The American College of Radiology, with more than 30,000 members, is the principal organization of radiologists, radiation oncologists, and clinical medical physicists in the United States. The College is a nonprofit professional society whose primary purposes are to advance the science of radiology, improve radiologic services to the patient, study the socioeconomic aspects of the practice of radiology, and encourage continuing education for radiologists, radiation oncologists, medical physicists, and persons practicing in allied professional fields.

The American College of Radiology will periodically define new practice guidelines and technical standards for radiologic practice to help advance the science of radiology and to improve the quality of service to patients throughout the United States. Existing practice guidelines and technical standards will be reviewed for revision or renewal, as appropriate, on their fifth anniversary or sooner, if indicated.

Each practice guideline and technical standard, representing a policy statement by the College, has undergone a thorough consensus process in which it has been subjected to extensive review, requiring the approval of the Commission on Quality and Safety as well as the ACR Board of Chancellors, the ACR Council Steering Committee, and the ACR Council. The practice guidelines and technical standards recognize that the safe and effective use of diagnostic and therapeutic radiology requires specific training, skills, and techniques, as described in each document. Reproduction or modification of the published practice guideline and technical standard by those entities not providing these services is not authorized.

Revised 2012 (Resolution 17)*

ACR–ASNR–SPR PRACTICE GUIDELINE FOR THE PERFORMANCE OF INTRACRANIAL MAGNETIC RESONANCE PERFUSION IMAGING

PREAMBLE

These guidelines are an educational tool designed to assist practitioners in providing appropriate radiologic and radiation oncology 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), and the Society for Pediatric Radiology (SPR).

Magnetic resonance perfusion imaging is a proven and useful tool for the evaluation, assessment of severity, and follow-up of diseases of the central nervous system. It can be performed with contrast administration using dynamic susceptibility contrast (DSC) or dynamic contrast enhancement (DCE) techniques, or without contrast administration using arterial spin-labeling (ASL) techniques.

II. INDICATIONS

Primary indications for perfusion MRI include, but are not limited to, the following:

A. Diagnosis and Characterization of Mass Lesions
   1. Differential diagnosis (tumor vs. tumor mimic).
   2. Diagnosis of primary neoplasms (may include grading).
   3. Surgical planning (biopsy or resection).
   4. Therapeutic follow-up.
a. Radiation necrosis vs. recurrent or residual tumor.
b. Chemonecrosis vs. recurrent or residual tumor.
c. Pseudoprogression and pseudoresponse.

B. Assessment of Neurovascular Disease
   1. Acute infarct (assessment of penumbra).
   2. Assessment of cervical or intracranial vascular steno-occlusive disease.
   3. Assessment of cervical or intracranial revascularization efficacy.
   4. Assessment of vasospasm.

C. Neurodegenerative Disease

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


Peer reviewed literature pertaining to MR safety should be reviewed on a regular basis.

V. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for MRI perfusion 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 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 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 for consultation. Patients should be screened and interviewed prior to the examination to exclude individuals who may be at risk by exposure to the MR environment.

Bolus perfusion studies require the 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 utilization. Although gadolinium is widely used in pediatric patients, the physician responsible for administering it should be aware that safety and efficacy of gadolinium agents is not as well established in children <2 years of age as it is in older children and adults. (See the ACR–SPR Practice Guideline for the Use of Intravascular Contrast Media and the ACR Manual on Contrast Media.)

Pediatric patients or patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of moderate sedation or general anesthesia may be needed to achieve a successful examination, particularly in young children. 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
   1. Dynamic susceptibility contrast MRI (DSC MRI) T2* perfusion
      a. Technique
         The most common method to perform DSC-MRI is a gradient-echo echo-planar sequence, which permits acquisition of an entire image slice with only a single radiofrequency excitation. In DSC, images are acquired dynamically during the passage of gadolinium through the brain. Image contrast is based on gadolinium’s susceptibility effect. Typically, approximately 10 seconds after the beginning of image acquisition, 0.1 mmol/kg of gadolinium is administered via a peripheral intravenous catheter at a rate of 5 cc/s using a power injector to assure standard, reproducible contrast agent administration. Ideally, images should be obtained at least once every 1.5 seconds. Sufficient number of repetitions should be acquired to capture the entire first pass of the contrast bolus – typically 40 repetitions at a TR=1.5 seconds. Examples may be found in the literature [1-3].

      The specific protocol may vary depending on the manufacturer and field strength. For imaging neoplasms, an initial gadolinium dose of approximately 0.05 mmol/kg may be injected prior to the DSC injection in order to correct for anticipated leakage effects.

      b. Data processing
         The images obtained during the examination (signal intensity versus time curves) are converted by a computer to contrast agent concentration-versus-time curves. Pre-injection points are typically averaged to produce an estimate of baseline signal intensity, \( S_0 \). Following the arrival of the bolus, the concentration of gadolinium in a voxel can be derived from signal intensity by the equation
         \[
         C(t) = -k \ln \left( \frac{S_t}{S_0} \right),
         \]
         in which \( C(t) \) is the contrast agent concentration at a particular time \( t \), \( S_t \) is the signal intensity at that time, \( S_0 \) is the baseline signal intensity before the arrival of the contrast agent, and \( k \) is a constant whose value depends on the pulse sequence used, the manner in which the contrast is injected, and complex characteristics of the patient’s circulatory system that are difficult to model. Because the value of \( k \) is difficult to estimate, most perfusion maps provide only relative quantification of perfusion parameters. Cerebral blood volume (CBV) is generally calculated by numerically integrating the area under the entire \( C(t) \). Some researchers have attempted to extract the first pass of the contrast bolus by fitting gamma variates to the first portion of \( C(t) \), but no particular model has been shown to reflect the first pass reliably. Calculation of cerebral blood flow (CBF) requires incorporation of the concentration-versus-time curve not just in any voxel but also in the arteries that supply blood to that voxel, the arterial input function (AIF). An AIF is calculated by measuring \( C(t) \) in voxels near an artery or arteries and averaging those \( C(t) \) functions, either manually or automatically.

      A mathematical process called deconvolution is used to derive a scaled residue function in each voxel from the AIF and the voxel’s \( C(t) \) function. The amplitude of the deconvolved signal is measured as the CBF, and the time at which this maximum value is reached is called Tmax. Mean transit time is calculated by dividing CBV by CBF. Time to peak (TTP) is the time at which signal intensity reaches its minimum.

   2. Dynamic contrast enhanced magnetic resonance imaging (MRI) (DCE MRI) – T1 permeability mapping [4-9]
      a. Technique
         The most common method to perform DCE-MRI uses a fast T1-weighted gradient-echo sequence with short TE (<1.5 ms) and TR (<7 ms) and flip angle around 30 degrees. A temporal resolution of 5 to 10 seconds for obtaining a series of two-dimensional (2D) slices or a single three-dimensional (3D) slab is possible with current technology while preserving spatial resolution. Obtaining a T1 map, commonly using a precontrast lower flip angle dataset, improves the accuracy of gadolinium concentration calculations and quantification. The use of a power injector for bolus (2 to 5 cc/second) or infusion (30 to 60 seconds) technique ensures reproducible and standardized contrast agent administration. As there is the potential for leakage effects that can cause the relative central blood volume (rCBV) measurements performed for DSC MRI to be overestimated or underestimated (see above), the DCE MRI injection is typically performed before the DSC MRI and also allows for saturation
of the extravascular space which provides for more accurate quantification of metrics such as rCBV from the DSC MRI acquisition described above.

b. Data processing
The determination of an AIF to obtain more accurate C(t) can be a challenge in DCE imaging. Ideally, the AIF would be determined in each patient using the dynamic curve of the carotid or middle cerebral artery. However, if this is not possible, the AIF of the superior sagittal sinus can suffice, with the understanding that this will introduce some error in the compartmental model output. The plasma concentration curve can be further fitted – e.g., to biexponential form (as in the Tofts model).

There are also “reference tissue” models that attempt to estimate the vascular tracer concentration from one or more normal-appearing surrounding tissues. The data can be reviewed qualitatively by characterizing the T1 signal intensity curves over time, or various DCE MRI quantitative metrics can also be estimated. The typical parameters that can be estimated from the DCE MRI include \( K^\text{trans} \) (vascular permeability), EES (extravascular, extracellular space), \( V_p \) (plasma volume) and the \( K_{ep} \) (\( K^\text{trans} \)/EES). In general malignant neoplasms will have a very high \( K^\text{trans} \) and \( V_p \) but lower EES, and more benign pathologies, including radiation necrosis and chemo necrosis, will have lower \( K^\text{trans} \) and \( V_p \), but higher EES.

3. Arterial spin-labeling perfusion MRI
a. Technique
Arterial spin-labeling (ASL) perfusion MRI uses magnetically labeled endogenous blood water as a tracer to derive information on cerebral hemodynamics. This is accomplished by manipulating the longitudinal magnetization of arterial blood water in order to differentiate it from the tissue magnetization. ASL does not require the use of an exogenous contrast agent, can be performed within about a 5 minute acquisition time, and provides both qualitative and quantitative measures on cerebral blood flow (CBF). The most common ASL approaches use either pulsed labeling (PASL) with an instantaneous spatially selective saturation or inversion pulse, or continuous labeling (CASL), most typically by flow driven adiabatic fast passage. The ASL images are acquired both with and without magnetization labeling of arterial blood water. The subtle difference between images acquired with (labeled) and without (control) ASL can be modeled to derive a calculated cerebral blood flow image showing perfusion in ml/min/100 g-tissue at each voxel.

b. Data processing
Analysis of the acquired ASL images can be performed using readily available software. The qualitative CBF map is created by subtracting the labeled images from the control images, resulting in an image with intensity proportional to CBF. The quantitative CBF in units of ml/min/100 g-tissue is much more challenging to measure and requires sophisticated software. Briefly, the equilibrium magnetization \( M_{eq} \) of the arterial blood is estimated by fitting the control or unlabeled signal in the brain tissue to a saturation-recovery curve. The CBF is calculated by a fit of the signal difference (\( \Delta M \)) to the perfusion model with the following values for the physical constants: \( R_1 \) (longitudinal relaxation rate of tissue); \( R_{1a} \) (longitudinal relaxation rate of blood); and \( \lambda \) (brain/blood partition coefficient of water).

2. Perfusion imaging in pediatric patients [10,11]

The need for small caliber IVs, intravenous access in hands and feet, and small caliber PICC lines in infants and small children limits the use of automated power injectors, and manual injection of gadolinium agents should be considered to avoid extravasation of contrast and damage to precarious IV access. The radiologist should confer with the clinician providing direct supervision of the child during the MRI procedure before ordering gadolinium to be given.

Perfusion models based on parameters derived from adults have been applied to children, but age-related normative values for CBF in children are not well established, and the effects of general anesthesia or conscious sedation on cerebral perfusion are not clear. ASL may be preferable to contrast-enhanced perfusion imaging in pediatrics, especially in neonates, given the theoretical improvement in SNR due to higher velocities of flow in children.

Special considerations in interpreting perfusion studies in infants and young children include: congenital heart disease involving right to left shunts, age related changes in flow velocity, and
sickle cell anemia in which flow velocity is typically elevated. The use of rCBV has limited application in pediatric brain tumors due to predominance of astrocytic tumors of low-grade and high prevalence of non-astrocytic tumors. Similarly, the utility of perfusion metrics in determination of penumbra in pediatric stroke is not known.

VI. DOCUMENTATION

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

VII. EQUIPMENT SPECIFICATIONS

The MRI equipment specifications and performance must meet all state and federal requirements. The requirements include, but are not limited to, specifications of maximum static magnetic strength, maximum rate of change of 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 web site (http://www.acr.org/guidelines).

Specific policies and procedures related to MRI safety should be in place along 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.

Equipment 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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