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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.

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## **PRACTICE GUIDELINE FOR THE PERFORMANCE OF INTRACRANIAL MAGNETIC RESONANCE BOLUS PERFUSION IMAGING**

### **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 on 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 developed and written collaboratively by the American College of Radiology (ACR) and the American Society of Neuroradiology (ASNR).

Magnetic resonance perfusion imaging is a proven and useful tool for the evaluation, assessment of severity, and follow-up of diseases of the brain, including but not limited to tumoral disease and stroke. It should be performed only for a valid medical reason.

### **II. INDICATIONS**

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

#### **A. Assessment of Intracranial Tumoral Disease**

1. Diagnosis of primary neoplasms (may include grading)
2. Surgical planning (biopsy or resection)
3. Therapeutic follow-up
  - a. Radiation necrosis vs. active tumor
  - b. Chemonecrosis vs. tumor

B. Assessment of Acute Infarct – Determination of “Area at Risk”

C. Dynamic Vascular Assessment – Diamox Challenge

1. Determination of critical stenosis
2. Surgical planning for synangiostomy surgery
3. Evaluation of chronic ischemia and stroke risk

### 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 (2007).

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 scope of practice requirements. (2006 - ACR Resolution 35)

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 employed 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 shall supervise patient selection and preparation, 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.

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. (See the [ACR Practice Guideline for the Use of Intravascular Contrast Media](#).)

Patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of moderate or “conscious” sedation may be needed to achieve a successful examination. If moderate sedation is necessary, refer to the [ACR Practice Guideline for Adult Sedation/Analgesia](#) or the [ACR Practice Guideline for Pediatric 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.

#### C. Examination Technique

An intravenous line should be inserted in the antecubital area for contrast agent administration prior to the start of imaging. The specific perfusion protocol may vary at the discretion of the radiologist but typically may include localizing sagittal T1-weighted images followed by unenhanced axial T1-weighted, T2-weighted, and FLAIR (fluid attenuated inversion recovery) images of the brain. From these images the area(s) of interest are localized for perfusion imaging. Echo planar perfusion imaging (EPI) during the first pass of a bolus of a gadolinium contrast agent administered via a power injector at 3-5 cc/sec would then be performed. Finally, postcontrast axial T1-weighted images may be obtained.

Perfusion imaging typically is performed using a lipid suppressed, T2\*-weighted, EPI sequence. The following parameters may be used as a guide: echo time, 54 msec;

field of view, 230 x 230 mm; slice thickness, 5 or 7 mm; data matrix, 128 x 128 matrix; in plane voxel size, 1.8 mm x 1.8 mm. A variable number of slices with varying thickness and interslice gap should be selected to cover the volume identified on the T2-weighted images. A series of 40 to 60 multislice acquisitions should be acquired at 1 to 1.5 second intervals. The first 10 acquisitions should be performed before contrast injection to establish a precontrast baseline. At the 10th acquisition, 0.1 mmol/kg of gadolinium-based contrast media should be injected by power injector at a rate of 3-5 ml/sec through a 20-22 gauge angiocatheter, immediately followed by continuous saline flush. A head coil should be used for signal reception.

#### D. Postprocessing

The EPI images should be postprocessed using programs readily available. The principles underlying the use of contrast agents to estimate perfusion can be summarized as follows: During the first pass of the contrast bolus, T2\* is reduced, and hence the signal intensity in T2\*-weighted images drops. The change in relaxation rate (i.e., the change in the reciprocal of T2\*),  $\Delta R2^*$ , can be calculated from the signal drop:

$$\Delta R2^*(t) = \frac{-\ln(S(t)/S_0)}{TE}$$

where S(t) is the signal at time t, S<sub>0</sub> is the precontrast signal and TE is the echo time.  $\Delta R2^*$  is proportional to the concentration of contrast agent in the tissue, and hence cerebral blood volume (CBV) is proportional to the area under the curve of  $\Delta R2^*$  against time provided there is no recirculation or leakage of contrast. In general, however, these assumptions are violated, but the effects can be reduced by fitting a gamma-variate function to the first pass of the measured  $\Delta R2^*$  curve. This function approximates the curve that would have been obtained without recirculation or leakage. CBV can then be estimated from the area under the fitted curve rather than the original data.

It should be emphasized that the procedure outlined here does not give an absolute measurement of CBV. It is therefore usual to express CBV figures relative to some standard tissue, typically normal appearing white matter, avoiding regions that are radiation damaged. Data analysis therefore consists of the following steps:

1. Obtain curves of signal intensity against time.
2. Estimate mean precontrast signal intensity (S<sub>0</sub>) from 10 data points acquired before arrival of the bolus. It is important to exclude the first 3-4 images during which the steady state is established.
3. Calculate  $\Delta R2^*$  and fit gamma-variate function to the  $\Delta R2^*$  curve.
4. Calculate area under the fitted curve.

5. Calculate relative CBV (rCBV): the ratio relative to a CBV value calculated for contralateral white matter.

Ideally, rCBV values would be calculated in this way for each pixel, but an alternative strategy may also be used. Maximum signal intensity drop (DS<sub>max</sub>) may be calculated for each pixel. These data are used to generate a color overlay for the base images. In order to reveal underlying anatomy, a threshold may be applied so that no overlay values would be calculated for white matter. In other words, DS<sub>max</sub> has to exceed some threshold value for the overlay to be calculated. Since perfusion in white matter is lower than in other tissues, careful selection of the threshold value could be used to exclude white matter. The DS<sub>max</sub> color overlays could then be used to select regions for rCBV calculation at the discretion of the radiologist.

While rCBV is the most common metric used in the study of brain tumors, other hemodynamic markers can be obtained from the bolus method and have been shown to be useful in the study of other cerebrovascular diseases, including ischemic stroke. In particular, one can examine the differences in the time at which the maximum amount of contrast arrives in each voxel. This simple and robust measurement, called time-to-peak (TTP), yields information about upstream vascular stenosis or collateral flow, and it has been used as a marker of perfusion abnormality in stroke studies. There is some evidence that viable brain tissue at risk of infarction may exist within the “mismatched” region between the initial diffusion-weighted lesion and the larger TTP abnormality (“diffusion weighted imaging [DWI] - perfusion weighted imaging [PWI] mismatch”).

By using more complex mathematical models, some of which involve deconvolution of an arterial input function to account for the finite time width of the bolus, cerebral blood flow (CBF) and mean transit time (MTT) can be derived. Because of this additional processing step, as well as errors that can arise from regional bolus delay and dispersion, estimation of these parameters tends to be less accurate than the measurement of rCBV or TTP.

## 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 shall 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 CONCERNS

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 Concerns appearing elsewhere in the ACR Practice Guidelines and Technical Standards book.

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](#).

### ACKNOWLEDGEMENTS

This guideline was developed according to the process described in the ACR Practice Guidelines and Technical Standards book by the Guidelines and Standards Committee of the Commission on Neuroradiology in collaboration with the American Society of Neuroradiology (ASNR).

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