRA images and the potential, in at risk populations, of nephrogenic systemic fibrosis (NSF) when gadolinium contrast agents are used.

Children demonstrate a different spectrum of disease than do adults, and the routine protocols used for evaluating the adult patient may not be optimal or even appropriate in evaluating children. As the brain and the cervicocerebral vascular region develop during infancy and childhood, cervicocerebral MRA can provide valuable information regarding flow conditions and pathologic processes within the brain and spine. However, technical and safety issues are more complex in pediatric patients. The smaller size of the pediatric patient increases the demand for higher resolution. In addition, sedation is frequently required to successfully complete the examination.

Application of this guideline should be in accordance with the ACR Practice Guideline for Performing and Interpreting Magnetic Resonance Imaging (MRI) and the ACR–SIR Practice Guideline for Sedation/Analgesia.

II. INDICATIONS

A. Pediatric Indications for Cervicocerebral MRA

MRA is applicable in children for first-line cervicocerebral vascular examination due to the risk (albeit low) related to invasive angiographic procedures. Various studies of children with strokes that compared MRA to conventional angiography found MRA to be 1) accurate in delineating stenosis and/or occlusion, and 2) able to demonstrate collateral vascular anatomy [2-5].

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

1. Arterial dissection or occlusive disease.
2. Dural sinus thrombosis and intracranial venous occlusive disease.
3. Cerebral arteriovenous malformations.
4. Vascular status following extracorporeal membrane oxygenation.
5. Intracranial aneurysm.
6. Vascular abnormalities, such as sickle cell anemia**,** large vessel vasculitis, and moyamoya disease.
7. Blood supply to vascular neoplasms for operative planning.
8. Etiology of intracranial hemorrhage and spinal hemorrhage.
9. Presence, nature, and extent of traumatic injury to cervicocerebral vessels, including dissection.
10. Nature and extent of other congenital or acquired vascular abnormality.

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 [6-8].
2. Etiology of intracranial hemorrhage and spinal hemorrhage [9].
3. Relevant vascular anatomy for preprocedural evaluation**,** determining the effect of therapeutic measures, including post-treatment evaluation of endovascular treatment of aneurysm and arteriovenous malformation (AVM) ablation [10,11].
4. Presence, location, and anatomy of extracranial and intracranial aneurysms and vascular malformations [12-14].
5. Presence, nature, and extent of traumatic injury to cervicocerebral vessels, including dissection [15,16].
6. Vascular supply to tumors.
7. Dural sinus thrombosis and intracranial venous occlusive disease.
8. Nature and extent of other congenital or acquired vascular abnormality [17-19]**.**

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 [20-22]:

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 (i.e., subclavian, innominate, common carotid).

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

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

IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the ACR Practice Guideline for Performing and Interpreting Magnetic Resonance Imaging (MRI), and the ACR Guidance Document for Safe MR Practices [23].

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [1,4].

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. (See the ACR Practice Guideline for Communication of Diagnostic Imaging Findings). 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.

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 [24].

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 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

Magnetic resonance angiography is a general term that refers to a diverse group of MR pulse sequences. Three different mechanisms can be used to generate signal from flowing blood and each sequence may be performed with 2D or 3D techniques. Time of flight (TOF) relies on inflow enhancement to generate images of blood flow. 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. A third method relies on enhancement of the blood signal by paramagnetic contrast agents and uses rapid, three-dimensional (3D) T1-

weighted gradient echo acquisitions. Individuals using MRA must understand the artifacts and limitations of 2D TOF, 3D TOF, 2D or 3D PC, and contrast-enhanced 3D and 4D time resolved imaging techniques. The most commonly used techniques are TOF and contrast enhanced 3D and 4D.

1. Non-contrast TOF MRA
   In 2D TOF acquisitions, multiple thin slices are obtained and combined to form a three-dimensional data set. Vascular structures are isolated from the surrounding tissue by selecting the pixels with maximum intensity. The 3D TOF technique directly acquires a three-dimensional volume. The vascular structures are delineated by selecting the pixels with maximum intensity [25-27].

   The MRA data sets are also displayed as two-dimensional source images. The supervising physician should review the source images to reduce possible confusion of high signal material (e.g., fat) 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 [28].

   MRA data are routinely postprocessed using a maximum-intensity projection (MIP) reconstruction algorithm. Rotating displays of three-dimensional data sets allow separation of vessels that are superimposed on routine projections. The supervising physician must be familiar with MIP, surface display, volume display, and multiplanar reformatting 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 [29].

2. Contrast-enhanced MRA
   Contrast-enhanced 3D MRA combines a fast T1-weighted gradient echo acquisition with an intravenously administered paramagnetic contrast agent [30]. 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 stenosis. MRA with contrast enhancement has been evaluated for use in assessing the cervical carotid arterial system, the vertebrobasilar system, the dural venous sinuses, and the ascending and descending thoracic aorta. MRA with contrast media has been successful in demonstrating atherosclerotic occlusive disease, dissection of the aorta, anomalies of the aortic arch, and vascular involvement by tumor. MRA with contrast medium does not require cardiac gating and is, therefore, more widely applicable in patients with irregular cardiac rhythms. Furthermore, respiratory artifacts are eliminated by breath holding, and artifacts due to flow-related enhancement are not encountered. These advantages make MRA with contrast media extremely useful for imaging of the aortic arch and great vessels.

   Contrast medium enhanced cervicocerebral MRA is optimized when the center of k space is sampled during the peak arterial concentration of the gadolinium chelate. Elliptical centric encoding is an example of a technique that improves capture of the arterial phase of the bolus and reduces venous contamination of the image.

   A contrast medium injection rate of 2 to 3 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 injection volume may vary based on the size of the patient. For very large patients and those with known poor cardiac output, volume of contrast media may need to be increased 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 injection rate and dose of contrast material will need to be adjusted for pediatric patients.

   Imaging of the cervicocerebral vascular system is particularly challenging due to the roughly 10 second circulation times within the brain. 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 enhancement of the soft tissues. Ideally the center of k space is scanned during the first pass of the bolus [31].

   A limitation of contrast medium enhanced MR angiography 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 are generated due to misregistration of the data sets. The high-signal-intensity enhanced stationary tissue will obscure vessels in the MIP images and may simulate flow signal pattern or degrade vessel detail.

Saturation (SAT) bands are less effective when the T1 of blood is significantly reduced. Venous structures such as the internal jugular vein cannot be eliminated from the MR angiogram by the selective placement of SAT bands and may obscure the carotid bifurcation. 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 [32-34].

3. Phase contrast (PC) MRA
   PC MRA is the third general category of MRA techniques. The PC data can be obtained as either a two-dimensional or three-dimensional dataset. Contrast medium 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 obtained with the TOF technique, although direction of flow can also be indicated. In some instances, it is necessary to gate the PC acquisition to the cardiac cycle to measure flow velocity or flow volume. Peripheral or cardiac gating should be available.

4. Wall imaging
   The previously described MRA methods display images of the vessel lumen. Techniques are emerging that permit imaging of the arterial wall and may be of clinical value. For example, the detection of methemoglobin within plaque has been reported to be associated with a higher risk of ischemic events [35].

VI. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Guideline for Communication of Diagnostic Imaging Findings.

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. 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. Also, the percent stenosis must be calculated using the distal cervical ICA diameter, where the walls are parallel, for the denominator. Similar to CTA, MRA with attention to the acquisition parameters and post-processing techniques can provide cross sectional measurements of stenosis that correlate with properly performed NASCET estimates of percent stenosis obtained with catheter angiography [36]. In the setting of near occlusion, it may not be accurate to calculate percent stenosis ratios in the presence of post-stenotic 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, maximum intensity projections, and 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 web page (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 [37-39].

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

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