ACR–AIUM–SPR–SRU PRACTICE PARAMETER FOR THE PERFORMANCE OF TRANSCRANIAL DOPPLER ULTRASOUND

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

The clinical aspects contained in specific sections of this practice parameter (Introduction, Indications, Specifications of the Examination, and Equipment Specifications) were developed collaboratively by the American College of Radiology (ACR), the American Institute of Ultrasound in Medicine (AIUM), the Society for Pediatric Radiology (SPR), and the Society of Radiologists in Ultrasound (SRU). Recommendations for physician requirements, written request for the examination, procedure documentation, and quality control vary between the 4 organizations and are addressed by each separately.

Transcranial Doppler ultrasound (TCD) is a noninvasive technique that assesses blood flow within the circle of Willis and the vertebrobasilar system.

II. INDICATIONS

A. Indications for a TCD examination of children and adults include, but are not limited to:

1. Evaluation of sickle cell disease to determine stroke risk [1-3]
2. Detection and follow-up of stenosis or occlusion of a major intracranial artery including monitoring and potentiation of thrombolytic therapy for acute stroke patients [3-5]
3. Detection of cerebral vasculopathy [3,6]
4. Detection and monitoring of vasospasm in patients with spontaneous or traumatic subarachnoid hemorrhage [7,8]
5. Evaluation of collateral pathways of intracranial blood flow, including after intervention [9-11]
6. Detection of circulating cerebral microemboli (MES) or high-intensity transient signals (HITS) [5]
7. Detection of right-to-left cardiac shunts [12,13]
8. Assessment of cerebral vasomotor reactivity (VMR) [14,15]
9. Adjunct to the clinical diagnosis of brain death [16,17]
10. Intraoperative and periprocedural monitoring to detect cerebral thrombosis, embolization, hypoperfusion, and hyperperfusion [18,19]
11. Assessment of arteriovenous malformations, pre- and posttreatment [6,20]
12. Detection and follow-up of intracranial aneurysms [6,20]
13. Evaluation of positional vertigo [21]

B. Additional applications in children include, but are not limited to:

1. Assessment of intracranial pressure and hydrocephalus [22,23]
2. Assessment of hypoxic-ischemic encephalopathy [6,23]
3. Assessment of dural venous sinus patency [6,24]

III. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the ACR–SPR–SRU Practice Parameter for the Performance and Interpretation of Diagnostic Ultrasound Examinations [25].

IV. SPECIFICATIONS OF THE EXAMINATION

The written or electronic request for a transcranial Doppler examination 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 scope of practice requirements. (ACR Resolution 35 adopted in 2006 – revised in 2016, Resolution 12-b)

Cerebral blood flow velocities resistive indices (RIs) and pulsatility indices (PIs) are variable and affected by age, arterial carbon dioxide (CO2) level, and cerebral and systemic perfusion. They are influenced by body temperature, state of patient arousal, mechanical ventilation and suctioning, presence of systemic shunts, cardiac disease, and/or anemia. It is important to perform the examination when the patient is awake, quiet, and calm. In general, examinations should not be performed if the patient has been sedated or anesthetized the same day. However, these considerations are not relevant when studies are done for determination of brain death or to detect brain perfusion abnormalities intraoperatively or postoperatively.

IV. SPECIFICATIONS OF THE EXAMINATION

A. Infants prior to fontanelle closure

Depending on the size of the patient and of the fontanelle, sector, curvilinear, or linear transducers with frequencies from approximately 5 to 15 MHz should be used [26]. The highest frequency transducer that permits adequate cerebrovascular interrogation is recommended. Duplex ultrasound is preferred over nonimaging Doppler methods in children for more precise localization and insonation of the targeted vessels [27,28]. Duplex imaging may be more difficult in adults, especially the elderly, in whom the acoustic window is often small.

In infants, open fontanelles provide an acoustic window to the intracranial circulation. The distal internal carotid artery and the branches of the circle of Willis can be interrogated through the anterior fontanelle in the coronal and sagittal planes (although the middle cerebral artery may be better interrogated via a transtemporal approach; see below) [3]. For basic assessment of global cerebral arterial flow and spectral waveform analysis, interrogation of the pericallosal branch of the anterior cerebral artery on sagittal imaging via the anterior fontanelle is the simplest, most reliable approach. The superior sagittal sinus can be evaluated through an open sagittal suture. Imaging of the posterior circulation can be performed via the foramen magnum or via the posterolateral fontanelle located just posterior to the mastoid process [29,30].

When assessing for elevated intracranial pressure, interrogation of the pericallosal branch of the anterior cerebral artery can be performed both before and after gentle compression of the anterior fontanelle [31,32]. Care should be taken to minimize the degree and duration of compression.

IV. SPECIFICATIONS OF THE EXAMINATION

B. Adults and children after fontanelle closure

After fontanelle closure, the two most frequently used acoustic windows are the temporal bone and the foramen magnum. The transtemporal window is located at the thinnest portion of the temporal bone (the pterion), cephalad to the zygomatic arch and anterior to the ear.

In adults, transcranial Doppler studies require the use of lower frequency transducers to adequately penetrate the calvarium to produce useful grayscale images and obtain Doppler signals. A 2- to 3-MHz transducer or multifrequency transducer is commonly required. For children or small adults, adequate imaging may be possible at higher transducer frequencies [20]. See Figure 1.

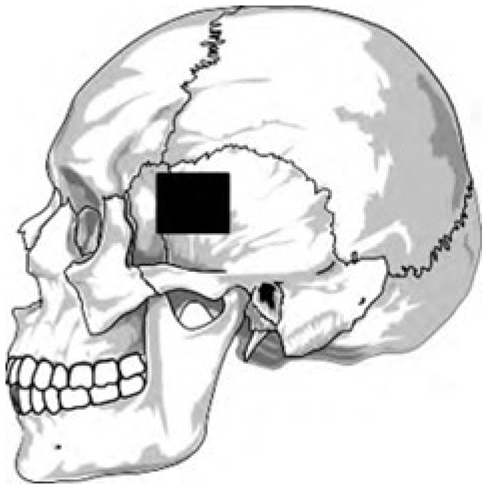


Figure 1. Location of the pterion.

If velocity reference standards have been previously acquired with nonimaging TCD methods (and thus not anglecorrected), velocity measurements with imaging methods should not be angle-corrected to allow comparison with reference values [27,33]. It should be noted that velocities obtained with duplex imaging equipment may be lower than those obtained with non-duplex imaging equipment. Therefore, stroke-risk thresholds determined with imaging equipment may need to be lowered depending on a center's protocol and technique [26,34-36]. If validated reference values for angle-corrected TCCS velocities exist in an ultrasound laboratory and a sufficient length of vessel is visualized to allow angle correction, then angle-corrected velocities can be obtained [37].

On grayscale images, the hypoechoic, heart-shaped cerebral peduncles and echogenic, star-shaped interpeduncular and suprasellar cisterns are the reference landmarks for the circle of Willis (Figure 2).

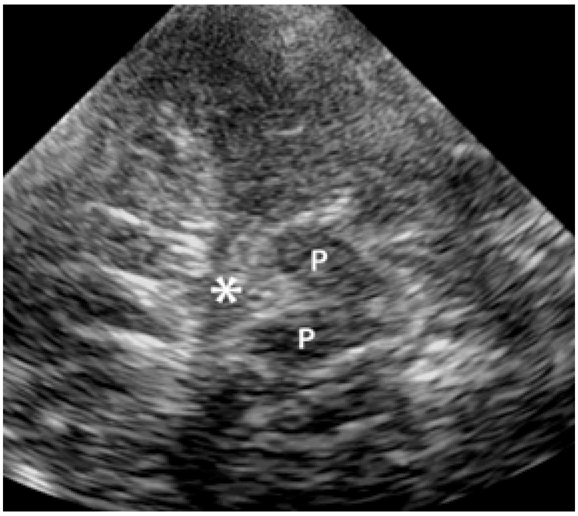
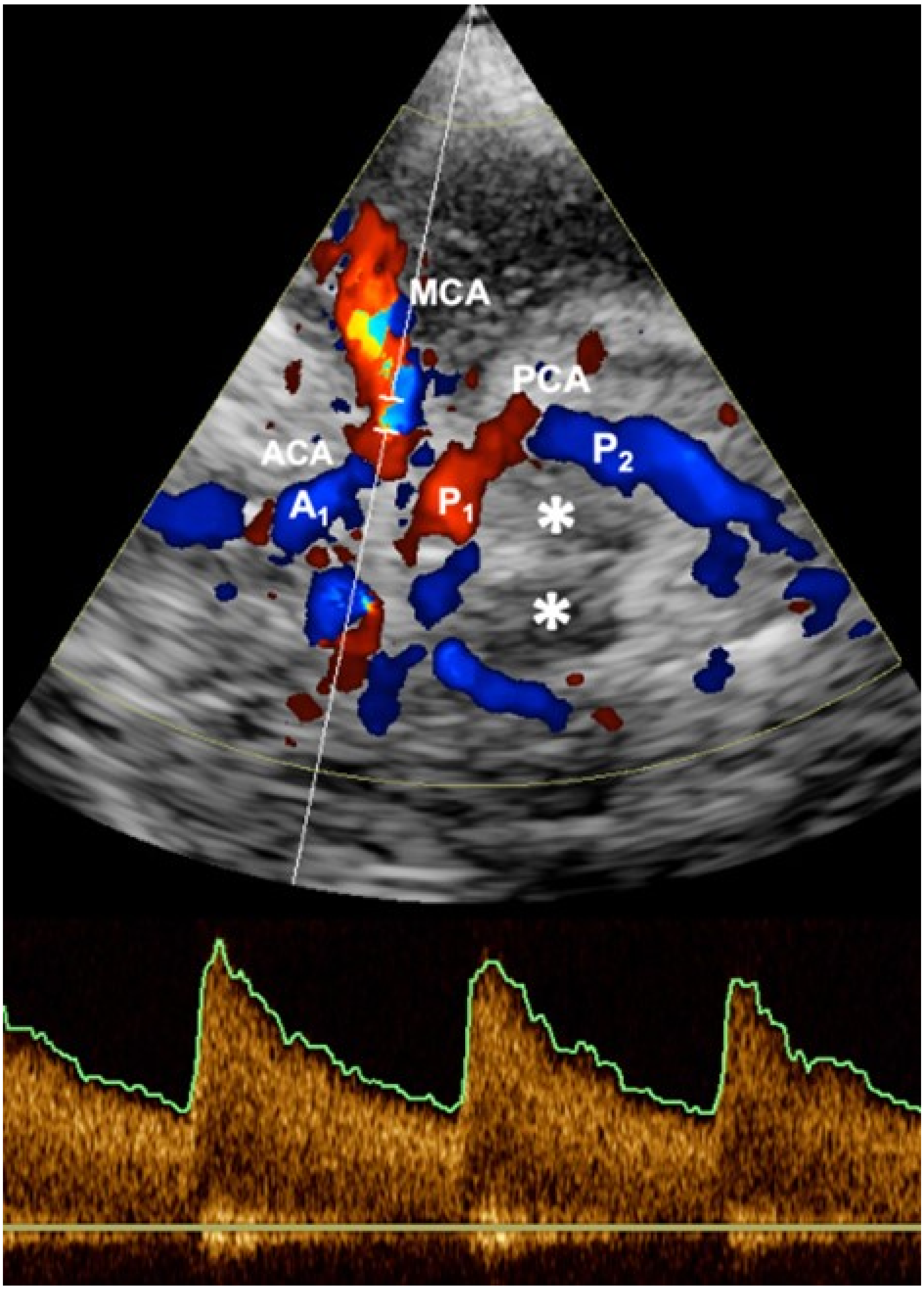


Figure 2. Transtemporal grayscale ultrasound image showing the cerebral peduncles (P) with the echogenic interpeduncular and suprasellar cisterns (*) located immediately anteriorly.

The vessels of the circle of Willis are evaluated with color and spectral Doppler (Figure 3).

Figure 3. Transtemporal color Doppler image of the circle of Willis with a spectral Doppler tracing from the middle cerebral artery (MCA). ACA = anterior cerebral artery; A1 = A1 segment of ACA; PCA = posterior cerebral artery; P1 = P1 segment of PCA; P2 = P2 segment of PCA; * = cerebral peduncle.

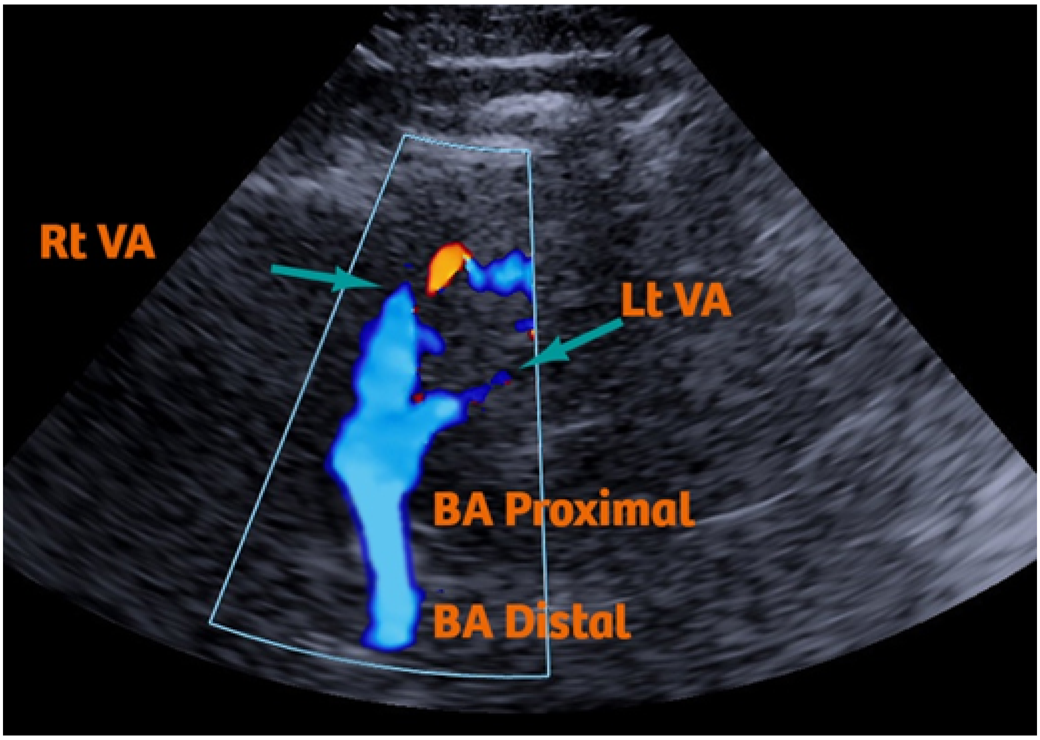


When imaging from a transtemporal approach, the MCA should be interrogated from its most superficial point below the calvarium to the bifurcation of the A1 segment of the ACA and the M1 segment of the MCA [27,28]. Normally, flow in the MCA is directed towards the transducer. The ACA should be interrogated distal to the bifurcation. Flow in the ipsilateral ACA should be away from the transducer (Figure 3). The posterior cerebral artery (PCA) courses around the heart-shaped cerebral peduncles, with flow in the ipsilateral artery directed towards the transducer in the P1 segment and directed away from the transducer in the more distal P2 segment [38,39].

The foramen magnum can be used to study the vertebral and basilar arteries. An optimal window is often obtained with the patient turned to one side with the neck flexed so that the chin touches the chest. The transducer is placed over the upper neck at the base of the skull and angled cephalad through the foramen magnum towards the nose [29,39].

On color Doppler imaging, the vertebral arteries have a V-shaped configuration as they extend cephalad to form the basilar artery. The reference landmark is the hypoechoic medulla (Figure 4). Flow in the vertebral and basilar arteries is directed away from the transducer and should be interrogated up to the distal end of the basilar artery.

Figure 4. Color Doppler image of the paired vertebral artery (VA) and basilar artery (BA).



In patients with suspected carotid artery stenosis or occlusion, a transorbital examination of the ophthalmic arteries and carotid siphons can be performed [10,40]. A transorbital window permits visualization of the ophthalmic artery and the carotid siphon. The transducer is placed so that it rests lightly on the closed superior eyelid [20]. The study must be performed at reduced power settings with a mechanical index (MI) not to exceed 0.23 and a thermal index (TI) not to exceed 1.0 to prevent ocular injury [41]. Angle correction is not performed.

In children with sickle cell disease, spectral Doppler waveform analysis should include the time-averaged maximum mean velocity as defined by the STOP trial criteria [42-45]. Velocity measurements are obtained at 2-mm intervals along the entire course of the MCA and PCA and at 2 depths from the ACA and distal ICA. Velocity can be measured with either an automatic tracing method or by manual placement of cursors. Angle-corrected velocities have typically not been used for pediatric sickle cell evaluation. Both imaging and nonimaging techniques are routinely used, with most pediatric radiology departments preferring the imaging technique and other departments using a nonimaging technique. To date, there is no evidence that TCD measurement is beneficial in individuals with sickle cell disease who are older than 16 years of age [1,46].

Patients with subarachnoid hemorrhage may develop vasospasm, with increased arterial velocities developing by day 3 after the onset of the hemorrhage and peaking between days 6 and 12 [15]. Parameters used to measure vasospasm include peak systolic velocity (PSV), mean flow velocity (MFV), RI, and PI. Threshold values depend on which vessels are insonated and which measurements are obtained. Since hyperemia, autoregulation, hypertension, and hypervolemia can also result in increased flow velocities, a submandibular approach can be used to sample the distal ICA in the neck to calculate MFV ratios between the middle cerebral and internal carotid arteries, the so-called hemispheric or Lindegaard index [47,48]. Measurements are obtained using 2 MHz spectral Doppler without angle correction. In adults, a Lindegaard ratio or index (MFVMCA/MFVICA) of 3 to 6 is indicative of mild to moderate vasospasm, and a ratio greater than 6 is indicative of severe vasospasm [48]. Angle correction is not performed. Elevated flow velocities with a Lindegaard ratio of less than 3.0 suggest the presence of an alternate diagnosis such as cerebral hyperemia, hypertension, or hypervolemia [20]. Application of adult vasospasm criteria may overestimate the true incidence of vasospasm in children [50].

Nonimaging TCD monitoring is useful for the assessment of cerebral vasomotor reactivity (VMR). VMR is the physiological mechanism that maintains constant cerebral flow across a wide range of blood pressure fluctuations through regulation of the vasomotor tone of the distal cerebral arterioles [12,14]. Under pathologic conditions (eg, traumatic and nontraumatic brain injury, stroke, and arterial occlusion), VMR may be impaired. VMR is measured with a TCD challenge test, most commonly the CO2 inhalation test or the breath-holding index (BHI). Continuous TCD tracings of MFV from the MCA (or PCA), heart rate, respiratory rate, and expiratory pCO2 are recorded during several minutes of baseline measurements, after inhalation of 5% CO2 and air for 2 minutes and for several minutes after inhalation. VMR is calculated as the percentage rise in MCA MFV per 1 mm Hg pCO2 increase from baseline. A normal VMR is defined as a rise in MCA MFV of >2% per mm Hg pCO2 [49]. Similarly, the BHI is calculated as the percentage rise in MCA (or PCA) MFV recorded immediately at the end of the breath-holding period (usually 30 seconds or less) from the MFV at baseline per seconds of breath holding [50]. A BHI ≥0.69 is considered normal [51].

Cerebral embolism accounts for up to 70% of all ischemic strokes [18,52]. Cerebral microemboli (MES) can be diagnosed by nonimaging TCD monitoring through the detection of high intensity transient signals (HITS), and are defined by the following criteria:

1. HITS usually lasting less than 300 m/sec
2. Doppler amplitude exceeding background Doppler frequency spectrum signal by at least 3 dB
3. Unidirectional signal within the Doppler velocity spectrum
4. A characteristic “moaning” or “chirping” sound [53]

The most common sources of HITS include artery-to-artery embolization from the proximal carotid, vertebral, or intracranial arteries; the aortic arch; or the heart (related to atrial fibrillation, right-to-left cardiac shunts [particularly from a patent foramen ovale], prosthetic heart valves, and after cardiac surgery). Bilateral or unilateral monitoring of a targeted intracranial vessel is recorded for a minimum of 30 minutes. Most TCD systems are equipped with automated HITS detection software that counts the number of MES and measures microembolic signal intensity [54]. However, both visual and auditory inspection and confirmation of each detected HITS are required by the rater/interpreter for a reliable diagnosis.

For detection of right-to-left shunts, TCD monitoring is performed during the intravenous injection of agitated saline or contrast medium and patient performance of a Valsalva maneuver to enhance flow across the shunt. The degree of shunting is quantitatively assessed by the number of detected HITS [55].

V. DOCUMENTATION

Reporting should be in accordance with the ACR Practice Parameter for Communication of Diagnostic Imaging Findings [56].

Adequate documentation is essential for high-quality patient care. There should be a permanent record of the ultrasound examination and its interpretation. Comparison with prior relevant imaging studies may prove helpful. Images of all appropriate areas, both normal and abnormal, should be recorded. Variations from normal size should generally be accompanied by measurements. Images should be labeled with the patient identification, facility identification, examination date, and image orientation. An official interpretation (final report) of the ultrasound examination should be included in the patient’s medical record. Retention of the ultrasound examination images should be consistent both with clinical need and with relevant legal and local health care facility requirements.

VI. EQUIPMENT SPECIFICATIONS

Equipment performance monitoring should be in accordance with the ACR-AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Real Time Ultrasound Equipment [57].

Transcranial Doppler should be performed using ultrasound frequencies that can penetrate the temporal bone and foramen magnum, or a nonimaging Doppler instrument (TCD or power M-mode Doppler). Color or spectral Doppler should be used to locate the intracranial vessels, and the Doppler setting should be adjusted to obtain the highest velocity in all cases. Doppler power output should be as low as reasonably achievable.

VII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INEFCTION 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).

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