ACR–NASCI–SIR–SPR PRACTICE PARAMETER FOR THE PERFORMANCE AND INTERPRETATION OF BODY COMPUTED TOMOGRAPHY ANGIOGRAPHY (CTA)

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 parameter was developed collaboratively by the American College of Radiology (ACR), the North American Society for Cardiovascular Imaging (NASCI), the Society of Interventional Radiology (SIR), and the Society for Pediatric Radiology (SPR).

Body computed tomography angiography (CTA) is a method for characterizing vascular anatomy, diagnosing vascular diseases, planning treatment for vascular diseases, and assessing the effectiveness of vascular

treatment. Following intravenous injection of iodinated contrast medium, CTA uses a thin-section CT acquisition that is timed to coincide with peak arterial and/or venous enhancement, depending on the vascular structures to be analyzed. The resultant volumetric data set is interpreted using primary transverse reconstructions as well as multiplanar reformations and 3-D renderings [1,2].

II. INDICATIONS

Indications for body CTA include, but are not limited to:

1. Aneurysmal disease: Diagnosis, localization, characterization, and pretreatment planning of vascular aneurysms
2. Dissection and dissection variants: Diagnose the presence, location, extent, and complications of vascular dissection and intramural hematoma and determine appropriate treatment
3. Arterial occlusive disease: Diagnose, localize, characterize, and plan treatment of disease entities including, but not limited to, aortioiliac stenoses and occlusion, upper- and lower-extremity peripheral arterial disease, renovascular disease, mesenteric ischemia, and vasculitis
4. Trauma: Assess for presence and location of vascular, solid organ, and visceral organ injury and hemorrhage and determine appropriate management options [3,4]
5. Nontraumatic hemorrhage: Assess for the presence, etiology, and location of nontraumatic arterial bleeding including, but not limited to, gastrointestinal bleeding, hemoptysis, intraperitoneal or retroperitoneal bleeding, which may be spontaneous, postsurgical, or related to an infectious, inflammatory, or neoplastic process
6. Thromboembolic disease: Diagnose presence and extent of arterial and venous thrombi and thromboemboli; guide endovascular treatment of thromboembolic and atheroembolic disease
7. Oncology: Determine vascular anatomy of tumors for prognostication, planning endovascular and surgical treatment and assessing treatment response [5,6]
8. Vascular malformations: Localize and characterize for the purpose of diagnosis and possible treatment planning as well as assessing treatment response
9. Anatomic mapping: Characterization of normal and variant vascular anatomy for planning organ transplantation [7], planning autografts for musculoskeletal and breast reconstruction [8], or treatment of ureteropelvic junction obstruction [9], popliteal entrapment syndrome, thoracic outlet syndrome, and transcatheter aortic [10], pulmonic [11], mitral [12], and tricuspid [13] valve replacement
10. Localize and characterize blood supply to congenital abnormalities for purpose of diagnosis and treatment planning
11. Diagnose, localize, and assess progression and/or response to treatment for diseases with primary manifestations in the arterial wall, including vasculitides, infection, and degenerative disorders
12. Venous disease: Diagnose normal and abnormal venous anatomy prior to venous sampling; determine presence of intrinsic/extrinsic, acute/chronic venous obstruction and dilated perforators in patients with venous hypertension [14]; and evaluate portal hypertension–related venous abnormalities
13. Assess the effectiveness of arterial and venous reconstruction or bypass using both traditional surgery and transluminal therapy; determine the patency, location, and/or integrity of grafts and other vascular devices, including, but not limited to, grafts, stent-grafts, stents, vena caval filters, and radiopaque embolic material
14. Congenital and acquired arterial stenosis

For the pregnant or potentially pregnant patient, see the ACR–SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Patients with Ionizing Radiation [15].

Cardiac indications for CTA are addressed in the ACR-NASCI-SPR Practice Parameter for the Performance and Interpretation of Cardiac Computed Tomography (CT) [16].

For additional information on the use of contrast and contrast reactions, see the ACR Manual on Contrast Media [17].

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [18].

Physician

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

1. The physician should meet the criteria listed in the ACR Practice Parameter for Performing and Interpreting Diagnostic Computed Tomography (CT) [18] and the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [19]. For cardiac qualifications, see the ACR-NASCI-SPR Practice Parameter for the Performance and Interpretation of Cardiac Computed Tomography (CT) [16].

2. The physician is responsible for reviewing indications for the examination and for specifying the parameters of image acquisition; the route, volume, concentration, timing, and rate of contrast injection; and the method of image reconstruction and rendering. The physician should monitor the quality of the images and interpret the study. Interpreting physicians must be knowledgeable of the anatomy and diseases of the cardiovascular system and their treatment.

3. Nonradiologist physicians meeting the aforementioned criteria additionally must be able to identify important nonvascular abnormalities that may be present on CT angiograms. The abnormalities include neoplasia, sequel of infection, visceral and musculoskeletal trauma, noninfectious inflammatory diseases, congenital anomalies and normal anatomic variants, and any other abnormalities that might necessitate treatment or further characterization through additional diagnostic testing.

4. The physician should be familiar with the use of 3-D processing workstations and be capable of performing or directing a technologist in the creation of 3-D renderings, multiplanar reformations, and measurement of vessel dimensions.

IV. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for a CTA 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)

IV. SPECIFICATIONS OF THE EXAMINATION

A. Patient Selection and Preparation

A brief history focused on identifying potential contraindications to the intravenous administration of iodinated contrast material should be obtained from each patient prior to the examination. If an absolute contraindication is present, CTA should not be performed, and an alternative vascular imaging modality should be considered. If a relative contraindication to iodinated contrast material, such as renal insufficiency or a previous allergic reaction, is identified, the patient should be prepared following the ACR–SPR Practice Parameter for the Use of Intravascular Contrast Media [19] and the ACR Manual on Contrast Media [17].

Once a patient is determined to be a candidate for CTA, additional steps to maximize the quality of the examination while minimizing any adverse effect on the patient should be taken. The patient should be well hydrated both before and after the examination. The utility of intravenous hydration with or without sodium bicarbonate for the prevention of contrast-associated nephropathy remains controversial [20-22]. Nephrotoxic medication should be held the day prior to the examination, when possible. The patient should not receive any positive bowel contrast agents, although use of a neutral contrast agent could be considered in cases of

gastrointestinal bleeding, particularly when an underlying mass is suspected.

If not already present, intravenous access should be established with placement of an appropriately sized catheter (typically 20 gauge or larger in an adult) in a vein in the antecubital fossa or forearm. The catheter should be tested with a rapid bolus injection of sterile saline to ensure that the venous access is secure and can accommodate power injection. A central venous catheter approved for power injection may also be used.

IV. SPECIFICATIONS OF THE EXAMINATION

B. CT Equipment

The use of a multidetector-row CT (MDCT) scanner is preferred for CTA [23]. Helical, wide-area detector cine, or prospectively electrocardiographic (ECG)-triggered CT acquisition is used for CTA. A complete gantry rotation should be no greater than 1 second, but newer-generation scanners, which have gantry rotation times of 0.4 to 0.27 seconds, are preferred if available. The scanner must be capable of detecting pathology in the adjacent structures and end organs of the vessels. For cardiac and some ascending aortic CTAs, an ECG-gated acquisition may be performed to allow reconstruction of the scan volume at one or multiple phases of the cardiac cycle.

A powered contrast material injector that allows programming of both the volume and flow rate should be used for CTA examinations. In some young pediatric patients, manual administration may be acceptable but is not suggested.

A workstation capable of creating multiplanar reformations, maximum-intensity projections, and volume renderings should be available for complete review of the imaging study. The workstation should also allow the direct measurement of vascular dimensions and, when appropriate, path lengths and angles.

For additional information, please see the ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [24].

IV. SPECIFICATIONS OF THE EXAMINATION

C. CTA Technique

Prior to acquiring the CTA, an unenhanced helical CT acquisition may be necessary for detecting mural or extravascular hemorrhage, distinguishing hyperdense ingested objects from intraluminal gastrointestinal bleed, mapping of arterial calcification, evaluating surgically or percutaneously deployed material such as endovascular stents [25] or embolic material, or localization of the anatomy of interest. Unenhanced CT acquisitions are not typically required in pediatric patients, particularly given the radiation exposure associated with additional phases of CT scanning. The section thickness for the preliminary noncontrast CT acquisition is application dependent. Ideally, it should be the same thickness as the CTA but should not exceed 5 mm. The radiation exposure to the patient should be minimized within the limits of diagnostic image quality and should consider the size and age of the patient to apply the principle of using a radiation dose that is as low as reasonably achievable (ALARA). Radiation exposure should be optimized using dose reduction techniques such as low kVp scanning, tube current modulation, and iterative reconstruction, as appropriate. Achieving an appropriate radiation dose is a particularly important consideration in pediatric patients and young adults, who are potentially more susceptible than older patients to harmful effects of ionizing radiation [26-29].

The CTA acquisition should be performed with a nominal section thickness of 1.5 mm or less, depending on the vascular territory to be assessed. The scan should be reconstructed with overlapping sections at a maximum increment of 50% of the effective section thickness to enhance the quality of 2-D and 3-D reconstruction images and to prevent artifacts [30-32]. The exception is when a very thin collimation (0.5–0.75 mm) is used, which results in an isotropic data set in which spatial resolution is the same regardless of the plane of reformation [33].

A delayed-phase acquisition may be indicated in some settings and is usually performed with a maximum section thickness of 3 mm. These settings include, but are not limited to, the detection of endoleaks following arterial stent grafting [34], the detection of bleeding, evaluation of venous anatomy following arterial assessment, and ureteral and renal collecting system evaluation.

IV. SPECIFICATIONS OF THE EXAMINATION

D. Contrast Material Delivery

Nonionic contrast material, with at least 300 mgI/mL, should be used for CTA. The dosage of iodine should be selected in consideration of the scan duration, the patient's weight, and comorbidities that might increase the risk of nephrotoxicity [35]. The administration of contrast material for the CTA should ideally be performed with a minimum flow rate of 3 mL/s in any patient weighing 50 kg or more. Higher flow rates of up to 6 mL per second or greater may be required for larger patients, and in general higher flow rates are required for shorter acquisitions. Therefore, contrast material injection parameters should be modified on an individual patient basis whenever necessary. For all patients, but particularly for children, contrast material dosing should be scaled to body weight. Although all CTA in adults and large children should be performed with a power injector, for infants with small intravenous catheters (eg, 24 gauge) or central venous catheters [36], the use of a power injector remains preferred, as the complication rates have been low [37,38]. In these pediatric patients, the contrast material can be successfully administered manually at a rate of 0.5 to 1.5 mL/s [38].

When performing thoracic CTA, a right arm injection is preferable to a left arm injection to avoid artifacts from undiluted contrast material in the left brachiocephalic vein. In infants without available antecubital veins for intravenous catheter placement, a lower-extremity peripheral vein can be used for intravenous contrast administration. When possible, a bolus of saline following the iodinated contrast material injection may be used to reduce the volume of contrast material required to achieve adequate vascular opacification.

Because of substantial variations in the time required for an intravenous contrast material injection to reach the target vascular anatomy, an assessment of patient-specific circulation time is frequently required, although not mandatory. Circulation timing can be performed using three techniques:

IV. SPECIFICATIONS OF THE EXAMINATION

D. Contrast Material Delivery

1. Test bolus:

Intravenous injection of a small bolus (eg, 10–15 mL in adults) of contrast material at the rate and through the access that will be used for the CTA, followed by acquisition of sequential stationary 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-attenuation curve. The peak of the curve is used to determine the scanning delay.

IV. SPECIFICATIONS OF THE EXAMINATION

D. Contrast Material Delivery

2. Bolus tracking:

The use of automated triggering software based on monitoring of the attenuation within the vessel of interest by the CT scanner during administration of the full dose of contrast material. The CTA is automatically or manually started when the enhancement in the vessel of interest reaches a predetermined operator-selected level. In small children, it can be monitored and started manually, considering the enhancement target(s), time delay in scan, and rate of injection [39]. This method may be challenging in infants and young children with small vessels. It carries a lower overall dose when compared with the iodine test bolus method.

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D. Contrast Material Delivery

3. Preset delay:

Although bolus tracking or administration of a timing bolus is recommended for CTA in general, in infants and young pediatric patients, because of limitations in total volume of contrast material to be administered and to save radiation dose, empiric determination of the scan delay may be used. In these circumstances, consideration of variations in circulation time to target vasculature for study should inform the delay time. Care should be taken that all of the calculated contrast volume is injected before the start of the scan by adjusting the injection

rate to the highest possible, given the caliber of the available IV access and/or by reducing the total contrast volume accordingly to accomplish this goal. Injection of a “chasing” bolus with saline to reduce streak artifacts from dense venous opacification is also encouraged whenever possible.
In patients with complex congenital heart disease involving cavopulmonary Glenn and/or Fontan anastomoses, the study should be set up so as to optimize the enhancement of the pulmonary vasculature or Fontan pathway based on the clinical question. This may involve splitting the bolus for combined upper-extremity and lower-extremity venous injections, preferentially with two separate power injectors [39,40]. In order to achieve diagnostic-quality contrast enhancement of pulmonary vasculature in these patients, consider these three CT techniques: 1) using simultaneous injections of contrast material via catheters placed in both upper-extremity and lower-extremity veins, 2) performing a delayed second-phase CT scan if there is suboptimal opacification in the Fontan pathway or pulmonary artery on the first-phase CT scan, and 3) using bolus tracking to initiate the scan when optimal contrast enhancement is observed within the Fontan pathway and/or pulmonary vasculature [39-41]. Knowledge of the clinical question that needs to be addressed prior to imaging (such as a focus on the cavopulmonary anastomosis, pulmonic, or systemic arterial anatomy), exact congenital heart disease and associated anomalies (such as left-sided superior vena cava (SVC), absent bridging brachiocephalic vein, interrupted inferior vena cava (IVC)) is crucial to achieve the diagnostic study [41].

IV. SPECIFICATIONS OF THE EXAMINATION

E. Postprocessing and Image Review

Postprocessing of the CTA by either physicians or radiology technologists to provide multiplanar reformations and/or 3-D renderings is mandatory. Technologists processing CT examinations should be certified by the American Registry of Radiologic Technologists (ARRT) or have an unrestricted state license with documented training and experience in CT. Volume renderings, maximum-intensity projections, and curved planar reformations must be created by a person knowledgeable of both cardiovascular anatomy and pathology to avoid misrepresenting normal regions as diseased and vice versa. Segmentation of the CT data through a variety of manual and automated means may facilitate vascular visualization but must be performed with care to avoid excluding key regions of the anatomy or the creation of pseudolesions.

Images should be clearly labeled to indicate left and right. Manual labeling that identifies the artery and its situs is required when lateral or sagittal views of one of the iliac, upper-extremity, or lower-extremity arteries are displayed or when aortic branches are presented in isolation, typically using curved planar reformations. Postprocessed images should be recorded and archived in a manner similar to the source CT reconstructions.

CTAs should be interpreted on a workstation that allows stacked cine viewing of the source and reformatted images. Interpretation of a CTA includes review of the transverse sections, multiplanar/curved reformations, volume renderings, and any other images produced during postprocessing. On occasion, the physician reading the study will create postprocessed images to document important findings that are essential for accurate interpretation of the study. These images should be archived with the patient’s original study and any other postprocessed images. Pertinent measurements of vascular dimensions should be performed digitally on the workstation. Complete interpretation of a CTA includes evaluation of all other structures in the field of view at appropriate window levels in order to identify any nonvascular pathology that may be present.

IV. SPECIFICATIONS OF THE EXAMINATION

F. Image Quality

The CTA examination involves a combination of selecting the right patient for the right examination and then performing it on an appropriate scanner using the correct scanning protocol. All of the preceding requirements and recommendations are designed so that the examination performed has the image quality necessary for correct interpretation of the study in order to optimize patient care. Image quality can be defined in many ways, but in this era of optimizing dose protocols, it is focused on the quality necessary to provide the information for which the study is ordered, yet doing so at the lowest dose possible (ALARA principle). It is a delicate balance between low radiation dose and high image quality. This balance is often not simple, especially when dealing with patients in the pediatric age group. However, even in adults, understanding appropriate image quality is challenging.

Defining adequate image quality is difficult and can vary between different radiologists, even when they are looking at the same data set. Regarding CTA, several points are worth emphasizing:

1. Optimal study quality requires enhancement of the interrogated arteries of at least 250 to 300 Hounsfield units (HU) above baseline in order to facilitate detection of arterial pathology. Veins enhanced using indirect CT venography should enhance by at least 100 HU. This requires the selection of the correct study protocol, including tube voltage (kVp), injected contrast material volume, injection rate (mL/s), and the timing of the injection relative to image acquisition. Whether preset timing delays, bolus tracking, or test bolus techniques are used, one needs to be certain of acquiring data sets at the appropriate time point(s) (ie, arterial versus venous phase imaging). The complexity of the study, be it CTA of the abdominal aorta versus CTA of the pancreas versus cardiac CTA, will help determine the optimal technique for the contrast injection protocol and data acquisition timing [42-46].
2. Although ≥64-slice MDCT is ideal for CTA, 16-slice MDCT may be satisfactory for select applications. Regardless of scanner used, protocols must be optimally designed for that specific scanner. Specific scanning variables, including injection rates, scan delays, and contrast volume, will vary depending on the capabilities of the CT scanner used.
3. The CT technologist must be trained specifically in acquiring CTA studies if optimal image quality is to be obtained. One cannot overemphasize the basics, which range from correct placement of adequate IV access to monitoring the safety of the IV access during delivery of the contrast bolus. Catheter size and placement may need to be modified in pediatric patients. Image quality depends on a motion-free study, so the CT technologist must be trained to provide the correct breathing instructions and support to the patient throughout all aspects of the examination.
4. The selection of scan protocols optimized for the scanner significantly impacts the image quality provided by the study. The use of smallest detector width, thin slice thickness, and appropriate overlap of reconstruction sections are critical parameters eventually helping to define image quality. Selection of the parameters chosen for specific applications will vary based on the specifications of the scanner, the area scanned, the blood vessels to be evaluated, the age and size of the patient, and preexisting medical conditions and prior medical procedures.
5. Single breath-hold for the duration of image acquisition is ideal for CTA of the chest and/or abdomen to prevent motion artifacts that significantly degrade 3-D reconstructions. If a single breath-hold is not possible because of patient clinical condition or scanner speed, consideration should be given to decreasing the scan volume to allow performance with a single breath-hold. Breath-holds may not be necessary in cases in which the anatomy is unaffected by respiratory motion (pelvis, lower extremities, etc) or when using high-pitch spiral acquisition techniques.

Image quality is a topic of critical importance regardless of whether one is looking at the primary transverse sections, multiplanar reformations, or 3-D renderings. Some of the components that are critical for optimal image quality include:

1. Selection of the appropriate scan parameters, especially of the section thickness and spacing. Thin sections (1 mm or less) with reconstruction at 50% overlap are ideal for most applications. The smaller the vessels that need to be evaluated, the smaller the slice thickness needs to be, especially if accurate measurement of the presence and degree of stenosis is required. With wider sections, partial volume averaging limits detailed assessment of the vessel lumen and wall.
2. Optimization of delivery of iodinated contrast material and data acquisition is necessary for optimal study performance. Although most studies use arterial phase acquisitions for CTA, other studies may require both arterial and venous phase acquisitions, and others may require just venous phase acquisition (eg, evaluate IVC or SVC patency). Regardless, the proper timing is critical for optimal image quality and proper study interpretation. Acquisition of data either too early or too late relative to peak vascular enhancement can result in errors in interpretation (both false-positive and false-negative studies) or even make the study impossible to properly interpret (eg, poor opacification in a pulmonary CTA may make it impossible to diagnose a pulmonary embolism).
3. Appropriate volumes of iodinated contrast material must be used for the clinical application selected. For example, an adult cardiac CTA may use 40 to 80 mL of iodinated contrast material, although an adult aortic study with runoff may require a range of 90 to 150 mL of contrast material. By comparison, 2 to 3 mL/kg is

typical for cardiac CTA in neonates and children, although the dose may depend on the length of the region scanned and presence of obstructive lesions. Similarly, for adult oncologic abdominal applications, such as pancreatic cancer staging, larger volumes (100–150 mL) are needed to assess the organs for malignant involvement in addition to the vascular evaluation. Delivery rates of contrast material will depend on the clinical question to be addressed, the CT acquisition protocol, and characteristics of the patient. Optimal image quality requires selection of the appropriate scan parameters for a specific scanner, as discussed above.

After a diagnostic-quality data set is acquired, the postprocessing of that data set becomes the critical component of the study. Different models exist as to who actually creates the multiplanar reconstruction (MPR) /3-D images, such as the interpreting radiologist versus CT technologist versus a dedicated 3-D imaging laboratory at which images are generated by either radiologists or well-trained "3-D technologists." Regardless of the model followed, it is important that whoever generates the images is experienced in the use of the appropriate software and that quality assurance measures be used to make certain that processing is performed correctly. It is equally important that the interpreting physician have the skills to ensure that the postprocessed data set is accurate prior to image interpretation. Correlation with surgical findings or with information from other studies often is ideal to maintain quality assurance through feedback about study accuracy [47].

A detailed discussion of the postprocessing phase is beyond the scope of this section. Some helpful rules include:

1. Three-dimensional reconstruction software availability and capability vary by manufacturer. Most processing packages include task- and organ-specific algorithms, and it is critically important that the appropriate algorithm be used for the intended clinical application. Modern software packages provide capabilities, such as automated bone removal, improved centerline automation for vessel tracking, and computer-assisted measurement of the degree of stenosis present. When automated segmentation of vessel margins is performed, there should be careful scrutiny of the segmentation accuracy, and manual adjustments should be considered.
2. The radiologist and/or technologist should be well-trained in using the software. Training can be provided by the software vendor or colleagues with more experience using the software.
3. The radiologist and/or technologist must be aware of the advantages of the various rendering techniques used, be it curved planar reconstruction, volume rendering, or maximum-intensity projection. Potential pitfalls of each technique must also be understood.
4. Image capture with appropriate measurements must be provided as needed for each study. Because situs may be ambiguous on processed images, all images must be carefully labeled to indicate the vessel being displayed. Processed images should be sent to PACS and included in the original study. Delivery of appropriate images to the referring or consulting clinician may also be accomplished by email, web servers, or even printed film delivered in a way that complies with the Health Insurance Portability and Accountability Act (HIPAA). Regardless of how the information is delivered, it must be done in a timely manner.

Optimization of image quality is a complex process that requires many steps for each patient [47]. Only a concerted effort of the referring clinician, the radiologist, and the radiologic technologist can meet the goals listed above.

IV. SPECIFICATIONS OF THE EXAMINATION

G. Special Applications

Special applications include modifying scanning techniques, increasing the number of sequences required, imaging with physiologic maneuvers, or modifying contrast material administration protocols. It is not possible to address all applications here, but general principles can be outlined.

Imaging with various physiologic maneuvers may elucidate nonatherosclerotic vascular stenosis as a result of compression by adjacent anatomic structures. For example, evidence of popliteal entrapment syndrome may be more apparent during forced plantar flexion; evidence of thoracic outlet syndrome may be more apparent with

abduction and external rotation of the affected arm; and compression of the celiac axis by the median arcuate ligament is most evident in expiration (though compression that persists on inspiratory phase imaging may be more clinically significant) [48,49]. Imaging with and without the physiologic maneuver may be accomplished using a split contrast bolus technique or by obtaining serial scans after administration of a single contrast bolus. If a single-bolus technique is used, the initial arterial phase scan can be performed with the physiologic maneuver or in the position in which the patient experiences symptoms, followed by delayed acquisition in the neutral position to preferentially enhance visualization of arterial compression. For imaging of the upper extremity, as in suspected thoracic outlet syndrome, the IV catheter should be placed in the uninvolved extremity to avoid extreme enhancement of adjacent veins and associated streak artifact during arterial phase imaging.

Precontrast series in a CTA examination need to be obtained occasionally, for example, to identify calcifications in a pathological process, such as a neoplasm, or to discriminate acute hemorrhage or previously administered embolic agent (lipiodol), or ingested intraluminal pill, or surgical material from contrast enhancement. In such cases, it is important to confine the additional series to the area of concern.

CTA includes imaging of both arteries and veins, although the techniques differ for each of these vascular systems. CT venography may be performed using an indirect, direct, or hybrid technique. Indirect CT venography is accomplished by imaging in the delayed phase after contrast material administration such that the contrast material has circulated through the arterial system and then fills the venous system. The precise delay between initiation of the contrast material bolus and scanning will depend upon the specific venous anatomy being imaged and the rate of contrast material administration. Direct venography is performed during injection of dilute contrast material through an IV intravenous line placed distally in the extremity of interest. Imaging of both extremities and central veins would require simultaneous bilateral injections, and therefore, a hybrid technique may be more practical in these cases, such as in evaluating SVC syndrome or planning for dialysis access. In this example, an initial bolus of full-strength contrast material is followed by imaging during delayed injection of dilute contrast material, thus producing direct venography of the arm with the IV catheter and indirect venography of the contralateral arm and chest.

A similarly divided contrast material injection technique may be used in cases in which both arterial and venous information is desired, such as in hepatic or renal angiography, or Fontan imaging. This may halve the radiation dose without loss of information by avoiding separate arterial phase and venous phase scans [50]. Approximately 60% of the contrast dose may be injected with scan delay appropriate for venous scanning, and the remaining 40% of the contrast can be given as a second dose, with a time interval prior to scan coincident with the arterial delay. In this manner, both arterial and venous information can be obtained with a single scan.

Novel applications are being applied to gain functional information from the anatomic data obtained from CTA. Combining anatomic information of an abdominal aortic aneurysm with the patient's gender and blood pressure has been used to mathematically predict an individualized risk of rupture, which may be more accurate than maximal aneurysm diameter measurements alone [51,52].

Recent advancements in CT technology include multienergy CT, either source-based (including dual source and rapid kV switching single-source scanners) or detector-based (including dual-layer spectral CT). In traditional, single-energy CT, materials of different composition are difficult to distinguish from one another if their mass density is similar. The additional attenuation information provided by a second x-ray spectrum in multienergy CT allows for improved differentiation of multiple materials by their relative quantities of water, iodine, or calcium [53,54]. Material decomposition with multienergy CT provides the opportunity to optimize image quality and radiation dose in CTA. Removing iodine from contrast-enhanced images provides a virtual noncontrast image, eliminating the need for an additional precontrast acquisition such as in poststent endoleak evaluation, although quality of virtual noncontrast images is significantly lower than that of true noncontrast images [55], as there are circumstances when true noncontrast images still need to be obtained. Synthesizing virtual monoenergetic imaging at different energies can reduce noise [56]. Improved bone removal with multi energy CT improves segmentation for 3-D CTA vascular renderings [57]. Iodine-based blood pool imaging with multienergy CT can provide additional physiologic information, aiding in the detection of perfusion deficits such as in pulmonary embolism [58].

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [59].

All vessel diameter measurements reported should be made orthogonal to the median vessel centerline using MPR. Diameter should not be reported from measurements made directly from CT source images transverse to the patient.

In addition to examining the vascular structures of interest, the CT sections must be examined for extravascular abnormalities that may have clinical relevance. These abnormalities must be described in the formal report of the examination.

VI. EQUIPMENT SPECIFICATIONS

Equipment performance monitoring should be in accordance with the ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment [24].

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 and sizes in the patient population.

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).

VIII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality (including standards for imaging protocol review), patient and imaging specialist 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 *ACR 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).

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 – Body Imaging (Cardiovascular) of the ACR Commission on Body Imaging and the Committee on Practice Parameters – Pediatric Radiology of the ACR Commission on Pediatric Radiology in collaboration with the NASCI, the SIR, and the SPR.

Writing Committee – members represent their societies in the initial and final revision of this practice parameter

ACR	NASCI
Steven S. Raman, MD, Chair	Charles White, MD
Dorothy Gilbertson, MD	Eric Williamson, MD
Ashley Prosper, MD	

SIR	SPR
Brian Schiro, MD	Marcos P. Ferreira Botelho
Matthew Walsworth, MD	Eric Hoggard, MD
	Evan Zucker, MD

Committee on Body Imaging – Cardiovascular

(ACR Committee responsible for sponsoring the draft through the process)

Klaus Hagspiel, MD, Chair	Ashley Prosper, MD
Lucia Flors Blasco, MD, Ph.D	Steven S. Raman, MD
Larissa Braga Casaburi, MD, MPH, MHA	Andrew L. Rivard, MD
Yoo Jin Lee, BS, MS, MD	Phillip M. Young, MD
Scott K. Nagle, MD, PhD	

Committee on Practice Parameters – Pediatric Radiology

(ACR Committee responsible for sponsoring the draft through the process)

Terry L. Levin, MD, FACR, Chair	Jane Sun Kim, MD
John B. Amodio, MD, FACR	Jennifer A. Knight, MD
Jesse Berman, MD	Jessica Kurian, MD
Tara M. Catanzano, MB, BCh	Matthew P. Lungren, MD, MPH
Harris L. Cohen, MD, FACR	Helen R. Nadel, MD
Kassa Darge, MD, PhD	Erica Poletto, MD
Dorothy L. Gilbertson-Dahdal, MD	Richard B. Towbin, MD, FACR

Committee on Practice Parameters – Pediatric Radiology

Lauren P. Golding, MD
Safwan S. Halabi, MD
Jason Higgins, DO
Andrew T. Trout, MD
Esben S. Vogelius, MD

Andrew B. Rosenkrantz, MD, Chair, Commission on Body Imaging
Richard A. Barth, MD, FACR, Chair, Commission on Pediatric Radiology
David B. Larson, MD, MBA, Chair, Commission on Quality and Safety
Mary S. Newell, MD, FACR, Chair, Committee on Practice Parameters and Technical Standards

Comment Reconciliation Committee

David Youmans, MD, FACR, Chair
Taj Kattapuram, MD, Co-Chair
Dianna Bardo, MD
Richard A. Barth, MD, FACR
Marcos F. Botelho, MD
Richard Duszak Jr., MD, FACR
Dorothy Gilbertson, MD
Klaus Hagspiel, MD
Eric Hoggard, MD
David H. Kim, MD, FACR
Amy Kotsenas, MD, FACR
David B. Larson, MD, MBA
Paul A. Larson, MD, FACR
Terry L. Levin, MD, FACR
Mary S. Newell, MD, FACR
Ashley Prosper, MD
Steven S. Raman, MD
Andrew B. Rosenkrantz, MD
Brian Schiro, MD
Lori Ann Sedrak, DO
Michael Stecker, MD
Matthew Walsworth, MD
Charles White, MD
Eric Williamson, MD
Evan Zucker, MD

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*Parameters and standards are published annually with an effective date of October 1 in the year in which amended, revised or approved by the ACR Council. For parameters and standards published before 1999, the effective date was January 1 following the year in which the parameter or standard was amended, revised, or approved by the ACR Council.

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

2011 (Resolution 36)
Amended 2014 (Resolution 39)
Revised 2016 (Resolution 16)
Revised 2021 (Resolution 47)

Amended 2023 (Resolution 2c, 2d)
Revised 2021 (Resolution 47)