NOT FOR PUBLICATION, QUOTATION, OR CITATION

RESOLUTION NO.

BE IT RESOLVED,

that the American College of Radiology adopt the ACR–ASNR–SPR Practice Parameter for the Performance of Computed Tomography (CT) Perfusion in Neuroradiologic Imaging

Sponsored By: **ACR Council Steering Committee**

Revised 2012 (Resolution 13)*

ACR–ASNR–SPR PRACTICE PARAMETER FOR THE PERFORMANCE OF COMPUTED TOMOGRAPHY (CT) PERFUSION IN NEURORADIOLOGIC IMAGING

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[1]. 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

[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.

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 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), and the Society for Pediatric Radiology (SPR).

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 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 practice parameter outlines the principles for obtaining a high-quality CT perfusion study [1,2].

II. INDICATIONS/CONTRAINDICATIONS

A. Indications for CT perfusion in neuroradiology in adults (18 years of age and over) include, but are not limited to:
   1. Brain
      a. Primary indications:
         i. **Differentiation of salvageable ischemic penumbra from unsalvageable ischemic core** [3-**15**]
         ii. **Distinguishing benign oligemia from true "at-risk" ischemic penumbra [16]**
         iii. **Help identify patients most likely to benefit from thrombolysis or thrombectomy [12,17]**
         iv. **Prediction of hemorrhagic transformation in acute ischemic stroke [18]**
         v. **Identifying patients with malignant profiles [19]**
         vi. Suspected vasospasm-related **cerebral ischemia and infarction and/or delayed cerebral ischemia (DCI)** following **aneurysmal** subarachnoid hemorrhage [20-26]
         vii. Cerebral hemorrhage with secondary local ischemia **[27-**31**]**
      b. Secondary indications:
         i. Follow-up of acute cerebral ischemia or infarction **and/or reperfusion** in the subacute or chronic phase of recovery [32-**35**]
         ii. To assist in planning and evaluating the effectiveness of therapy for cervical or intracranial arterial occlusive disease (as an isolated test or in combination with a cerebrovascular reserve challenge) **and/or chronic cerebral ischemia** [36-**39**]
         iii. **Identifying cerebral hyperperfusion syndrome following revascularization [40]**
         iv. **Detection of crossed cerebellar diaschisis in acute ischemic stroke [**41**]**
         v. **Contrast delay as a predictor of new incident infarct [42]**
         vi. CT perfusion scanning may also be helpful in the setting of acute traumatic brain injury [43,44] **and in the setting of acute seizures [45]**
         vii. **Assessment of neoplastic disease [24,46-49]** ~~intracranial tumors~~

viii. In patients with contraindication to magnetic resonance imaging (MRI)–**based perfusion imaging**
or with devices or material in or close to the field of view that would result in nondiagnostic MRI scans.
~~iii. Acute neurological change suspicious for stroke~~

2. Head and neck [50]
   a. Primary indications:
   Evaluation of the vascular status of solid tumors where MRI is degraded due to susceptibility artifact from air-containing spaces, ~~from~~ surgical clips, or dental work
   b. Secondary indications:
   Follow-up of tumor response to therapy

B. Pediatric Indications

At the time of this practice parameter revision, there ~~are no~~ **is little** data ~~to support a~~ **supporting the** role of CT ~~brain~~ perfusion ~~imaging~~ in pediatric stroke [51,52]. It may be reasonable to use CT brain perfusion imaging in individual patients under 18 years of age for the same indications listed for adults, but the increased risk to the pediatric patient associated with radiation exposure obligates the practitioner to apply a higher threshold to any decision to use this technique and to strongly consider MRI as an alternative. **Furthermore, the clinical considerations in the pediatric setting more often include a broader differential, warranting MRI.**

C. Contraindications [53,54]

Prior documented major allergic reaction to iodinated contrast material.

See the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [**55**] and the ACR Manual on Contrast Media [**56**].

For the pregnant or potentially pregnant patient, see the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation [**57**].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [**58**].

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**, medical risks,** and limitations for CT perfusion. Limitations of CT perfusions technology include CT imaging, computerized data processing, and the quantitative modeling techniques used to generate the **hemodynamic** 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

   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 examinations 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

   The physician must have spent a minimum of 12 months interpreting cross-sectional neuroradiologic imaging examinations with at least 6 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

   In the absence of residency training in diagnostic radiology or radiology, the physician must have had 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.

2. The physician should be thoroughly acquainted with the many morphologic and pathophysiologic 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.

3. 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.

4. The physician must 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 hemodynamic maps; generating written reports; and maintaining the quality of the images, maps, and interpretations.

~~5. The physician must have documented training in the physics of diagnostic radiology. Additionally, the physician must be familiar with principles of radiation protection, the hazards of radiation, and radiation monitoring requirements as they apply to both patients and personnel~~

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 Parameter for Continuing Medical Education (CME) [**59**].

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 American College of Radiology considers certification, 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 strongly 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 the American Board of Medical Physics (ABMP).

A Qualified Medical Physicist should meet the ACR Practice Parameter for Continuing Medical Education (CME) [**59**]. (ACR Resolution 17, 1996 – revised in 2012, Resolution 42)

The appropriate subfield of medical physics for this practice parameter is Diagnostic Medical Physics. (Previous medical physics certification categories including Radiological Physics, Diagnostic Radiological Physics, and Diagnostic Imaging Physics are also acceptable.)

The Qualified Medical Physicist should be familiar with the principles of CT imaging physics and of radiation protection, **and safety**; 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 **hemodynamic** maps. ~~of vascular physiologic function The Qualified Medical Physicist should periodically estimate the radiation dose delivered during CT perfusion studies and make sure that it is under the FDA-suggested alert level of 1 Gy $CTDI_{vol}$ (or a lower one established by the facility). Protocols exceeding this alert level should be reviewed by a Qualified Medical Physicist, supervising physician, and quality assurance committee. However, any alert level should not be misinterpreted as a cutoff or limit, as there may be good reasons for exceeding it [60]~~

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 [60]. The technologist should be fully trained to operate CT equipment and be knowledgeable in radiation physics, ~~and~~ protection **and safety**, 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 in collaboration with the Qualified Medical Physicist. 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.

Intravenous (IV) contrast injection should be performed using injection protocols that are in accordance with the institution's policy on IV contrast use. 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~~ **hemodynamic** 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 and may choose to waive the need for laboratory evaluation of renal function prior to the CT perfusion study in **select** patients [53,61].

A patient is prepared for a CT perfusion study by inserting a cannula into a vein **ideally** at or above the antecubital region **or forearm** prior to the patient's entry into the scanner. An 18-gauge or 20-gauge cannula is~~required (18-gauge preferred)~~ **preferred**. Contrast can also be injected through an existing IV access provided it has the required caliber and specifications. **In select patients without peripheral IV access, contrast may be administered through an existing central venous line (CVL) catheter under the supervision of a physician following a strict protocol [62].** In children, depending on their age and size, a smaller cannula may be necessary. The patient should lie on the scanner table in supine position with his or her head in a head holder. If needed, the head can be immobilized using forehead and chin straps. A contrast infusion pump should be connected to the cannula. The head is centered to the scanner isocenter.

C. Examination Techniques

There are 2 CT perfusion approaches **using intravenously administered iodinated contrast** that use different data acquisition and analysis methods. These methods differ in their volume coverage (ie, the amount of tissue that can be imaged during 1 data acquisition or 1 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 temporal resolution of data acquisition [63,64].

Protocols vary with the manufacturer and model of the scanner used. Although protocols continue to evolve, current expert consensus is available [65]. Scanner-specific examination protocols are also available from the American Association of Physicists in Medicine at http://www.aapm.org/pubs/CTProtocols/default.asp [66]. **Care must be taken to optimize CT perfusion scanning parameters as per statements from the US Food and Drug Administration, the ACR, and the ASNR** [12,67,68]

Injection of contrast should be performed using a power injector and adhering to the institution's policies on contrast utilization. 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. A saline chase of at least 15 to 20 cc is recommended [61,69].

Given the significant radiation dosage with this examination it should be repeated only after physician review. Alternative modalities should be considered if repeat CT perfusion examinations are indicated.

1. First-pass or dynamic CT perfusion [4-6,70-77]

A first-pass or dynamic CT perfusion study is performed by acquiring repeated images at the same location through a volume of interest during bolus injection and passage of contrast through the region of

interest. **Dynamic CT perfusion acquires a temporal set of images through a volume of interest during a bolus injection of contrast. This technique can provide absolute measures of cerebral blood flow (CBF), cerebral blood volume (CBV), mean transit time (MTT), time to peak (TTP), Tmax), and blood-brain barrier permeability. Newer 320-slice CT scanners can provide whole-brain coverage with this technique [78]. Most commonly, selective axial sections are obtained through the basal ganglia to image the middle cerebral artery (MCA) territory. Protocols may be adjusted to evaluate anterior or posterior cerebral circulation [12,79].** 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/s. 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~~ **hemodynamic** maps. Of note, in children, smaller injection rates and smaller volumes of contrast should be used [80]. 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 the imaging 5 seconds (or less) after the onset of injection will suffice to achieve this goal.

First-pass or dynamic CT perfusion can be performed using cine mode, a combination of cine and axial modes, or an axial or volumetric toggling table technique [81]. In all cases, imaging should cover the whole first passage of contrast through the tissue under investigation, without truncating the end of the washout of the contrast bolus demonstrated by the downslope of the venous curve and of the ischemic tissue. This is of particular concern in patients with impaired cardiac output. Also, 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.

In a pure cine mode, the temporal resolution of the CT acquisition should be 1 image per second, and the acquisition should span a total of at least 50 to 60 seconds.

When a combination of cine and axial modes is used, the cine acquisition should come first, have a temporal resolution of 1 image per second, and span approximately 35 to 37 seconds. This should be followed by the axial acquisition, with a temporal resolution of 1 image per 3 seconds and for a total duration of another 33 to 35 seconds.

In the axial and volumetric toggling table technique, the CT table moves back and forth between 2 table locations during the injection of contrast and the acquisition of images. The temporal resolution at each location should be no less than 1 image per 3 seconds. The acquisition should span a total of at least 50 to 70 60 seconds [81,82].

~~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 image thickness in single-detector-row scanners.~~

IV contrast injection should be performed in accordance with the institution's policy on IV contrast use. 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. For further information, see the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [**55**].

A CT perfusion study, if performed in conjunction with a CT angiogram of the intracranial and/or cervical vessels, can be performed before~~**, after,**~~**, after,** or concurrent with the CT angiogram.

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 a minimum radiation

dose. Parameters of ~~80~~ **70 to 90** kVp and 100 to 200 mAs are strongly recommended, as they allow the radiation dose associated with CT perfusion to be maintained as low as reasonably achievable **(ALARA principle) [83]**.

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 [**84**]. The ~~physiological~~ **hemodynamic** 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, mean transit time, **Tmax,** and ~~tissue~~ **blood-brain barrier** permeability 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~~ **images** available for review **and/or in the absence of the clinical context** [4-6].

CT perfusion (CTP) parameters that are commonly calculated and reported by commercially available postprocessing software platforms include CBF, CBV, MTT, TTP, and Tmax. These parameters are related by the central volume principle: CBF = CBV/MTT. These are derived from CTP source data by using deconvolutional analysis [12,51,85]. CTP measures blood perfusion of brain tissues. CBV is defined as the volume of blood for a given volume of brain and is measured in units of milliliters (mL) of blood per 100 grams (g) of brain. MTT is defined as the average amount of time it takes blood to transit through the given volume of brain and is measured in seconds (s). TTP and Tmax measure the time from the arterial peak to the tissue peak before and after deconvolution, respectively. CBF is defined as the volume of flowing blood moving through a given volume of brain in a specific amount of time and is measured in units of milliliters of blood per 100 g of brain tissue per minute [12,51].

The responsible physician should understand the limitations of various CT perfusion imaging methodologies and the limitations of mathematical models used to construct the ~~physiologic~~ **hemodynamic** maps [86,87]. ~~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 [86, 87].~~

2. Whole-brain CT perfused blood volume [88-90]

Whole-brain CT perfused blood volume is assessed by acquiring a helical scan through the whole brain with and without contrast. **Whole-brain perfusion CT provides a map of CBV (cerebral blood volume) and has the advantage of providing whole-brain coverage but is limited by its inability to provide measurement of CBF (cerebral blood flow) or time parameters [78].**

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

Acquiring a helical data set through the whole brain after injection of a nonionic contrast agent constitutes a contrast scan. The total volume of contrast material injected is typically between ~~90~~ **75** and 150 mL, depending on the volume imaged and the speed of data acquisition. Injection rates of 3 to 3.5 mL/s are typical, producing a 25- to 40-second ~~long~~ bolus **duration**. 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. Of note, in children, smaller injection rates and smaller volumes of contrast should be used according to the ACR Manual on Contrast Media [**56**,80]. The contrast data should be scanned and reconstructed in images with a thickness matching that of the noncontrast CT scan.

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.

Of note, some large-coverage scanners now offer whole-brain 4D CT angiography/CT perfusion in a combined single study with only 1 injection of contrast medium [91].

Also of note, modern angiography suites with flat-panel detectors can perform rotational CT examinations, including perfusion imaging [92,93] using either intravenous or intra-arterial contrast injections. The role of such examinations before, during, or after interventions for acute ischemic stroke, vascular malformations, and other indications is not yet defined.

Diagnostic pitfalls include small and chronic infarcts, severe microvascular ischemia, extracranial and intracranial stenosis, and mimicking conditions such as vasospasm, traumatic brain injuries, and seizures [12,94-96].

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [**97**].

The **type and** 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~~ **hemodynamic** maps. This serves as a quality control parameter for any particular CT perfusion scan. **The specific hemodynamic maps of blood flow, blood volume, MTT (mean transit time), Tmax, and/or blood-brain barrier permeability parameters should be mentioned in the description of the postprocessing techniques.**

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 50 to 60 seconds. “Toggle table” or “shuttle mode” technique is optional.
3. A multidetector-row CT scanner with either cine and axial or volumetric toggling 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–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [98].~~

B. Patient Monitoring Equipment

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 or sizes in the patient populations.

C. Image Processing Workstation and Software

An image processing workstation with appropriate software is necessary for producing ~~physiologic~~ **hemodynamic** maps from both first-pass and/or dynamic CT perfusion data. The software should allow reasonable motion correction. Automated and semiautomated selection of the arterial input function and partial volume reference **(venous curve)** is preferred [86,87,99,100]. **Supervision of the automated selection of the arterial and venous curves is recommended to ensure appropriate location in a given patient according to disease status.**

VII. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, registered radiologist assistants, radiologic technologists, and all supervising physicians have a responsibility for safety in the workplace by keeping radiation exposure to staff, and to society as a whole, "as low as reasonably achievable" (ALARA) and to assure that radiation doses to individual patients are appropriate, taking into account the possible risk from radiation exposure and the diagnostic image quality necessary to achieve the clinical objective. All personnel that work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection and application of dose limits) and the principles of proper management of radiation dose to patients (justification, optimization and the use of dose reference levels).
http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1578_web-57265295.pdf

Nationally developed guidelines, such as the ACR's Appropriateness Criteria®, should be used to help choose the most appropriate imaging procedures to prevent unwarranted radiation exposure.

Facilities should have and adhere to policies and procedures that require varying ionizing radiation examination protocols (plain radiography, fluoroscopy, interventional radiology, CT) to take into account patient body habitus (such as patient dimensions, weight, or body mass index) to optimize the relationship between minimal radiation dose and adequate image quality. Automated dose reduction technologies available on imaging equipment should be used whenever appropriate. If such technology is not available, appropriate manual techniques should be used.

Additional information regarding patient radiation safety in imaging is available at the Image Gently® for children (www.imagegently.org) and Image Wisely® for adults (www.imagewisely.org) websites. These advocacy and awareness campaigns provide free educational materials for all stakeholders involved in imaging (patients, technologists, referring providers, medical physicists, and radiologists).

Radiation exposures or other dose indices should be measured and patient radiation dose estimated for representative examinations and types of patients by a Qualified Medical Physicist in accordance with the applicable ACR Technical Standards. Regular auditing of patient dose indices should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry, the NCRP Report No. 172, Reference Levels and Achievable Doses in Medical and Dental Imaging: Recommendations for the United States or the Conference of Radiation Control Program Director's National Evaluation of X-ray Trends. (ACR Resolution 17 adopted in 2006 – revised in 2009, 2013, Resolution 52).[101]

The FDA recommends that each facility set its own alert level for brain perfusion studies beyond which further review by a Qualified Medical Physicist, supervising physician, and quality assurance committee may be

necessary. Based on the FDA's review of the literature, a reasonable alert level could be set at 1 Gy $CTDI_{vol}$. **The Qualified Medical Physicist should periodically estimate the radiation dose delivered during CT perfusion studies and make sure that it is under the FDA-suggested or the facility-established alert level.** ~~of 1 Gy $CTDI_{vol}$ (or a lower one established by the facility).~~ **Typical acquisition parameters should be between 70 and 90 kVp and 100 and 200 mAs**. **Protocols exceeding alert levels should be reviewed by a Qualified Medical Physicist, supervising physician, and quality assurance committee. However, a**ny alert level should not be misinterpreted as a cutoff or limit, as there may be good reasons for exceeding it [67].

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).

~~For specific issues regarding CT quality control,~~ **Also** see the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) **[58] for specific issues regarding CT quality control.**

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–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment **[98]**.

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