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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.

2007 (Resolution 2)*

ACR–ASNR PRACTICE GUIDELINE FOR THE PERFORMANCE OF COMPUTED TOMOGRAPHY (CT) PERFUSION IN NEURORADIOLOGIC 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 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 developed and written collaboratively by the American College of Radiology (ACR) and the American Society of Neuroradiology (ASNR).

Computed tomography (CT) perfusion is a technique used in neuroradiology to assess tissue level perfusion and delivery of blood to the brain and/or tissues of the head and neck. The linear relationship between CT numbers or Hounsfield units (HU) and the amount of iodinated contrast material in an image pixel, together with the high spatial and temporal resolution characteristics of the scanning paradigm, make CT perfusion a valuable tool for evaluating blood supply to neoplastic and non-neoplastic tissue (including normal and ischemic tissue). In particular, the evaluation of cerebral ischemia or the angiogenesis state of a tumor is readily performed with CT perfusion imaging. CT perfusion should be performed only for a valid medical reason and with the minimum radiation dose necessary to achieve an optimal study. This standard outlines the principles for obtaining a high-quality CT perfusion study.

II. INDICATIONS/CONTRAINDICATIONS

A. Indications for CT perfusion in neuroradiology include, but are not limited to:

1. Brain

Primary indications: acute neurological change suspicious for stroke, suspected vasospasm following subarachnoid hemorrhage, cerebral hemorrhage with secondary local ischemia, and intracranial tumors.

Secondary indications: follow-up of acute cerebral ischemia or infarction in the subacute or chronic phase of recovery; to assist in planning, and evaluating the effectiveness of, therapy for arterial occlusive disease; and in patients with contraindication to magnetic resonance imaging (MRI) or with devices or material in or close to the field of view that would result in nondiagnostic MRI scans. CT perfusion scanning may also be helpful in the setting of acute trauma.

2. Head and neck

Primary indications: evaluation of the vascular status of solid tumors where MRI is degraded due to susceptibility artifact from air-containing spaces or from surgical clips or dental work.

Secondary indications: Follow-up of tumor response to therapy.

B. Absolute Contraindications

Prior documented major allergic reaction to iodinated contrast material.

C. Relative Contraindications

1. Diabetes mellitus.
2. Renal failure, unless dialysis is planned.
3. Prior documented minor allergic reactions to contrast materials or history of atopy, asthma, or other life-threatening allergies. Consider premedication if time permits.

For the pregnant or potentially pregnant patient, see the [ACR Practice Guideline for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation](#).

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the [ACR Practice Guideline for Performing and Interpreting Diagnostic Computed Tomography \(CT\)](#).

Physicians who supervise, perform, and interpret CT perfusion studies should be licensed medical practitioners who have a thorough understanding of the indications for CT perfusion as well as a familiarity with the basic physical principles and limitations of the CT perfusion technology, including CT imaging, computerized data processing, and the quantitative modeling techniques used to generate the maps of vascular physiologic parameters. The physicians should have a thorough understanding of radiation safety in CT. They should be familiar with alternative and complementary imaging and diagnostic procedures and should be capable of correlating the results of these with CT perfusion studies. Physicians responsible for CT perfusion studies should be able to demonstrate familiarity with the anatomy and especially the physiology and pathophysiology of those organs and anatomic areas that are being examined. These physicians should be able to provide evidence of training and requisite competence needed to perform CT perfusion studies successfully.

A. Physician

Examinations must be performed under the supervision of and interpreted by a physician with the following qualifications:

1. Certification in Radiology or Diagnostic Radiology by the American Board of Radiology (ABR), the American Osteopathic Board of Radiology, the Royal College of Physicians and Surgeons of Canada, or the Collège des Médecins du Québec provided the board examination included CT in neuroradiology.
or
2. If appropriately certified by the ABR before it examined in CT (1978), the physician can qualify by experience (including at least 2 years during which 500 examinations of the brain, spine, and head and neck were supervised, interpreted, and formally reported) or by completing a mentoring program of 1 year or less during which the physician interprets 300 exams under the supervision of an on-site qualified physician (including generating a formal report). If pediatric neuroradiologic CT examinations are to be performed, the physician should have had 3 months of documented formal training in pediatric radiology and should have had documented training and experience in the administration of appropriate sedation and iodinated contrast to pediatric patients.

- or
3. The physician shall have spent a minimum of 6 months interpreting cross-sectional neuro-radiologic imaging examinations with at least 3 months' training in the interpretation and formal reporting of CT images in a documented formal training program in an institution with accredited residency, fellowship, or equivalent programs in diagnostic radiology and/or neuroradiology.

or

4. In the absence of residency training in diagnostic radiology or radiology, formal fellowship training in neuroradiology, or other postgraduate training that included instruction in neuroradiologic CT, and at least 2 years of experience with CT under the supervision of an on-site qualified physician during which a minimum of 1,000 CT examinations of the brain, spine, and head and neck were supervised, interpreted, and formally reported.

and

5. The physician shall have documented training in the physics of diagnostic radiology. Additionally, the physician must be familiar with principles of radiation protection, the hazards of radiation exposure to both patients and radiologic personnel, and appropriate monitoring requirements.
6. The physician should be thoroughly acquainted with the many morphologic and patho-physiologic aspects, variations, and diseases of the central nervous system, spine, and head and neck and the subtle findings for which urgent therapy may be warranted, such as in acute stroke. Additionally, supervising physicians should have appropriate knowledge of alternative imaging methods, including the use of and indications for such specialized studies as angiography, ultrasonography, MRI, and nuclear medicine studies.
7. The physician should be familiar with the appropriate requirements for patient preparation for the examination. He or she must have had training in the recognition and treatment of adverse effects of contrast materials used for these studies. Training and proficiency in cardiopulmonary resuscitation are required when patients undergo contrast-enhanced CT.
8. The physician shall be responsible for reviewing all indications for the examination; specifying the use, dosage, and rate of administration of contrast agents; supervising the safe and effective administration of sedative to and monitoring of patients requiring conscious sedation; specifying the scanning technique; interpreting images and constructed physiologic maps; generating written reports; and

maintaining the quality of the images, maps, and interpretations.

Maintenance of Competence

Physicians must regularly perform and interpret a sufficient number of CT and CT perfusion studies to maintain their skills and should participate in an ongoing quality-improvement program.

Continuing Medical Education

Continuing education should be in accordance with the [ACR Practice Guideline for Continuing Medical Education \(CME\)](#).

B. Qualified Medical Physicist

A Qualified Medical Physicist is an individual who is competent to practice independently in one or more of the subfields in medical physics. The ACR considers certification and continuing education and experience in the appropriate subfield(s) to demonstrate that an individual is competent to practice in one or more of the subfields in medical physics and to be a Qualified Medical Physicist. The ACR recommends that the individual be certified in the appropriate subfield(s) by the American Board of Radiology (ABR), the Canadian College of Physics in Medicine, or for MRI, by the American Board of Medical Physics (ABMP) in magnetic resonance imaging physics.

The appropriate sub-fields of medical physics for this standard are Diagnostic Radiological Physics and Radiological Physics.

A Qualified Medical Physicist should meet the [ACR Standard for Continuing Medical Education \(CME\)](#). (ACR Resolution 17, 1996 – revised in 2008, Resolution 7)

The Qualified Medical Physicist should be familiar with the principles of CT imaging physics and of radiation protection; the guidelines of the National Council on Radiation Protection and Measurements; laws and regulations pertaining to the performance of the equipment; the function, clinical uses, and performance specifications of the imaging equipment; and calibration processes and limitations of the instruments used for testing performance. The Qualified Medical Physicist should be knowledgeable in the field of computerized image processing and mathematical modeling of physiological processes.

The Qualified Medical Physicist should have a working understanding of clinical CT perfusion imaging protocols and methods of their optimization, as well as of the

implementation and limitations of computer algorithms used to construct maps of vascular physiologic function.

C. Registered Radiologist Assistant

A registered radiologist assistant is an advanced level radiographer who is certified and registered as a radiologist assistant by the American Registry of Radiologic Technologists (ARRT) after having successfully completed an advanced academic program encompassing an ACR/ASRT (American Society of Radiologic Technologists) radiologist assistant curriculum and a radiologist-directed clinical preceptorship. Under radiologist supervision, the radiologist assistant may perform patient assessment, patient management, and selected examinations as delineated in the Joint Policy Statement of the ACR and the ASRT titled “Radiologist Assistant: Roles and Responsibilities” and as allowed by state law. The radiologist assistant transmits to the supervising radiologists those observations that have a bearing on diagnosis. Performance of diagnostic interpretations remains outside the scope of practice of the radiologist assistant. (ACR Resolution 34, adopted in 2006)

D. Radiologic Technologist

Under the supervision of the physician, the technologist should be responsible for the comfort and safety of the patient; preparing and positioning the patient for the CT perfusion examination; and acquiring, recording, and processing the CT data in a manner appropriate for interpretation by the physician. The technologist should be fully trained to operate CT equipment and be knowledgeable in radiation physics and protection, with documented evidence of such training and experience. The technologist should be certified by the ARRT and, if applicable, have an unrestricted state license in radiological technology.

E. Nurse, if Applicable

Under the supervision of the physician, the nurse, if available, should be responsible for the care of the patient, including screening, preparation, sedation, monitoring of vital signs, support, recovery, discharge, and medical record documentation. The nurse should have documented training or experience in the care of patients undergoing neuroradiologic exams, including airway management, the use of sedative agents and contrast media, the recognition and management of adverse effects, and cardiopulmonary resuscitation. He or she should be certified by the appropriate registry and have an unrestricted state license.

IV. SPECIFICATIONS OF THE EXAMINATION

A. Written Request for the Examination

The written or electronic request for CT 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)

CT perfusion protocols in neuroradiology require close attention and development by the supervising physician. Protocols should be reviewed and updated periodically in order for the studies to be optimized to match current technology. The supervising physician should be familiar with the indications for each study, patient history, and potential adverse reactions to contrast media. The supervising physician must understand the underlying physics of CT imaging and how various imaging parameters affect the image quality and the radiation dose. Guidelines should be provided that deal with potential hazards associated with CT imaging of the brain to the patient as well as others in the immediate area. The supervising physician should understand the limitations of the data analysis technique used and of the physiological model applied algorithmically to the data; this can be achieved by collaborating with a medical physicist.

Intravenous (IV) contrast injection should be performed using injection protocols that are in accordance with the institution’s policy on IV contrast utilization. The responsible physician should be able to treat adverse reactions arising from administration of contrast. The supervising physician should be familiar with the effects of contrast injection rate, contrast volume, and concentration on the quality of the temporal enhancement curves and constructed physiologic maps.

B. Patient Selection and Preparation

The physician responsible for a CT perfusion study should supervise patient selection and preparation. Patients should be screened for any history of contrast reactions prior to the examination to exclude individuals who may be at risk. In an acute situation a supervising physician decides about the performance of a CT perfusion study based on a risk/benefit analysis.

A patient is prepared for a CT perfusion study by inserting a cannula into a vein at or above the antecubital region prior to the patient's entry into the scanner. For first pass or dynamic studies, at least an 18-gauge cannula is required; for whole brain perfusion studies only, a 20-gauge cannula could suffice. The patient should lie on the scanner table in supine position with his or her head in a head holder. The head should be immobilized using forehead and chin straps, and a contrast infusion pump should be connected to the cannula. The head is centered to the scanner isocenter.

C. Examination Techniques

There are three CT perfusion approaches that use different data acquisition and analysis methods. These methods differ in their volume coverage (i.e., the amount of tissue that can be imaged during one data acquisition or one imaged series), the amount of contrast agent injected, the injection rate, the data acquisition mode used to acquire the data (helical or cine), and the frequency of data acquisition.

Injection of contrast should be performed using a power injector and adhering to the institution's policies on contrast utilization. Relatively high injection rates are preferable in cine studies to improve the data quality. An appropriately qualified person should monitor contrast administration in the scanner room, adhering to appropriate radiation protection measures per the institution's guidelines. Dual bore, saline chase injection pumps are preferable to optimize the use of contrast material.

When high resolution helical imaging is used, various slice thicknesses and multiple image planes (coronal, sagittal, oblique) can be reconstructed from the same raw data set obviating the need for separate or repeated data acquisitions.

1. Whole brain CT perfused blood volume

Whole brain CT perfused blood volume is assessed by acquiring a helical scan through the whole brain with and without contrast.

A noncontrast scan is first acquired through a prescribed volume of interest and reconstructed into 3 to 5 mm contiguous or overlapping slices. Reconstructed slice thickness should not exceed 5 mm.

Acquiring a helical data set through the whole brain during injection of a nonionic contrast agent constitutes a contrast scan. The total volume of contrast material injected is typically between 90 to 150 ml depending on the volume imaged and the speed of data acquisition. Injection rates of 3 to 3.5 ml/second are typical producing a 25 to 40 second long bolus. Delay time between onset of injection and image data acquisition should be long enough to assure that all perfused arteries, capillaries, and veins are filled with contrast material during the time of helical scanning. A 20 to 25 second delay is long enough for most patients. The contrast data should be scanned and reconstructed in thin slices using the minimum slice thickness available on the scanner.

Technique parameters affecting the radiation dose (kVp, mA, and beam collimation) should be optimized for each scanner type so that diagnostic quality images are produced with a minimum radiation dose.

Interpretation is best done using soft copy reading, interactively varying the window and level settings. Noncontrast and contrast scans should be interpreted together.

2. First pass CT perfusion

A first pass or bolus tracking CT perfusion study is performed by acquiring repeated images at the same location (a cine scan) through a volume of interest during bolus injection and passage of contrast through the region of interest. The total volume and injection rate of contrast material should be optimized for each pathophysiologic situation being investigated, with a minimum volume of 40 ml and a minimum injection rate of 4 ml/second. The higher the injection rate the better the peak opacification and the better the image and temporal curve quality, which in turn determines the quality of the constructed physiologic maps. The relationship between the start of imaging and start of contrast injection should be such that at least 2 baseline images are obtained prior to arrival of contrast into the tissue of interest. Normally, starting imaging 5 seconds (or less) after the onset of injection will suffice to achieve this goal. Cine imaging should

cover the whole first passage of contrast through the tissue under investigation. Images should be reconstructed at least at one-second intervals, although more frequent images can be reconstructed as computer resources allow without alteration of the acquisition rate.

A multislice cine scan is preferable, although a single slice scan can be useful in some circumstances. The maximum width of the imaged volume is determined by the CT scanner's detector array width in multi-detector-row scanners, and by the collimated slice thickness in single-detector-row scanners.

IV contrast injection should be performed in accordance with the institution's policy on IV contrast utilization. Higher injection rates will increase the quality of a first pass cine CT perfusion study by increasing the transient contrast agent concentration and thus the signal to noise ratio of the time contrast curves used to construct the physiologic maps. (See the [ACR Practice Guideline for the Use of Intravascular Contrast Media](#).)

Technique parameters affecting the radiation dose (kVp, mA and beam collimation) should be optimized for each scanner type so that diagnostic quality images and maps are produced at minimum radiation dose.

Cine images should be viewed electronically using cine display in order to demonstrate possible patient or organ movement. If movement is observed, the effects of motion on the constructed maps should be considered. The physiological maps should be interpreted with the knowledge of all clinical data and the findings of anatomical imaging. Images are better viewed on a dedicated computer display rather than from film or paper copy as this permits interactive adjustment of brightness, contrast, and color scale. If maps of blood volume, blood flow and mean transit time are produced, they should be interpreted as a coherent set of data; none of the maps should be interpreted in isolation without knowledge of other types of maps available for review.

3. Dynamic CT perfusion

Acquiring a temporal set of images through an extended volume of interest during a bolus injection of contrast constitutes a dynamic CT perfusion study. In this context, the extended volume of interest refers to imaging of tissue beyond the absolute width of the detector array.

The total volume and rate of injection of contrast material should be optimized to the pathophysiology being investigated. Delay time between onset of imaging and injection of contrast should be long enough to obtain at least two baseline sets: one acquired before the contrast agent reaches the portion of tissue being imaged, and one after. Frequency of image acquisition should be matched to the tissue physiology and be such that an arterial input curve as well as tissue enhancement curves can be constructed. Generation of data for the arterial input curve may require interleaved dedicated imaging at a higher rate, for a specific subset of the imaged volume containing an appropriate artery.

Intravenous (IV) contrast injection should be performed in accordance with the institution's policy on IV contrast utilization.

Technique parameters affecting the radiation dose (kVp, mA and beam collimation) should be optimized for each scanner type so that diagnostic quality images and maps are produced at minimum radiation dose.

Temporal images should be viewed electronically using cine display in order to demonstrate possible movement. If movement is observed, the effects of motion on the constructed maps should be considered. The physiological maps should be interpreted with the knowledge of all clinical data and the findings of anatomical imaging. Images are better viewed on a computer display rather than from film or paper copy as this permits interactive adjustment of brightness, contrast, and color scale. If various maps of tissue physiology are produced they should be interpreted as a coherent set of data; none of the maps should be interpreted without considering the information presented in any other type of maps.

The responsible physician should understand the limitations of various CT perfusion imaging methodologies and the limitations of mathematical models used to construct the physiologic maps. The responsible physician should decide which of the various CT perfusion methodologies to use for a particular pathology or organ part. This decision should be based on clinical information, expected physiological behavior of underlying pathology, and contrast pharmacokinetic behavior.

V. DOCUMENTATION

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

The amount of contrast injected and the injection rate used should be included.

Observation of any visible movement during a cine scan should be included in the report, and its impact on the calculated maps should be considered when interpreting them. Specifically, for dynamic and first pass cine imaging it is essential that the arterial and venous curves used for calculating the perfusion maps be archived together with the temporal images and physiologic maps. This serves as a quality control parameter for any particular CT perfusion scan.

VI. EQUIPMENT SPECIFICATIONS

A. CT Scanner

For patient imaging, the CT scanner should meet or exceed the following specifications:

1. Tube rotation time should not exceed 1 second.
2. Helical and cine imaging should be available. Continuous cine imaging should be possible for a minimum of 60 seconds.
3. A multi-detector row CT scanner with cine scanning capability is preferable.
4. A power injector for contrast administration must be used; a dual bore injection pump is preferable.

Equipment performance monitoring should be in accordance with the [ACR Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography \(CT\) Equipment](#).

B. Patient Monitoring Equipment

Patient monitoring equipment and facilities for cardiopulmonary resuscitation, including vital signs monitoring, support equipment, and an emergency crash cart, should be immediately available. Radiologists, technologists, and staff members should be able to assist with procedures, patient monitoring, and patient support. A written policy should be in place for dealing with emergency procedures such as cardiopulmonary arrest.

C. Image Processing Workstation and Software

An image processing workstation with appropriate software is necessary for producing physiologic maps

from both first pass cine and extended coverage dynamic CT perfusion data.

VII. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, radiologic technologists, and all supervising physicians have a responsibility to minimize radiation dose to individual patients, to staff, and to society as a whole, while maintaining the necessary diagnostic image quality. This concept is known as “as low as reasonably achievable (ALARA).”

Facilities, in consultation with the medical physicist, should have in place and should adhere to policies and procedures, in accordance with ALARA, to vary examination protocols to take into account patient body habitus, such as height and/or weight, body mass index or lateral width. The dose reduction devices that are available on imaging equipment should be active; if not, manual techniques should be used to moderate the exposure while maintaining the necessary diagnostic image quality. Periodically, radiation exposures should be measured and patient radiation doses estimated by a medical physicist in accordance with the appropriate ACR Technical Standard. (ACR Resolution 17, adopted in 2006 – revised in 2009, Resolution 11)

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>).

For specific issues regarding CT quality control, see the [ACR Practice Guideline for Performing and Interpreting Diagnostic Computed Tomography \(CT\)](#).

The supervising physician should review all practices and policies at least annually. Policies with respect to contrast and sedation must be administered in accordance with institutional policy as well as state and federal regulations. A physician should be available on-site whenever contrast or sedation is administered.

Equipment monitoring should be in accordance with the [ACR Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography \(CT\) Equipment](#).

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Suggested Reading (Additional articles that are not cited in the document but that the committee recommends for further reading on this topic)

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*Guidelines and 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 guidelines and standards published before 1999, the effective date was January 1 following the year in which the guideline or standard was amended, revised, or approved by the ACR Council.

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