AIUM Practice Parameter for the Performance of a Transcranial Doppler Ultrasound Examination for Adults and Children

Parameter developed in conjunction with the American College of Radiology (ACR), the Society for Pediatric Radiology (SPR), and the Society of Radiologists in Ultrasound (SRU).

The American Institute of Ultrasound in Medicine (AIUM) is a multidisciplinary association dedicated to advancing the safe and effective use of ultrasound in medicine through professional and public education, research, development of parameters, and accreditation. To promote this mission, the AIUM is pleased to publish, in conjunction with the American College of Radiology (ACR), the Society for Pediatric Radiology (SPR), and the Society of Radiologists in Ultrasound (SRU), this AIUM Practice Parameter for the Performance of a Transcranial Doppler Ultrasound Examination for Adults and Children. We are indebted to the many volunteers who contributed their time, knowledge, and energy to bringing this document to completion.

The AIUM represents the entire range of clinical and basic science interests in medical diagnostic ultrasound, and, with hundreds of volunteers, the AIUM has promoted the safe and effective use of ultrasound in clinical medicine for more than 65 years. This document and others like it will continue to advance this mission.

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Practice parameters of the AIUM are intended to provide the medical ultrasound community with parameters for the performance and recording of high-quality ultrasound examinations. The parameters reflect what the AIUM considers the minimum criteria for a complete examination in each area but are not intended to establish a legal standard of care. AIUM-accredited practices are expected to generally follow the parameters with recognition that deviations from these parameters will be needed in some cases, depending on patient needs and available equipment. Practices are encouraged to go beyond the parameters to provide additional service and information as needed.

I. Introduction

The clinical aspects contained in specific sections of this parameter (Introduction, Indications, Specifications of the Examination, and Equipment Specifications) were developed collaboratively by the American Institute of Ultrasound in Medicine (AIUM), the American College of Radiology (ACR), the Society for Pediatric Radiology (SPR), and the Society of Radiologists in Ultrasound (SRU). Recommendations for Qualifications and Responsibilities of Personnel, Written Request for the Examination, Documentation, and Quality Control and Improvement, Safety, Infection Control, and Patient Education vary among the organizations and are addressed by each separately.

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

II. Indications

A. Indications for a TCD ultrasound 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 in a major intracranial artery in the circle of Willis or vertebrobasilar system, 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 or high-intensity transient signals (HITS)[5]
7. Detection of right-to-left shunts.[12,13]
8. Assessment of cerebral vasomotor reactivity (VMR).[13,14]
9. As an adjunct to the clinical diagnosis of brain death.[15,16]
10. Intraoperative and periprocedural monitoring to detect cerebral thrombosis, embolization, hypoperfusion, and hyperperfusion.[17,18]
11. Assessment of arteriovenous malformations, before and after treatment.[6,19]
12. Detection and follow-up of intracranial aneurysms.[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.[6,24]
3. Assessment of dural venous sinus patency.[6,25]

III. Qualifications and Responsibilities of Personnel

See www.aium.org for AIUM Official Statements, including *Standards and Guidelines for the Accreditation of Ultrasound Practices* and relevant Physician Training Guidelines.[26]

IV. Written Request for the Examination

The written or electronic request for an ultrasound examination should provide sufficient information to allow for the appropriate performance and interpretation of the examination.

The request for the examination must be originated by a physician or another appropriately licensed health care provider or under the physician's or provider's direction. The accompanying clinical information should be provided by a physician or another appropriate health care provider familiar with the patient's clinical situation and should be consistent with relevant legal and local health care facility requirements.

V. Specifications of the Examination

Cerebral blood flow velocities and the resistive indices are variable and affected by age, the arterial carbon dioxide (CO_2) level, and cerebral and systemic perfusion. They are influenced by body temperature, the state of patient arousal, mechanical ventilation and suctioning, the presence of systemic shunts, cardiac disease, and/or anemia. It is important to perform the examination when the patient is awake, quiet, and calm. Generally speaking, examinations should not be performed if the patient has been sedated or anesthetized earlier 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.

A. Infants Before Fontanelle Closure:

Depending on the size of the child, sector, curvilinear, or linear transducers with grayscale and Doppler frequencies from approximately 5 to 15 MHz should be used.[27] 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.[28,29] Duplex imaging may be more difficult in adults, especially the elderly, in whom the acoustic window is often small.

In infants, an open fontanelle provides an acoustic window to the intracranial circulation. The distal internal carotid vessels 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 [MCA] 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 (ACA) 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.[30,31]

When assessing for elevated intracranial pressure, interrogation of the pericallosal branch of the ACA can be performed both before and after gentle compression of the anterior fontanelle.[32,33] Care should be taken to minimize the degree and duration of compression.

B. Adults and Children After Fontanelle Closure

Transcranial spectral Doppler sonography, power M-mode Doppler sonography, or transcranial color-coded duplex sonography (TCCS) should be performed with the patient supine. If velocity reference standards have been previously acquired with nonimaging TCD methods (and thus not angle corrected), velocity measurements with imaging methods (TCCS) should not be angle corrected to allow comparison with reference values.[28,34] It should be noted that velocities obtained with duplex imaging equipment may be lower than those obtained with nonduplex imaging equipment. Therefore, stroke risk thresholds determined with imaging equipment may need to be lowered.[27,35–37] However, if validated reference values for angle-corrected TCCS velocities exist in an ultrasound laboratory, and a sufficient length of a vessel is visualized during TCCS to allow angle correction, then angle-corrected velocities can be obtained.[38]

In adults, TCD 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 with 2- to 3-MHz spectral Doppler capability is commonly required. For children or small adults, adequate imaging may be possible at higher transducer frequencies.[20]

Representative views and velocities should be obtained of the distal internal carotid arteries (ICAs); the ACAs, MCAs, and posterior cerebral arteries (PCAs) in the circle of Willis; and the vertebrobasilar system. Any abnormalities should be further evaluated and documented. Both the left and right sides of the brain should be interrogated unless the examination is performed to follow up a known abnormality of a specific vessel.

After fontanelle closure, the two available 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 (Figure 1).

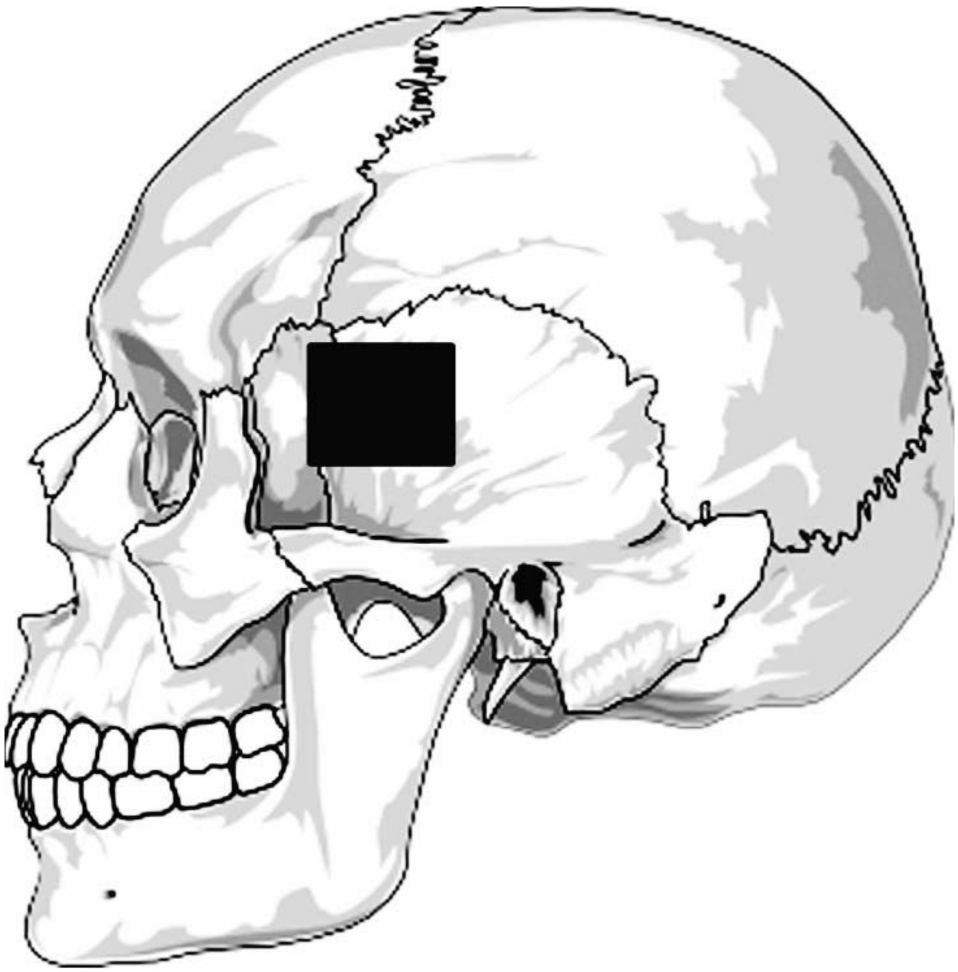

Figure 1. Location of the pterion.

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).

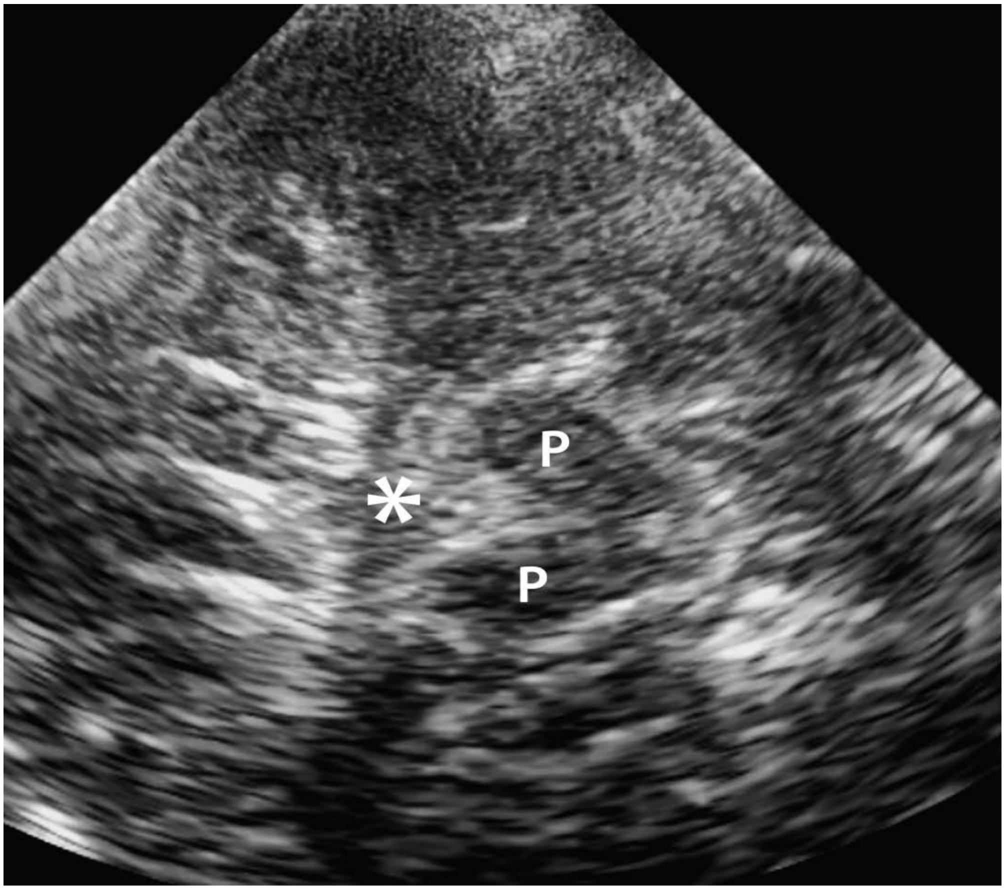

Figure 2. Transtemporal grayscale image showing the cerebral peduncles (P) with the echogenic interpeduncular and suprasellar basilar cistern (*) located immediately anteriorly.

Anterior and lateral to the cistern is the MCA, which should be insonated by using color and spectral Doppler imaging (Figure 3).

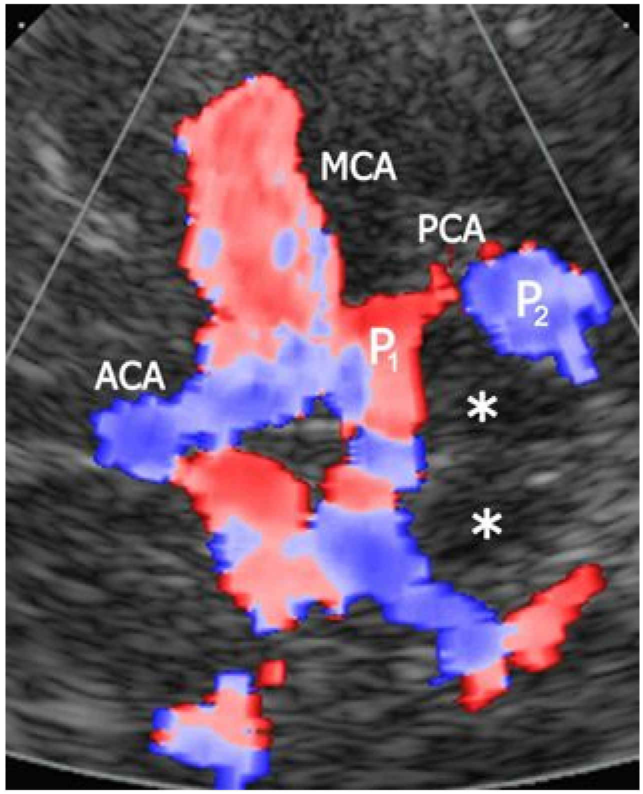

Figure 3. Transtemporal color Doppler image of the circle of Willis. * indicates cerebral peduncle.

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.[28,29] Normally, flow in the MCA is directed toward the transducer. The ACA should be interrogated distal to the bifurcation. Flow in the ACA should be away from the transducer (Figure 3). The PCA courses around the heart-shaped cerebral peduncles with flow directed toward the transducer in the P1 segment and directed away from the transducer in the more distal P2 segment.[39,40] Tracing the PCAs medially to the top of the basilar artery with its normally bidirectional flow can be used to verify correct positioning of the Doppler sample volume within the posterior cerebral arteries.

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 toward the nose.[30,40]

On TCCS, the vertebral arteries have a V-shaped configuration as they extend superiorly 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.

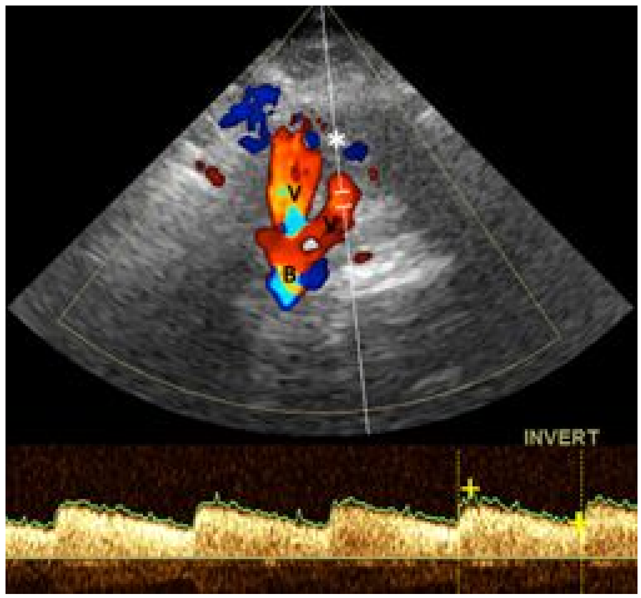

Figure 4. Color Doppler image of the paired vertebral (V) and basilar (B) arteries with a spectral tracing obtained from the right vertebral artery. * indicates medulla.

In patients with suspected carotid artery stenosis or occlusion, a transorbital examination of the ophthalmic arteries and carotid siphons can be performed.[10,41] 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 not to exceed 0.23 to prevent ocular injury.[42] 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 Stroke Prevention Trial in Sickle Cell

Anemia criteria.[43–46] 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 TCCS velocities have typically not been used for pediatric sickle cell evaluations. 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.[1,47]

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, mean flow velocity (MFV), pulsatility index, and resistive index. Threshold values depend on which vessels are insonated and which measures are performed. Since hyperemia, autoregulation, hypertension, and hypervolemia can also result in increased flow velocities, a submandibular approach can be used to sample the distal internal carotid artery in the neck to calculate mean flow velocity ratios between the middle cerebral and internal carotid arteries, the so-called hemispheric or Lindegaard index.[48,49] A Lindegaard ratio or index (MFV_{MCA}/MFV_{ICA}) of 3 to 6 is indicative of mild to moderate vasospasm, and a ratio of greater than 6 is indicative of severe vasospasm.[49] Angle correction is not performed.

Nonimaging TCD monitoring is useful for the assessment of cerebral VMR. VMR is the physiologic 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.[13,14] 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_2 inhalation test or the breath-holding index (BHI). Continuous TCD tracings of the MFV from the MCA (or PCA), heart rate, respiratory rate, and expiratory pCO_2 are recorded during several minutes of baseline measurements, after inhalation of 5% CO_2 and air for 2 minutes, and for several minutes after inhalation. VMR is calculated as the percent rise in the MCA MFV per 1-mm Hg pCO_2 increase from baseline. Normal VMR is defined as a rise in the MCA MFV of greater than 2%/mm Hg pCO_2 [50]. Similarly, the BHI is calculated as the percent rise in the 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.[51] A BHI of 0.69 or higher is considered normal.[52]

Cerebral embolism accounts for up to 70% of all ischemic strokes.[18,53] Cerebral microemboli can be diagnosed by nonimaging TCD monitoring through the detection of HITS and are defined by the following criteria:

1. HITS usually lasting less than 300 milliseconds.
2. Doppler amplitude exceeding background the Doppler frequency spectrum signal by at least 3 dB.
3. A unidirectional signal within the Doppler velocity spectrum.
4. A characteristic “moaning” or “chirping” sound.[54]

The most common sources of HITS include artery-to-artery embolization from the proximal carotid, vertebral, and 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 microemboli and measures the microembolic signal intensity.[55] 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 a 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.[56]

VI. Documentation

Adequate documentation is essential for high-quality patient care. There should be a permanent record of the ultrasound examination and its interpretation. Images of all appropriate areas, both normal and abnormal, should be recorded. Variations from normal size should be accompanied by measurements. Images should be labeled with the patient identification, facility identification, examination date, and side (right or left) of the anatomic site imaged. An official interpretation (final report) of the ultrasound findings should be included in the patient's medical record. Retention of the ultrasound examination should be consistent both with clinical needs and with relevant legal and local health care facility requirements.

Reporting should be in accordance with the *AIUM Practice Parameter for Documentation of an Ultrasound Examination.*

VII. Equipment Specifications

Transcranial Doppler imaging should be performed with a real-time imaging scanner with Doppler capability 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 imaging should be used to locate the intracranial vessels in all cases. The color gain settings should be maximized so that a well-defined vessel is displayed. The Doppler settings should be maximized so that a well-defined vessel is displayed. The Doppler setting should be adjusted to obtain the highest velocity in all cases. The Doppler power output should be as low as reasonably achievable.

VIII. Quality Control and Improvement, Safety, Infection Control, and Patient Education

Policies and procedures related to quality control, patient education, infection control, and safety should be developed and implemented in accordance with the AIUM *Standards and Guidelines for the Accreditation of Ultrasound Practices.*

Equipment performance monitoring should be in accordance with the AIUM *Standards and Guidelines for the Accreditation of Ultrasound Practices.*

IX. ALARA Principle

The potential benefits and risks of each examination should be considered. The ALARA (as low as reasonably achievable) principle should be observed when adjusting controls that affect the acoustic output and by considering transducer dwell times. Further details on ALARA may be found in the AIUM publication *Medical Ultrasound Safety*, Third Edition.

Acknowledgments

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Collaborative Committee: Members represent their societies in the initial and final revision of this parameter.

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