Revised 2022 (Resolution 22)*

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 considering 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 variables such as the condition of the patient, limitations of available resources, or advances in knowledge or technology after publication of this document. However, a practitioner who employs an approach substantially different from the guidance in this document may consider documenting in the patient record information sufficient to explain the approach taken.

The practice of medicine involves the science, and 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 purpose of this document is to assist practitioners in achieving this objective.

[1] Iowa Medical Society and Iowa Society of Anesthesiologists v. Iowa Board of Nursing 831 N.W.2d 826 (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.

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 nonneoplastic 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 [1-4].

II INDICATIONS AND 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. Diagnosis of ischemic stroke
      ii. Differentiation of salvageable ischemic penumbra from unsalvageable ischemic core [5-8]
      iii. Distinguishing benign oligemia from true "at-risk" ischemic penumbra [9]
      iv. Helping identify patients most likely to benefit from thrombolysis or thrombectomy [10-14]
      v. Prediction of hemorrhagic transformation in acute ischemic stroke [15]
      vi. Identifying patients with malignant profiles [16]
      vii. Suspected vasospasm-related cerebral ischemia and infarction and/or delayed cerebral ischemia (DCI) following aneurysmal subarachnoid hemorrhage [17-19] even in the presence of aneurysm coils or clips [20]
      viii. Cerebral hemorrhage with secondary local ischemia [21,22]
   b. Secondary indications:
      i. 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 [23,24]
      ii. Identifying cerebral hyperperfusion syndrome following revascularization [25]
      iii. Detection of crossed cerebellar diaschisis in acute ischemic stroke [26]
      iv. Detection of ischemia from distal vessel occlusions [27]
      v. Contrast delay as a predictor of new incident infarct [28]
      vi. CT perfusion scanning may also be helpful in the setting of acute traumatic brain injury [29,30] and in the setting of acute seizures [31]
      vii. Assessment of neoplastic disease [3,32-34]
      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.

2. Head and neck [35-37]
   a. Primary indications:
      Evaluation of the vascular status of solid tumors in which MRI is degraded because of susceptibility artifact from air-containing spaces, 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 is little data supporting the role of CT perfusion in pediatric stroke [35,38,39]. 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 [40]

Previously documented major allergic reaction to iodinated contrast material.

See the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [41] and the ACR Manual on Contrast Media [42].

For the pregnant or potentially pregnant patient, see the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation [43].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [44].

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. 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 examinations of the brain, spine, and head and neck that were supervised, interpreted, and formally reported) or by completing a mentoring program during which the physician interprets 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 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 documentation of interpreting cross-sectional neuroradiologic imaging examinations with training in the interpretation and formal reporting of CT images in a documented formal training program in an 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, including CT perfusion examinations.

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. The physician 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.

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) [45].

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, the American Board of Science in Nuclear Medicine (ABSNM), or the American Board of Medical Physics (ABMP).

A Qualified Medical Physicist should meet the ACR Practice Parameter for Continuing Medical Education (CME) [45].

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). (ACR Resolution 17, adopted in 1996 – revised in 2008, 2012, 2022, Resolution 41f)

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 the 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.

C. Non-Physician Radiology Provider (NPRP)

NPRPs are all Non-Physician Providers (eg, RRA, RPA, RA, PA, NP, ...) who assist with or participate in portions of the practice of a radiologist-led team (Radiologists = diagnostic, interventional, neurointerventional radiologists, radiation oncologists, and nuclear medicine physicians). The term "NPRP" does not include radiology, CT, US, NM MRI technologists, or radiation therapists who have specific training for radiology related tasks (eg, acquisition of images, operation of imaging and therapeutic equipment) that are not typically performed by radiologists.

The term 'radiologist-led team' is defined as a team supervised by a radiologist (ie, diagnostic, interventional, neurointerventional radiologist, radiation oncologist, and nuclear medicine physician) and consists of additional healthcare providers including RRAs, PAs, NPs, and other personnel critical to the provision of the highest quality of healthcare to patients. (ACR Resolution 8, adopted 2020).

C. 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; acquiring, recording, and processing the CT data in a manner appropriate for interpretation by the physician; and using the appropriate CT parameters for the CT perfusion examination (including low kVp and relatively low mAs) in order to minimize the radiation dose to the patient [46]. The technologist should be fully trained to operate CT equipment and be knowledgeable in radiation physics, 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.

D. 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. The nurse 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 – revised in 2016, Resolution 12-b)

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. 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 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 before 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 before the CT perfusion study in select patients [40,41].

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 before the patient's entry into the scanner. An 18-gauge or 20-gauge cannula is 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 according to institutional protocols [47]. 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 their 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

CT perfusion techniques are evolving. Although complicated, some degree of general conceptualization of scanning protocols is required [48,49].

Scanning protocols vary with the manufacturer and model of the scanner used. Although protocols continue to evolve, current expert consensus is available [1,50,51]. Scanner-specific examination protocols are also available from the American Association of Physicists in Medicine at http://www.aapm.org/pubs/CTProtocols/default.asp [52].

Care must be taken to optimize CT perfusion scanning parameters as per statements from the US Food and Drug Administration (FDA), the ACR, and the ASNR [53,54]. 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.

Injection of contrast should be performed using a power injector and adhering to the institution's policies on contrast utilization. Dual-bore saline-chase injection pumps are preferable to optimize the use of contrast material. A saline chase of at least 15 to 20 mL is recommended [1,51].

Dynamic CT perfusion can be performed alone, or with conventional multidetector CT (MDCT), together with a noncontrast CT and CT angiogram (CTA) of the head and neck.

1. 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 [7,8,55-59]. In other words, dynamic CT perfusion acquires a temporal set of images through a volume of interest during a bolus injection of contrast. Z-axis is determined by the width of the CT detector and is, therefore, dependent upon the manufacturer and generation of the CT scanner. Sufficient coverage of the brain in the z-axis (circa 70 mm-80 mm) can be obtained with 256 or 320 detector row CT scanners. Alternatively, CT scanners with fewer detector rows and, therefore, limited z-axis coverage (typically 2 cm-4 cm) require selective axial sections through the basal ganglia in order to image the proximal middle cerebral artery (MCA) territory and representative territories of the anterior cerebral artery (ACA) and posterior cerebral artery (PCA). A second CT perfusion acquisition using a second bolus of contrast can be obtained through the centrum semi-ovale for such CT scanners with limited z-axis coverage.

2. First-pass or dynamic CT perfusion can be performed with MDCT using a variety of techniques and modes, including axial and helical techniques, which, in combination with a toggling table technique, will increase cranial-caudal coverage. The frequency of imaging during the length of the perfusion scan (also known as temporal resolution) varies with each technique and can vary from arterial to venous phase, depending on the manufacturer. In all cases, the physician should be familiar with the modus of the scanner, including the z-axis coverage, imaging technique, temporal resolution, and length of the scan. The length of the scan should cover the entire first passage of contrast through the tissue without truncating the washout of the contrast bolus, as demonstrated by the downslope of the venous curve.

   The acquisition should span a total of 50 to 70 seconds, which will accommodate most patients' cardiac output.

   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 70 to 90 kVp and 100 to 200 mAs are strongly recommended because they allow the radiation dose associated with CT perfusion to be maintained as low as reasonably achievable (ALARA principle).

   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 in adults. 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 hemodynamic maps. Of note, in children, smaller injection rates and smaller volumes of contrast should be used [60]. The relationship between the start of imaging and the start of contrast injection should be such that at least 2 baseline images are obtained before arrival of contrast into the tissue of interest. Normally, starting the imaging 4 seconds after the onset of injection will suffice to achieve this goal; however, this may vary based on the patient's cardiac output.

3. Images should be viewed electronically using cine display in order to demonstrate possible patient movement. If movement is observed, the effects of motion on the constructed maps should be considered [61,62]. CT perfusion parameters that are commonly calculated and reported by commercially available postprocessing software platforms include CBF, CBV, MTT, time to peak (TTP), and Tmax. Some software platforms provide automated calculations of infarct and penumbra volume for acute stroke. The responsible physician should understand the evidence basis for infarct and penumbra volume calculation when provided, and, furthermore, how to interpret CT perfusion parameters when automated results are not provided. The 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, because this permits interactive adjustment of brightness, contrast, and color scale. These maps should be interpreted as a coherent set of data; none of the maps should be interpreted in isolation without knowledge of other types of images available for review and/or in the absence of the clinical context.

   The responsible physician should understand the limitations of various CT perfusion imaging methodologies and the limitations of the mathematical models used to construct the hemodynamic maps, particularly if the software requires some degree of manual postprocessing [61-64].

   Large-coverage 320 detector row scanners offer 16 cm of z-axis coverage without moving the CT table, which

allows dynamic "volume" scanning of the whole brain. This feature allows for the simultaneous acquisition of intracranial 4-D CT angiography (the fourth dimension being time) and CT perfusion with only 1 injection of contrast medium [65].

4. Modern angiography suites with flat-panel detectors can perform rotational CT examinations, including perfusion imaging, using either IV 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 a current focus of clinical research [66].

5. Diagnostic pitfalls for CT perfusion include small and chronic infarcts, posterior fossa infarcts, severe microvascular ischemia, extracranial and intracranial stenosis, and mimicking conditions such as vasospasm, traumatic brain injuries, and seizures [67-70].

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [71].

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, it is essential that the arterial and venous curves used for calculating the perfusion maps be archived together with the temporal images and hemodynamic maps. This serves as a quality control parameter for any particular CT perfusion scan. The specific hemodynamic maps of CBF, CBV, MTT, TTP, and Tmax and/or blood-brain barrier permeability parameters should be mentioned in the description of the postprocessing techniques.

VI. EQUIPMENT SPECIFICATIONS

Equipment monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [72].

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 approximately 50 to 70 seconds. "Toggling-table" 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 for saline injection is preferable.

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 hemodynamic maps from 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. 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 [62,64].

VII. RADIATION SAFETY IN IMAGING

Radiologists, medical physicists, non-physician radiology providers**,** 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 who work with ionizing radiation must understand the key principles of occupational and public radiation protection (justification, optimization of protection, application of dose constraints and limits) and the principles of proper management of radiation dose to patients (justification, optimization including the use of dose reference levels). https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1775_web.pdf

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

Facilities should have and adhere to policies and procedures that require ionizing radiation examination protocols (radiography, fluoroscopy, interventional radiology, CT) to vary according to diagnostic requirements and patient body habitus to optimize the relationship between appropriate radiation dose and adequate image quality. Automated dose reduction technologies available on imaging equipment should be used, except when inappropriate for a specific exam. If such technology is not available, appropriate manual techniques should be used.

Additional information regarding patient radiation safety in imaging is available from the following websites – Image Gently® for children (www.imagegently.org) and Image Wisely® for adults (www.imagewisely.org). 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 periodically measured by a Qualified Medical Physicist in accordance with the applicable ACR Technical Standards. Monitoring or regular review of dose indices from patient imaging should be performed by comparing the facility's dose information with national benchmarks, such as the ACR Dose Index Registry and relevant publications relying on its data, applicable ACR Practice Parameters, 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; 2006, 2009, amended 2013, revised 2023 (Res. 2d).[73]

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 CTDIvol. 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. 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, any alert level should not be misinterpreted as a cutoff or limit, because there may be good reasons for exceeding it [54,73].

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 Quality Control & Improvement, Safety, Infection*

Control, and Patient Education on the ACR website (https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Quality-Control-and-Improvement).

Also see the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [44] 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.

ACKNOWLEDGEMENTS

This practice parameter was revised according to the process described under the heading *The Process for Developing ACR Practice Parameters and Technical Standards* on the ACR website (https://www.acr.org/Clinical-Resources/Practice-Parameters-and-Technical-Standards) by the Committee on Practice Parameters – Neuroradiology of the ACR Commission on Neuroradiology and the Committee on Practice Parameters – Pediatric Radiology of the ACR Commission on Pediatric Radiology in collaboration with the ASNR and the SPR.

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*Practice parameters and technical 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 practice parameters and technical standards published before 1999, the effective date was January 1 following the year in which the practice parameter or technical standard was amended, revised, or approved by the ACR Council.

Development Chronology for this Practice Parameter
Adopted 2007 (Resolution 2)
Amended 2009 (Resolution 11)
Revised 2012 (Resolution 13)
Amended 2014 (Resolution 39)
Revised 2017 (Resolution 18)
Amended 2020 (Resolution 8)
Revised 2022 (Resolution 22)
Amended 2023 (Resolution 2c, 2d)