

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

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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<sup>1</sup>. 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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<sup>1</sup> *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 (CO<sub>2</sub>) 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.

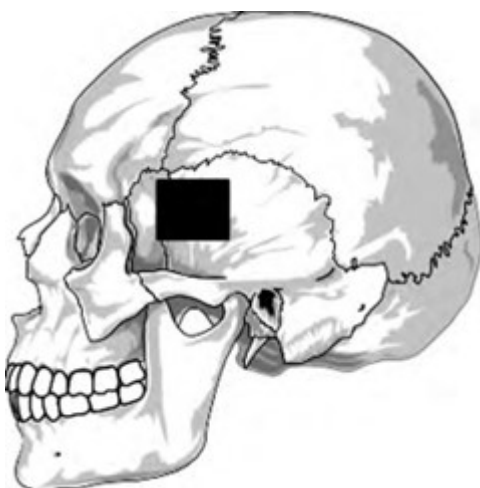


Figure 1. Location of the pterion.

If velocity reference standards have been previously acquired with nonimaging TCD methods (and thus not angle-corrected), 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).

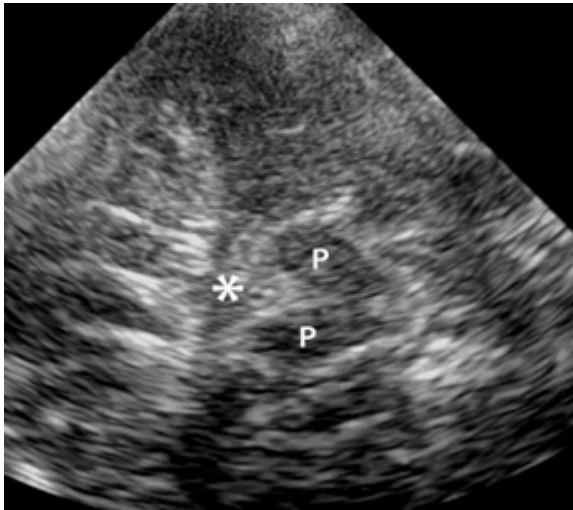
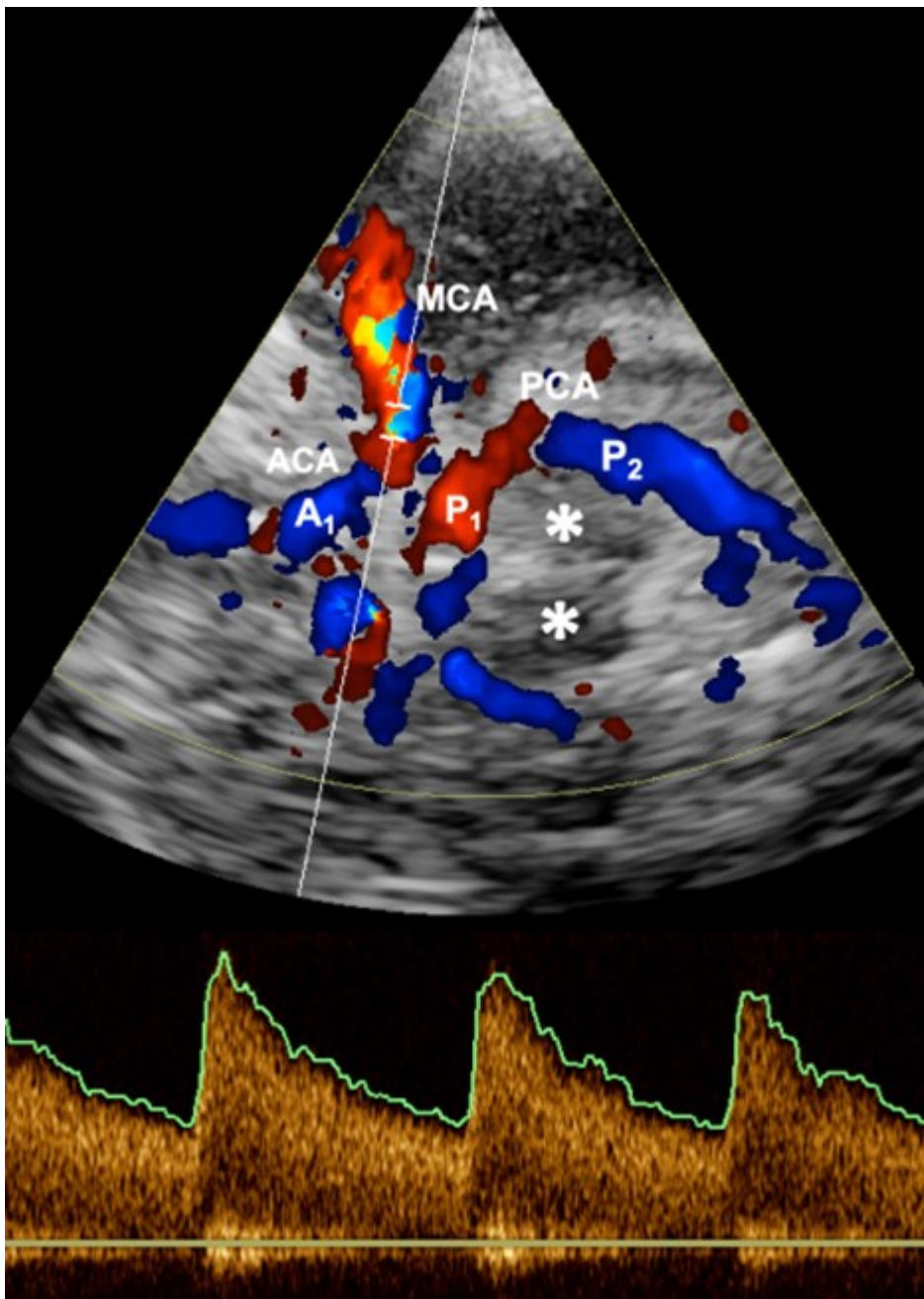


Figure 2. Transtemporal grayscale ultrasound image showing the cerebral peduncles (P) with the echogenic interpeduncular and suprasellar cisterns (\*) located immediately anteriorly.

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.



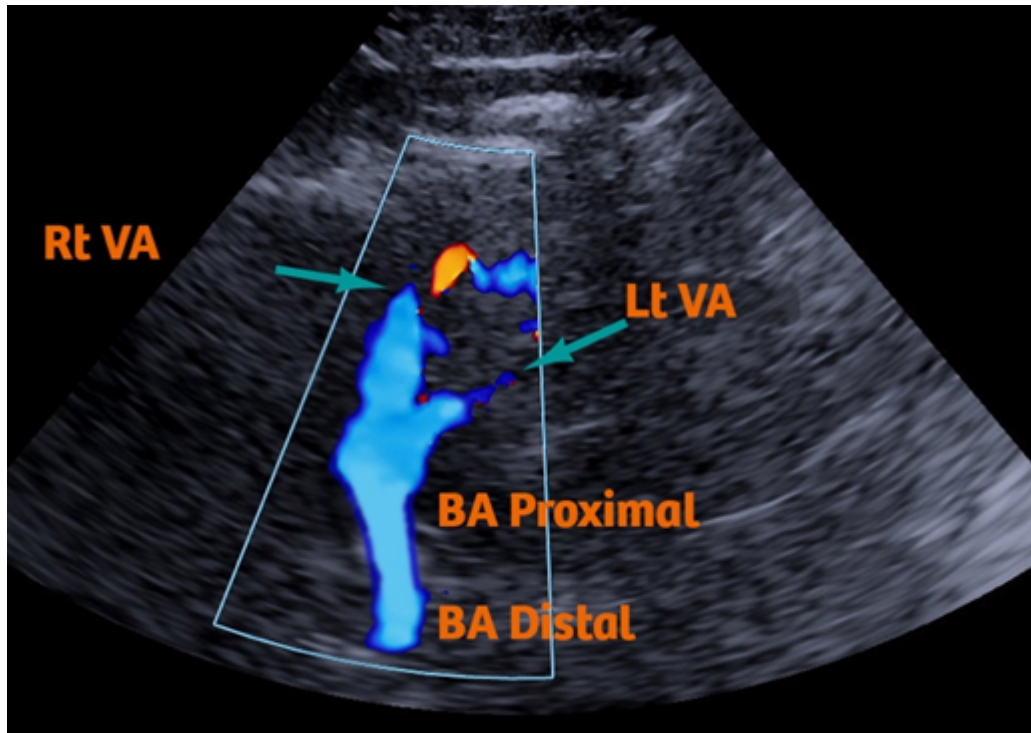
When imaging from a transtemporal approach, the MCA should be interrogated from its most superficial point below the calvarium to the bifurcation of the A1 segment of the ACA and the M1 segment of the MCA [27,28]. Normally, flow in the MCA is directed towards the transducer. The ACA should be interrogated 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 CO<sub>2</sub> inhalation test or the breath-holding index (BHI). Continuous TCD tracings of MFV from the MCA (or PCA), heart rate, respiratory rate, and expiratory pCO<sub>2</sub> are recorded during several minutes of baseline measurements, after inhalation of 5% CO<sub>2</sub> 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 pCO<sub>2</sub> increase from baseline. A normal VMR is defined as a rise in MCA MFV of >2% per mm Hg pCO<sub>2</sub> [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  $\geq$ 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, 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>).

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## **REFERENCES**

1. DeBaun MR, Kirkham FJ. Central nervous system complications and management in sickle cell disease. *Blood*. 2016 Feb 18;127(7):829-38.
2. Brousse V, Kossorotoff M, de Montalembert M. How I manage cerebral vasculopathy in children with sickle cell disease. *Br J Haematol*. 2015 Sep;170(5):615-25.
3. Verlhac S. Transcranial Doppler in children. *Pediatr Radiol*. 2011 May;41 Suppl 1():S153-65.
4. Saqqur M, Tsvigoulis G, Nicoli F, et al. The role of sonolysis and sonothrombolysis in acute ischemic stroke: a systematic review and meta-analysis of randomized controlled trials and case-control studies. *J Neuroimaging*. 2014;24(3):209-20.
5. Purkayastha S, Sorond F. Transcranial Doppler ultrasound: technique and application. *Semin Neurol*. 2012 Sep;32(4):411-20.
6. Soetaert AM, Lowe LH, Formen C. Pediatric cranial Doppler sonography in children: non-sickle cell applications. *Curr Probl Diagn Radiol*. 2009;38(5):218-27.
7. Kalanuria A, Nyquist PA, Armonda RA, Razumovsky A. Use of Transcranial Doppler (TCD) ultrasound in the Neurocritical Care Unit. *Neurosurg Clin N Am*. 2013 Jul;24(3):S1042-3680(13)00007-7.
8. Marshall SA, Nyquist P, Ziai WC. The role of transcranial Doppler ultrasonography in the diagnosis and management of vasospasm after aneurysmal subarachnoid hemorrhage. *Neurosurg Clin N Am*. 2010 Apr;21(2):291-303.
9. Guan J, Zhang S, Zhou Q, Li C, Lu Z. Usefulness of transcranial Doppler ultrasound in evaluating cervical-cranial collateral circulations. *Interv Neurol*. 2013 Oct;2(1):8-18.
10. Baumgartner RW. Intracranial stenoses and occlusions, and circle of willis collaterals. *Front Neurol Neurosci*. 2006;21():117-126.
11. von Büdingen HC, Staudacher T, von Büdingen HJ. Ultrasound diagnostics of the vertebrobasilar system. *Front Neurol Neurosci*. 2006;21():57-69.
12. Tsvigoulis G, Alexandrov AV, Sloan MA. Advances in transcranial Doppler ultrasonography. *Curr Neurol Neurosci Rep*. 2009 Jan;9(1):46-54.
13. Mojadidi MK, Roberts SC, Winoker JS, et al. Accuracy of transcranial Doppler for the diagnosis of intracardiac right-to-left shunt: a bivariate meta-analysis of prospective studies. *JACC Cardiovasc Imaging*. 2014 Mar;7(3):S1936-878X(14)00038-2.
14. Wolf ME. Functional TCD: regulation of cerebral hemodynamics--cerebral autoregulation, vasomotor reactivity, and neurovascular coupling. *Front Neurol Neurosci*. 2015;36():40-56.

- 15.** Rasulo FA, De Peri E, Lavinio A. Transcranial Doppler ultrasonography in intensive care. *Eur J Anaesthesiol Suppl.* 2008;42():167-73.
- 16.** Monteiro LM, Bollen CW, van Huffelen AC, Ackerstaff RG, Jansen NJ, van Vught AJ. Transcranial Doppler ultrasonography to confirm brain death: a meta-analysis. *Intensive Care Med.* 2006 Dec;32(12):1937-44.
- 17.** Alexandrov AV, Sloan MA, Tegeler CH, et al. Practice standards for transcranial Doppler (TCD) ultrasound. Part II. Clinical indications and expected outcomes. *J Neuroimaging.* 2012 Jul;22(3):215-24.
- 18.** Sloan MA, Alexandrov AV, Tegeler CH, et al. Assessment: transcranial Doppler ultrasonography: report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology. *Neurology.* 2004 May 11;62(9):1468-81.
- 19.** Fu B, Zhao JZ, Yu LB. The application of ultrasound in the management of cerebral arteriovenous malformation. *Neurosci Bull.* 2008 Dec;24(6):387.
- 20.** Kirsch JD, Mathur M, Johnson MH, Gowthaman G, Scoutt LM. Advances in transcranial Doppler US: imaging ahead. *Radiographics.* 2013;33(1):E1-E14.
- 21.** Machaly SA, Senna MK, Sadek AG. Vertigo is associated with advanced degenerative changes in patients with cervical spondylosis. *Clinical Rheumatology.* 30(12):1527-34, 2011 Dec.
- 22.** Cassia GS, Faingold R, Bernard C, Sant'Anna GM. Neonatal hypoxic-ischemic injury: sonography and dynamic color Doppler sonography perfusion of the brain and abdomen with pathologic correlation. *AJR Am J Roentgenol.* 2012 Dec;199(6):W743-52.
- 23.** Taylor GA. Sonographic assessment of posthemorrhagic ventricular dilatation. *Radiol Clin North Am.* 2001 May;39(3):541-51.
- 24.** Stolz EP. Role of ultrasound in diagnosis and management of cerebral vein and sinus thrombosis. *Front Neurol Neurosci.* 2008;23():112-21.
- 25.** American College of Radiology. ACR–SPR–SRU Practice Parameter for Performing and Interpreting Diagnostic Ultrasound Examinations. Available at: <https://gravitas.acr.org/PPTS/GetDocumentView?docId=24+&releaseId=2>
- 26.** Bulas D. Transcranial Doppler: applications in neonates and children. *Ultrasound Clin* 2009;4:533-51.
- 27.** McCarville MB. Comparison of duplex and nonduplex transcranial Doppler ultrasonography. *Ultrasound Q.* 2008 Sep;24(3):167-71.
- 28.** Bulas D. Screening children for sickle cell vasculopathy: guidelines for transcranial Doppler evaluation. *Pediatr Radiol.* 2005;35(3):235-241.
- 29.** Brennan CM, Taylor GA. Sonographic imaging of the posterior fossa utilizing the foramen magnum. *Pediatr Radiol.* 2010 Aug;40(8):1411-6.
- 30.** Buckley KM, Taylor GA, Estroff JA, Barnewolt CE, Share JC, Paltiel HJ. Use of the mastoid fontanelle for improved sonographic visualization of the neonatal midbrain and posterior fossa. *AJR Am J Roentgenol.* 1997 Apr;168(4):1021-5.
- 31.** Taylor GA, Madsen JR. Neonatal hydrocephalus: hemodynamic response to fontanelle compression--correlation with intracranial pressure and need for shunt placement. *Radiology.* 1996 Dec;201(3):685-9.
- 32.** Taylor GA, Phillips MD, Ichord RN, Carson BS, Gates JA, James CS. Intracranial compliance in infants: evaluation with Doppler US. *Radiology.* 1994 Jun;191(3):787-91.
- 33.** Neish AS, Blews DE, Simms CA, Merritt RK, Spinks AJ. Screening for stroke in sickle cell anemia: comparison of transcranial Doppler imaging and nonimaging US techniques. *Radiology.* 2002 Mar;222(3):709-14.
- 34.** McCarville MB, Li C, Xiong X, Wang W. Comparison of transcranial Doppler sonography with and without imaging in the evaluation of children with sickle cell anemia. *AJR Am J Roentgenol.* 2004 Oct;183(4):1117-22.
- 35.** Jones AM, Seibert JJ, Nichols FT, et al. Comparison of transcranial color Doppler imaging (TCDI) and transcranial Doppler (TCD) in children with sickle-cell anemia. *Pediatr Radiol.* 2001 Jul;31(7):461-9.
- 36.** Krejza J, Rudzinski W, Pawlak MA, et al. Angle-corrected imaging transcranial doppler sonography versus imaging and nonimaging transcranial doppler sonography in children with sickle cell disease. *AJNR Am J Neuroradiol.* 2007 Sep;28(8):1613-8.
- 37.** Nedelmann M, Stolz E, Gerriets T, et al. Consensus recommendations for transcranial color-coded duplex sonography for the assessment of intracranial arteries in clinical trials on acute stroke. *Stroke.* 2009 Oct;40(10):3238-44.
- 38.** Krejza J, Mariak Z, Melhem ER, Bert RJ. A guide to the identification of major cerebral arteries with transcranial color Doppler sonography. *AJR Am J Roentgenol.* 2000 May;174(5):1297-303.
- 39.** Lupetin AR, Davis DA, Beckman I, Dash N. Transcranial Doppler sonography. Part 1. Principles, technique, and normal appearances. *Radiographics.* 1995 Jan;15(1):179-91.
- 40.** You Y, Hao Q, Leung T, et al. Detection of the siphon internal carotid artery stenosis: transcranial Doppler versus digital subtraction angiography. *J Neuroimaging.* 2010 Jul;20(3):234-9.

**41.** Guidance for Industry and Food Administration Staff. GUIDANCE DOCUMENT Marketing Clearance of Diagnostic Ultrasound Systems and Transducers. Available at: <https://www.fda.gov/regulatory-information/search-fda-guidance-documents/marketing-clearance-diagnostic-ultrasound-systems-and-transducers>. .

**42.** Ware RE, Davis BR, Schultz WH, et al. Hydroxycarbamide versus chronic transfusion for maintenance of transcranial doppler flow velocities in children with sickle cell anaemia-TCD With Transfusions Changing to Hydroxyurea (TWITCH): a multicentre, open-label, phase 3, non-inferiority trial. *Lancet*. 2016 Feb 13;387(10019):S0140-6736(15)01041-7.

**43.** Adams RJ, Brambilla D. Discontinuing prophylactic transfusions used to prevent stroke in sickle cell disease. *N Engl J Med*. 2005;353(26):2769-2778.

**44.** Adams RJ. TCD in sickle cell disease: an important and useful test. *Pediatr Radiol*. 2005;35(3):229-234.

**45.** Adams R, McKie V, Nichols F, et al. The use of transcranial ultrasonography to predict stroke in sickle cell disease. *N Engl J Med*. 1992 Feb 27;326(9):605-10.

**46.** Valadi N, Silva GS, Bowman LS, et al. Transcranial Doppler ultrasonography in adults with sickle cell disease. *Neurology*. 2006 Aug 22;67(4):572-4.

**47.** Lindegaard KF, Nornes H, Bakke SJ, Sorteberg W, Nakstad P. Cerebral vasospasm diagnosis by means of angiography and blood velocity measurements. *Acta Neurochir (Wien)*. 1989;100(1-2):12-24.

**48.** Alexandrov AV, Sloan MA, Wong LK, et al. Practice standards for transcranial Doppler ultrasound: part I--test performance. *J Neuroimaging*. 2007 Jan;17(1):11-8.

**49.** Marshall RS, Rundek T, Sproule DM, Fitzsimmons BF, Schwartz S, Lazar RM. Monitoring of cerebral vasodilatory capacity with transcranial Doppler carbon dioxide inhalation in patients with severe carotid artery disease. *Stroke*. 2003 Apr;34(4):945-9.

**50.** Markus HS, Harrison MJ. Estimation of cerebrovascular reactivity using transcranial Doppler, including the use of breath-holding as the vasodilatory stimulus. *Stroke*. 1992 May;23(5):668-73.

**51.** Vernieri F, Pasqualetti P, Passarelli F, Rossini PM, Silvestrini M. Outcome of carotid artery occlusion is predicted by cerebrovascular reactivity. *Stroke*. 1999 Mar;30(3):593-8.

**52.** Babikian VL, Feldmann E, Wechsler LR, et al. Transcranial Doppler ultrasonography: year 2000 update. *J Neuroimaging*. 2000 Apr;10(2):101-15.

**53.** Ringelstein EB, Droste DW, Babikian VL, et al. Consensus on microembolus detection by TCD. International Consensus Group on Microembolus Detection. *Stroke*. 1998 Mar;29(3):725-9.

**54.** Markus HS, MacKinnon A. Asymptomatic embolization detected by Doppler ultrasound predicts stroke risk in symptomatic carotid artery stenosis. *Stroke*. 2005 May;36(5):971-5.

**55.** Homma S, Messe SR, Rundek T, et al. Patent foramen ovale. [Review]. *Nat Rev Dis Prim*. 2:15086, 2016 01 21.

**56.** American College of Radiology. ACR Practice Parameter for Communication of Diagnostic Imaging Findings. Available at <https://gravitas.acr.org/PPTS/GetDocumentView?docId=74+&releaseId=2>

**57.** American College of Radiology. ACR–AAPM Technical Standard for Diagnostic Medical Physics Performance Monitoring of Real Time Ultrasound Equipment. Available at <https://gravitas.acr.org/PPTS/GetDocumentView?docId=118+&releaseId=2>

\*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.

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