ACR–ASNR–SPR PRACTICE PARAMETER FOR THE PERFORMANCE OF COMPUTED TOMOGRAPHY (CT) IN THE EVALUATION AND CLASSIFICATION OF TRAUMATIC BRAIN INJURY

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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.

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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 developed collaboratively by the American College of Radiology (ACR), the American Society of Neuroradiology (ASNR), and the Society for Pediatric Radiology (SPR).

Traumatic brain injury (TBI) is one of the most common neurologic disorders, currently affecting 1.7 million Americans each year [1,2]. The incidence of TBI, especially mild TBI, is underestimated [3], as patients frequently dismiss their symptoms and never present to the emergency department, or they believe that the admission of symptoms may compromise their work situation (eg, athletes, military [4]). Although the majority of patients (nearly 80%) with diagnosed TBI are treated and released from the emergency department [5], the remaining 20% have more significant injuries resulting in approximately 275,000 hospitalizations and 52,000 deaths each year. Furthermore, TBI contributes to a third of all injury-related deaths in the United States. The economic cost of TBI was estimated at $76.5 billion in 2010 ($11.5 billion in direct medical costs and $64.8 billion in indirect costs such as lost wages, lost productivity, and nonmedical expenditures) [6]. Moreover, affected military veterans generate an annual cost of $11,700 of medical treatment per patient compared with $2,400 in TBI-free veterans [7]. Leading causes of TBI in the general population include falls, motor vehicle accidents, assaults, and sports-related injuries.

Imaging plays an essential role in identifying TBI patients with intracranial injury. The goals of imaging include (1) detecting injuries that may require immediate surgical or procedural intervention; (2) detecting injuries that may benefit from early medical therapy and/or vigilant neurologic supervision; and (3) determining the prognosis of patients to tailor rehabilitative therapy or help with family counseling and discharge planning. A wide variety of imaging techniques have become available to assess patients presenting with TBI. This, coupled with the inconsistent use of clinical decision rules [8], has led to increased utilization and numerous variation in imaging practices. Among hospitals reporting to the National Hospital Ambulatory Medical Care Survey, CT utilization for head trauma in the pediatric population increased from 12.8% in 1995 to 28.6% in 2000 despite stable hospitalization rates from head trauma [9]. The practical challenge for physicians is to understand which imaging techniques to implement and how to use them optimally for specific patients. There are early reports at individual institutions that adoption of machine learning algorithms into the clinical workflow might assist physicians in triage and detection of intracranial hemorrhage in patients with TBI [10,11].

This practice parameter focuses on computed tomography (CT) and should assist referring physicians faced with the task of appropriately ordering CT scans in the particular TBI patient for whom they are providing care. It should also help radiologists advise their clinical colleagues on appropriate CT imaging utilization for TBI patients. For practical purposes, recommendations are presented separately for TBI severity and for acute, subacute, and chronic TBI, as defined by the Defense and Veterans Brain Injury Center (DVBIC) recommendations. Acute injuries refer to those from time of injury to 7 days; subacute injuries refer to those between 8 days to 89 days post-injury; and chronic injuries refer to those injuries 90 days or greater post-injury. The severity of TBI is usually classified by the Glasgow Coma Scale (GCS) score as mild, moderate, or severe. Mild TBI is generally defined as demonstrating GCS scores of 13 to 15, moderate TBI demonstrates GCS scores of 9 to 12, and severe TBI demonstrates GCS scores of 3 to 8 [12-14]. These recommendations are concordant with the ACR Appropriateness Criteria for head trauma [15].

II. INDICATIONS

Indications for CT TBI include, but are not limited to, the following:

1. Acute moderate or severe TBI [12,16-30]
2. Acute mild TBI [20,31-49]
3. Follow-up imaging in TBI [50-53]
4. Subacute to chronic TBI [54-56]
5. Pediatric TBI [15,24,57-83]

6. Neurovascular trauma [84-96]

For information on contrast, see the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [97] and the ACR Manual on Contrast Media [98].

For the pregnant or potentially pregnant patient, see the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation [99].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [100] and the ACR–ASNR–SPR Practice Parameter for the Performance and Interpretation of Cervicocerebral Computed Tomography Angiography (CTA) [101].

A. Physician

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

The physician should meet the criteria listed in the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [100] and in the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [97] and should be trained in radiation safety.

1. The supervising physician must have adequate understanding of the indications, risks, and benefits of the examination, as well as alternative imaging procedures. The supervising physician is responsible for specifying the parameters of image acquisition; the route, volume, timing, type, and rate of contrast injection; and the method of image reconstruction and archival. The physician should monitor the quality of the images, be aware of potential artifacts [102], and interpret the study. Interpreting physicians must have knowledge of the benefits and risks of the procedures. Knowledge of the head and neck anatomy, including the vascular anatomy, and diseases of the intracranial and extracranial cerebrovascular system and their treatment is required.
2. Physicians meeting the aforementioned criteria additionally must have knowledge of the anatomy and pathophysiology relevant to the examination and of the spectrum of nonvascular abnormalities presenting on CT scans. They should be capable of identifying and characterizing important nonvascular abnormalities that may be visualized on CT scan and CT angiography (CTA), such as neoplasia, sequelae of infection, noninfectious inflammatory diseases, congenital anomalies, and normal anatomic variants, and any other abnormalities that may affect patient care and might necessitate treatment or further characterization through additional diagnostic testing.
3. The physician should be familiar with the use of 3-D processing workstations and be capable of performing or directing creation of 3-D renderings, multiplanar reformations, and measurements of vessel dimensions.
4. The physician should work with a Qualified Medical Physicist to optimize site-specific CT scan and CTA scan protocols, when possible.

B. Technologist

The technologist should have the responsibility of patient comfort, preparing and positioning the patients for the CT examination, monitoring the patient during the examination, and obtaining the CT data in a manner prescribed by the supervising physician. For the intravenous (IV) administration of contrast material for CTA, qualifications for technologists performing IV injections should be in compliance with current ACR policy and existing operating procedures or manuals at the imaging facility. The technologist should perform the regular quality control testing of the CT system under the supervision of a medical physicist (ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [97]).

The technologist performing CT examinations should be certified by the American Registry of Radiologic Technologists or have an unrestricted state license with documented training and experience in CT.

IV. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for CT of the head should provide sufficient information to demonstrate the medical necessity of the examination and allow for the proper performance and interpretation of the examination.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). The provision of additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient’s clinical problem or question and consistent with the state scope of practice requirements. (ACR Resolution 35 adopted in 2006 – revised in 2016, Resolution 12-b)

A. General Considerations

CT protocols for brain imaging should be designed to answer the specific clinical question. The supervising physician should be familiar with the indications for each examination, relevant patient history, and potential adverse reactions to contrast media. The supervising physician should be familiar with how individual CT settings affect radiation dose and image quality, including field of view (FOV), collimation, pitch, automated exposure control, and image reconstruction algorithms such as iterative reconstruction [103]. The goal of CT scanning is to obtain diagnostic information from images of sufficient quality. Protocols should be optimized to deliver the lowest dose required to achieve appropriate image quality, especially in pediatric patients, and should be reviewed and updated as needed in light of new clinically applicable developments [104-112].

B. Head CT

Performance Standards

To achieve acceptable clinical CT scans of the brain, the CT scanner should meet or exceed the following specifications:

1. Scan times: per slice or image not more than 2 seconds.
2. Slice thickness: acquired slice thickness should be 2 mm or less, whereas reconstructed slice thickness should be 5 mm or less. Axial reconstructions might be performed to correct acquisition plane if necessary.
3. Limiting spatial resolution: must be measured to verify that it meets the unit manufacturer’s specifications. Limiting spatial resolution should be >10 lp/cm for a display FOV <24 cm.
4. Table pitch: no greater than 2 for most CT scanners, but pitch may be increased for dual-source scanners for sole evaluation of bone anatomy (craniofacial)

For further information, see the American Association of Physicists in Medicine (AAPM) Routine Adult Head (Brain) Protocols [113].

CT brain imaging is performed for the evaluation of a variety of pathologies that require appropriate techniques for acquisition and viewing. CT brain imaging may be performed with a sequential single-slice technique, multislice helical (spiral) protocol, or multidetector multislice algorithm [114,115]. Use of these techniques is dependent on clinical indication, scanner capability, and image quality requirements. For CT of the brain, contiguous or overlapping axial slices should be acquired with a slice thickness of no greater than 5 mm. In addition to directly acquired axial images, reformatted images in coronal, sagittal, true axial, or other more complex planes may be constructed from the axial data set to answer specific clinical questions. Additionally, axial reconstructed images should be presented with at least 2 different kernels, using both a brain/soft-tissue and bone kernel. Brain images should be reviewed at dedicated workstations and with window settings appropriate for demonstrating brain, bone, and soft-tissue abnormalities as well as hemorrhage.

C. Cervicocerebral CTA

1. Patient Selection and Preparation

Patients without absolute contraindication to the administration of iodinated contrast media are candidates for cervicocerebral CTA. In cases of relative contraindication to the administration of iodinated contrast medium, measures to reduce the possibility of contrast medium reactions or nephrotoxicity should be followed to the extent that the patient's condition allows, as defined in the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [97,116].
When possible, patients should be well hydrated, and IV access should be established. A 20-gauge or larger antecubital IV catheter should be placed ideally on the right side to accommodate an optimal rate of 4 or 5 mL/s of iodinated contrast media. Smaller catheters that can withstand the prescribed injection rates can be used, and lower injection rates may be used for pediatric patients. All catheters used for the CTA examination should first be tested with a rapidly injected bolus of sterile saline to ensure that the venous access is secure and can accommodate the rapid bolus, minimizing the risk of contrast medium extravasations. The injection site should be monitored by medical personnel trained in the rapid recognition of IV extravasations. Department procedures for care of IV extravasations should be documented and applied if necessary.

2. Examination Technique
The CTA acquisition should be performed with a section thickness of 1.5 mm or less, depending on the vascular territory to be assessed. The scan should be reconstructed with overlapping sections. In the setting of trauma, CTA imaging of the neck should be obtained and the acquisition should at least cover the aortic arch, the origin and cervical course of the subclavian and carotid arteries, and proximal subclavian arteries, through the Circle of Willis. Automated tube voltage selection can also be employed in conjunction with tube current modulation when available. Finally, the display FOV must be sufficient to allow an assessment of the vasculature of interest, the end-organ, and adjacent tissues.

Because of substantial variations in the time required for an IV injection of nonionic contrast medium (iodine, 300-370 mg/mL) to reach the target vascular anatomy, an assessment of patient-specific circulation time is frequently required, especially for arterial imaging, although not mandatory. Circulation timing can be performed using one of the following techniques [117].

a. IV injection of a small test bolus (eg, 10-15 mL) of contrast medium at the same rate and through the same access that will be used for the CTA followed by acquisition of sequential cine CT images at the level of the artery or vein of interest. The rate and intensity of enhancement of the lumen of interest are then used to create a time density curve. The peak of the curve is used to calculate the scanning delay postinjection. A perfusion CT series performed before the CTA can be used similarly to a test bolus for determining the timing of the CTA acquisition.
b. The use of automated or semiautomated triggering software based on monitoring of the attenuation within the vessel of interest (or a great vessel such as the aorta) by the CT scanner following initiation of the full dose of contrast media injection. The CTA is automatically started when the enhancement in the vessel reaches a predetermined operator-selected level.

   Ideally the administration of iodinated contrast media for the CTA should be performed with a minimum flow rate of 4 mL/s in any patient weighing 50 kg or more. Higher flow rates up to 6 mL/s are frequently required for larger patients, and in general, higher flow rates are required for shorter acquisitions. In children, contrast medium dosing should be scaled to body weight. Injection rate should be scaled similarly and preferably delivered via powered injection. For young children and infants, a 22- or 24-gauge IV catheter may be the only option, and a 2 mL/s injection rate may be reasonable for these patients. For patients under 50 kg, a dose of 2 mL/kg should be considered. In summary, contrast injection parameters should be modified on an individual patient basis, and the volume of contrast medium should be selected with consideration of the patient's weight and comorbidities that might increase the risk of nephrotoxicity. When performing a cervicocerebral CTA, a right-arm injection is preferable to a left-arm injection to avoid artifacts from undiluted contrast medium in the left brachiocephalic vein. When possible, a bolus of saline should follow the iodinated contrast medium injection as this may reduce the volume of contrast medium required to achieve adequate vascular opacification.

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [118].

Since 2009, multiple healthcare agencies involving experts from the international TBI community have worked on developing and refining Common Data Elements (CDEs) in TBI to promote the use of consistent terminology and definitions in characterizing intracranial injuries across all imaging studies, as well as all clinical aspects of TBI [119,120]. These CDEs can be used in a consistent manner for clinical practice, research, and treatment trials across multiple institutions and research studies. The CDEs include a list of the injuries that can be identified, with definitions of terms used to describe these injuries on the images, and recommended protocols and descriptors for image acquisition methods. The goal of the CDEs is to promote consistency across the field in future investigations aimed at evaluating TBI imaging. Clinical implementation of CDEs is time-consuming and challenging. Different groups have been working on streamlining the clinical implementation and adoption of CDEs for the reporting of TBI imaging studies. One such example is the NIRIS system [17,18,29,30] mentioned above. The supervising and interpreting physician should be aware of efforts to standardize reporting and consider adopting these when appropriate, to enhance communication with clinical care team members.

Cervicocerebral CTAs are preferentially interpreted on equipment that allows stacked dynamic paging of the primary axial and the reformatted CTA sections. A complete interpretation includes review of all images, including the scout and the axial CT sections (source images) and, as indicated, multiplanar/curved reformations, volume renderings, maximum-intensity projections, and other reconstructions produced during postprocessing. On occasion, the interpreting physician will personally create postprocessed images documenting important findings that are essential to the interpretation of the study [121]. These images should be archived with the patient's original study or other postprocessed images. Interpretation of the cervicocerebral CTA includes an assessment of the patency and caliber of the carotid and vertebral arteries, their origins, the carotid bifurcations, the intracranial arteries, possible occlusion, dissection, stenosis, and aneurysmal dilatation.

The visible regional anatomy and pathology should be commented on when appropriate. In the setting of suspected traumatic injury, the soft issues surrounding the vasculature and adjacent bony structures in the cervical region should be assessed. Comparison with prior studies should be performed when appropriate.

VI. EQUIPMENT SPECIFICATIONS

For specific issues regarding CT quality control, see the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [100].

Equipment monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [122].

A. For diagnostic quality CTA, the CT scanner should meet or exceed the following specifications:
   1. Cervicocerebral CTA should be performed on a multidetector CT (MDCT) scanner, preferably with greater than or equal to 4 active detector rows.
   2. Gantry rotation: 1 second or less for cervicocerebral CTA.
   3. Tube heat capacity that allows for a single =10-second acquisition.
   4. Section thickness: no greater than 1.5 mm.
   5. A contrast medium power injector that allows programming of both the volume and flow rate must be used for head and neck CTA examinations.

      To maximize information available from the CT scan and thus derive the full diagnostic benefit for the patient following X-ray irradiation, any CT scanner used for CTA must allow display and interpretation of the full 12 bits (from -1,000 to 3,095 Hounsfield units) of attenuation information. Dual-energy CTA can be obtained when available to decrease total patient radiation dose, lower contrast administration, distinguish contrast from hemorrhage and calcium, and reduce hardware artifacts [123-126].

B. Patient monitoring equipment and facilities for cardiopulmonary resuscitation, including vital signs monitoring equipment and support equipment, should be immediately available.

   Appropriate emergency equipment and medications must be immediately available to treat adverse reactions associated with administered contrast. 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.

   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 emergencies, such as cardiopulmonary arrest.

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).

When possible, CT imaging of the head should consider the following to minimize radiation dose and maintain image quality:

1. Center the patient in the gantry [127].
2. Angling of the gantry to exclude the orbits during brain imaging [128,129].

3. Remove unnecessary objects from the patient.

Dose-minimization CT techniques should be used, especially in the pediatric population [130].

Diagnostic Reference Levels (DRL) and Achievable Doses (AD) are national benchmarks for radiation protection and optimization that provide a comparison for facilities in order to review techniques and determine whether acceptable image quality can be achieved at lower doses. Published levels are available [131]. For further information, see the ACR–AAPM–SPR Practice Parameter for Diagnostic Reference Levels and Achievable Doses in Medical X-Ray Imaging [132]. Attention to dose is particularly important but also particularly challenging in the pediatric population, when age and size specific protocols should be considered [133].

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).

In addition to CT radiation safety and quality control, appropriateness studies, and utilization review, a facilitation of best practices for CT brain imaging should be considered and encouraged as part of a comprehensive continuous quality improvement program [23,134-141]. Moreover, best practices that are evidence based and instituted as part of care team and/or multidisciplinary policies to assure equitable access and utilization and the reduction of health disparities should also be considered and encouraged [142-144].

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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.

<u>Development Chronology for this Practice Parameter</u>

2022 (Resolution 20)

Amended 2023 (Resolution 2c, 2d)