

AIUM Practice Parameter for the Performance of Vascular Ultrasound Examinations for Postoperative Assessment of Hemodialysis Access

Introduction

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 clinical practice parameters, and accreditation of practices performing ultrasound.

The *AIUM Practice Parameter for the Performance of Vascular Ultrasound Examinations for Postoperative Assessment of Hemodialysis Access* was developed (or revised) by the AIUM in collaboration with other organizations whose members use ultrasound for performing this examination(s) (see “Acknowledgments”). Recommendations for personnel requirements, the request for the examination, documentation, quality assurance, and safety may vary among the organizations and may be addressed by each separately.

This practice parameter is intended to provide the medical ultrasound community with recommendations for the performance and recording of high-quality ultrasound examinations. The parameter reflects what the AIUM considers the appropriate criteria for this type of ultrasound examination but is not intended to establish a legal standard of care. Examinations performed in this specialty area are expected to follow the parameter with recognition that deviations may occur depending on the clinical situation.

As the number of patients with kidney failure requiring hemodialysis each year exceeds 660,000, initial creation and maintenance of a functional hemodialysis access are increasingly critical health care concerns.¹ To improve the care of hemodialysis patients, the National Kidney Foundation established the Kidney Disease Outcomes Quality Initiative (KDOQI) in 2000 and updated it in 2006.²⁻⁴ The project set recommendations for placement and monitoring of hemodialysis access. Although there have been no hemodialysis access monitoring updates from the KDOQI since 2006, additional information on the subject has been published, indicating that there has been a movement toward earlier and more frequent hemodialysis in patients with chronic kidney disease, which in turn

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has resulted in more complications requiring an estimated 68% increase in interventions to repair accesses.⁵

The failure rate of hemodialysis access in the first year is high.⁶ In 5.1% of patients, early thrombosis occurs within 18 days of arteriovenous fistula (AVF) creation and is associated with a small arterial diameter, a forearm location, a small draining vein diameter, protamine use, female sex, surgeon frustration/concern during the access creation procedure, and a reduced or absent thrill at surgery.⁷ After fistula maturation and use, subsequent failure is frequently associated with thrombosis secondary to underlying focal stenosis, most commonly at the anastomosis. Clinical monitoring of AVF function is recommended to detect deterioration in function before thrombosis occurs.⁸⁻¹⁰ However, in arteriovenous grafts (AVGs), occult stenosis may be present in a significant number of patients with normal findings on clinical evaluations.^{11,12} The reported sensitivity of a clinical examination for stenosis in AVGs is only 36% to 57%.^{13,14} In patients who have abnormal flow volumes, salvage procedures or surgical revision may lengthen the life of the access, but there are conflicting data in the literature.¹⁵⁻¹⁸ In a data analysis of 40,132 Centers for Medicare and Medicaid Services beneficiaries, the benefits of percutaneous intervention were greatest in patients with new-access or low-access flow rates.⁶ Differences in flow parameters within an AVF versus an AVG must be considered, as different diagnostic Doppler criteria for stenosis are associated with these two access types. This practice parameter is intended to help physicians in the performance of hemodialysis access evaluations by ultrasound, to ensure a high-quality diagnostic examination, and to promote further understanding of potential salvage options.

This practice parameter will address primarily upper extremity hemodialysis access. Although lower extremity hemodialysis grafts have a significant role in patients without usable upper extremity access, the diagnostic Doppler criteria for lower extremity hemodialysis graft evaluation are less well defined.

Indications

Indications for hemodialysis access ultrasound include but are not limited to the following:

1. Hemodialysis access blood flow inadequate for dialysis, defined as a flow volume of less than

500 to 600 mL/min or patients who have an interval 25% decrease in blood flow.

2. Patients who develop persistent ipsilateral upper extremity edema or pain after access placement or during hemodialysis.
3. Patients with delayed maturity (>6 weeks) of a surgically created AVF.
4. Patients suspected of having a pseudoaneurysm (PSA), AVF, graft stenosis, perigraft soft tissue infection, or adjacent fluid collection.
5. Patients with a decreased or absent thrill or abnormal bruit over hemodialysis access.
6. Follow-up after an intervention.
7. Patients with clinical signs or symptoms of hand/digit ischemia typically during or immediately after hemodialysis but that may occur at other times.
8. Access collapse during hemodialysis.
9. Prolonged bleeding (>20 minutes) from access needle sites.
10. Unexplained decrease in the delivered dose of hemodialysis (Kt/V). Kt/V is the product of dialyzer clearance and time divided by the volume of water in the patient.
11. Repeated difficult cannulation.
12. Thrombus aspiration during hemodialysis.
13. Elevated venous pressure greater than 200 mm Hg on a 300-mL/min pump.
14. Elevated recirculation time greater than 15%.

There are no absolute contraindications to performance of this examination, but there may be physical limitations that prevent a complete duplex Doppler examination, such as the presence of indwelling catheters, open wounds, recent surgery, pain, scar tissue or calcification especially in the regions of multiple puncture sites, severe edema, contractures, and other reasons for immobility.

Qualifications and Responsibilities of Personnel

Physicians interpreting or performing this type of ultrasound examination should meet the specified AIUM Training Guidelines in accordance with AIUM accreditation policies.

Sonographers performing the ultrasound examination should be appropriately credentialed in the

specialty area in accordance with AIUM accreditation policies.

Physicians not personally performing the examination must provide supervision, as defined by the Centers for Medicare and Medicaid Services Code of Federal Regulations 42 CFR §410.32.

Request for the Examination

The written or electronic request for an ultrasound examination must originate from a physician or other appropriately licensed health care provider or under the provider's direction. The clinical information provided should allow for the performance and interpretation of the appropriate ultrasound examination and should be consistent with relevant legal and local health care facility requirements.

Specifications of the Examination

The ultrasound examination is designed to detect abnormalities that may cause access thrombosis, poor function, inability to access for dialysis, or undesirable upper extremity symptoms and to assess for causes of AVF nonmaturation.

It is important to understand the anatomic configuration of the hemodialysis access to enable an accurate and complete evaluation. Review of clinical records can be useful if there is a history of documented variant anatomy or surgery, such as failed fistulas or jump grafts.

Arteriovenous fistulas are most commonly placed in the upper extremity, either in the forearm or upper arm. A forearm AVF directly connects an artery (usually radial) to a vein (usually cephalic) at the wrist or distal forearm to increase flow in the draining vein (forearm cephalic vein AVF). This results in dilatation and wall thickening of the vein, allowing for frequent cannulation for hemodialysis. An upper arm AVF is typically created at the antecubital fossa and connects the brachial artery to the cephalic vein or at the basilic vein, which is usually transposed more anterolaterally for easier access and is called a basilic vein transposition fistula.

If AVF creation is not possible or not preferred, a prosthetic graft may be placed to create an AVG. A graft is a tube connecting an artery and vein that is

used to provide a conduit for needle access during hemodialysis. Graft configurations may include a forearm loop graft anastomosed between the brachial artery and an antecubital vein at the antecubital fossa, an upper arm straight graft from the brachial artery at the antecubital fossa to the axillary or proximal basilic vein, and an upper arm loop graft anastomosed to the axillary artery and axillary vein.

Whether an examination is requested for failure to mature or dysfunction, the components of the ultrasound study of both AVFs and grafts are similar.^{19,20} Copious amounts of ultrasound gel and careful attention to apply only limited pressure from the transducer will minimize deformity of the vein, which may affect measurements of the vein diameter. Evaluation of arterial inflow, venous outflow, turbulent or stenotic flow, and the anterior AVF vein wall depth from skin and identification of PSAs or large accessory veins or an area of significant diameter narrowing are basic components of the hemodialysis access examination. Characterization of any collection/mass near the access should be performed.

Note: For anatomic localization of an abnormality in the upper extremity venous structures, the words "cranial" and "caudal" are preferred because there is some uncertainty in the use of the terms "proximal" and "distal" with regard to the veins. Alternatively, the location of a draining vein stenosis may be described by its distance from the anastomosis. The longitudinal, or long, axis is parallel to or along the length of the vessel. The transverse, or short, axis is perpendicular to the long axis of the vessel. When measuring the velocity in the feeding artery or draining vein to be used as the denominator in the peak velocity ratio of a stenosis, the location may be described as "2 cm upstream," indicating the distance from the anastomosis. The artery supplying the anastomosis is commonly described as the "feeding artery" or "arterial inflow."

Upper Extremity AVF Examination for Fistula Dysfunction

Decreased blood flow in a hemodialysis fistula is a hallmark of access dysfunction. An ultrasound evaluation of an AVF seeks to detect stenosis, which may limit flow within the AVF and progress to thrombosis.²¹

The initial evaluation to measure the fistula diameter and to detect stenosis is performed with grayscale imaging. Significant stenosis is usually defined as

luminal narrowing equal to or exceeding 50% compared with the normal vascular segment (artery or vein) located upstream from the stenosis.^{15,22,23} Using color and spectral Doppler imaging in a long-axis plane, the peak systolic velocity (PSV) at the anastomosis is compared with the PSV in the feeding artery 2 cm upstream from the anastomosis. A PSV ratio (anastomosis/artery 2 cm upstream) greater than 3:1 has been suggested to represent a stenosis with diameter reduction greater than 50%.²⁴⁻²⁶ A small study using a PSV greater than 375 cm/s for detection of AVF anastomotic stenosis greater than 50% demonstrated sensitivity and specificity of 96% (26 of 27) and 76% (13 of 17), respectively.²⁷ However, any anastomotic stenosis should be confirmed with grayscale imaging because there is often sharp angulation of the venous origin at the anastomosis, which may elevate the PSV, simulating a stenosis.²⁸ It is important to note that although a stenosis is present, AVF vein blood flow may be adequate and the AVF useable for hemodialysis.²⁹

Inaccurate Doppler angle correction and incorrect Doppler settings can contribute to a velocity measurement error.³⁰ The Doppler angle of insonation should be maintained at 60° or less, and the angle correction cursor should be parallel to the vessel wall. In the setting of stenosis, the resistive index (RI) measured within the inflow artery was greater than 0.5 in 84% (99 of 118) of patients, compared with an RI less than 0.5 in 71% (10 of 14) of those without dysfunction.³¹

In addition to the area of the anastomosis, any visible narrowing of the draining vein on grayscale imaging or area of color aliasing within the vein should be further assessed with velocity measurements by spectral Doppler imaging. The PSV at the narrowing is compared with the PSV of the vein 2 cm upstream (caudal). A draining vein PSV ratio (narrowed draining vein/vein 2 cm upstream) greater than 2:1 suggests stenosis of 50% or greater.²⁰ Alternatively, a large retrospective study of stenoses (excluding the anastomotic region) showed poor accuracy of the PSV ratio and better sensitivity (89%) for 50% stenosis using a PSV less than 500 cm/s. However, the location of stenosis was not described, and volume flows were not reported.³² Using a PSV greater than 375 cm/s, Doelman et al²⁷ detected draining vein stenoses, including those in the cephalic vein, with 91%

sensitivity (31 of 34) and 95% specificity (71 of 75). If there is poor draining vein flow in the absence of anastomotic stenosis, the downstream (cranial) venous system may be stenotic or thrombosed. An assessment of spectral Doppler waveforms in the ipsilateral internal jugular vein and subclavian vein can detect signs of central stenosis, which may be further assessed with other imaging modalities. Central stenoses can be present even with high flow in an access, causing arm swelling. Note that multiple abnormalities may be present in a single dysfunctional access.³³

An AVF must have adequate arterial inflow to mature and function.³⁴ The prevalence of inflow arterial stenosis is much higher in dysfunctional AVFs (40%) or grafts (29%) than in functional accesses, and more than half of all patients with inflow arterial stenosis have associated venous abnormalities.²² Poststenotic arterial waveforms with parvus and tardus characteristics should be considered abnormal in the inflow vessel (feeding artery). Failure to document velocity elevation in the presence of luminal narrowing on grayscale imaging may indicate inflow disease/stenosis or low systemic pressure.^{26,35,36}

The direction of flow in the artery distal (caudal) to the anastomosis of an AVF may be evaluated to determine whether flow in the artery is reversed or bidirectional. Reversal of arterial flow is common in AVFs, although it is usually asymptomatic and does not require an intervention.³⁷ Arterial steal symptoms are more common in upper arm accesses with a brachial artery anastomosis. In a large prospective series of AVF-related hand ischemia, 7% of patients with hemodialysis access AVFs had symptoms, and 4% required interventions. Interventions are associated with female sex, diabetes, capacious outflow veins, and coronary artery disease.³⁸ Hand ischemia may occur for several reasons: inflow artery stenosis or occlusion, either in the feeding or a more proximal artery (such as the subclavian artery), outflow artery stenosis or occlusion, poor arterial collaterals, or an excessive fistula flow volume. A Doppler ultrasound evaluation may assist in the diagnosis of each of these etiologies.³⁹ In addition, pulse volume recordings of the upper extremities with and without access compression will provide an indication of the adequacy of flow and the impact of the access on digital perfusion, as some patients may have fixed arterial disease as a cause for their digital ischemia. Alternatively, the fistula can be

manually compressed just beyond the arterial anastomosis to see whether this maneuver redirects flow toward the hand or alleviates symptoms.

Other nonstenotic abnormalities, such as a PSA, hematoma, and an abscess, can be diagnosed by a combination of grayscale and duplex Doppler ultrasound. Color Doppler imaging should be used to evaluate any collection adjacent to the fistula. Grayscale and color Doppler imaging can diagnose aneurysmal dilatation, which may not be detected angiographically if a mural thrombus fills at least 50% of the lumen.³¹ A small aneurysm in a draining vein may not require treatment if the overlying skin remains intact. However, a PSA secondary to repeated needle sticks in a graft or, rarely, an AVF may worsen and lead to hemorrhage; it can require surgical management if greater than 1 cm in diameter, especially if it contains a mural thrombus.⁴⁰

Evaluation of an AVF for Failure to Mature

A normal AVF may take up to 3 months to fully mature and be usable for dialysis. Additionally, a large proportion (28%–60%) of surgically created AVFs do not initially adequately mature such that they become usable for hemodialysis within a typical maturation period of 6 weeks to 6 months.^{41–44} A mature AVF must be easily palpable and support cannulation by two 17-gauge needles. Clinical determination of fistula maturity by skilled nursing was reportedly 80% accurate⁴⁵ in one study; however, palpation had 96% sensitivity in another study if a thrill was present.⁴⁶ If an adequate AVF is not clinically identified in the first 4 to 8 weeks after surgical access creation, an ultrasound examination can be performed to assess for a potentially correctable anatomic problem. In a series of 153 patients with surveillance Doppler evaluations 4 to 8 weeks after access creation (but before attempted hemodialysis), ultrasound detected 9 occluded fistulas. An additional 40% had significant lesions, even though only 17% had abnormal clinical examination findings. In this series, 70% of the AVFs that underwent secondary interventions matured, compared with 25% without interventions.⁴⁷ If the fistula is still not useable after 3 months despite interventions, it is considered failure to mature.⁴⁸ A prospective study of 602 fistulas suggested that low blood flow and a small venous diameter at 2 weeks are predictive of AVFs that may not develop optimally at 6 weeks.⁴⁵ A follow-up

evaluation of the 602 AVFs showed that measurement of the AVF blood flow rate, AVF diameter, and distance of the anterior AVF vein wall from the skin was moderately predictive of AVF maturation.⁴⁹ A separate study showed an increased risk of failure to mature if blood flow was less than 413 mL/min at 2 weeks after fistula creation.⁵⁰

The anastomosis is evaluated for stenosis using the same diagnostic criteria defined in the section above on an upper extremity AVF examination for fistula dysfunction. Again, a greater than 3:1 PSV ratio of anastomosis compared with the feeding artery 2 cm upstream should suggest anastomotic stenosis. Special attention is given to detect stenosis of the draining vein, using a 2:1 threshold ratio for stenosis at the point of narrowing relative to 2 cm upstream.

Blood flow is measured in the midportion of the AVF draining vein where the vein is straight and non-tapering, without turbulent flow typically around 10 cm cranial to the anastomosis.³³ The Doppler gate is adjusted to encompass the lumen of the vein with alignment of the sample volume markers perpendicular to the venous walls. The angle of Doppler insonation for blood flow calculation is standardized at 60° or less to minimize the degree of measurement error. A sequence of 3 to 5 cardiac cycles is obtained to allow calculation of time-averaged velocities, and the average of 3 separate measurements is reported.¹⁷ On follow-up examinations, blood flow should be measured in the same location.

If no stenosis is identified, thresholds for the AVF vein diameter and blood flow and AVF depth from the skin may suggest whether the AVF is adequately mature for hemodialysis.⁴⁹ An AVF with a venous diameter of at least 0.4 to 0.6 cm and blood flow of at least 500 to 600 mL/min predicts that an AVF has a high likelihood of supporting successful hemodialysis.^{19,33} The lower range of values may be chosen to reduce abandonment of a fistula that may subsequently mature and recognize the measurement error in determining flow volumes. In one study, fistulas measuring greater than 0.4 cm in diameter and with volume flow greater than 500 mL/min were usable for hemodialysis in 95% of patients, whereas, those measuring less than 0.4 cm in diameter and with volume flow less than 500 mL/min matured in only 33% of patients.¹⁹ Another study of

125 hemodialysis fistulas and bridge grafts found that a volume flow threshold of 800 mL/min had improved accuracy for detection of access dysfunction relative to a 500-mL/min threshold.⁵¹ Yet another study found a 0.5-cm diameter to be a better diameter threshold than 0.4 cm.⁴⁷ A draining vein that is greater than 0.5 to 0.6 cm deep to the skin surface may mature but be too deep for consistent cannulation, and the draining vein in these situations may require superficialization. Last, there should be at least 5 to 6 cm of straight vein to allow placement of the dialysis needles.

Venous branches are documented on the basis of the size and distance from the anastomosis. Large draining venous branches (accessory veins) may be surgically ligated to increase flow through the main draining vein to allow AVF maturation.⁵² The venous drainage to the level of the medial subclavian vein may be evaluated if not done previously on a preoperative study because downstream central venous stenosis or thrombosis may inhibit AVF maturation.

Therapy for AVF dysfunction depends on the underlying abnormality and its location. Treatment of stenosis in the anastomotic/juxta-anastomotic region relies primarily on balloon angioplasty. Persistent dysfunction after 2 to 3 weeks following angioplasty should encourage repeated ultrasound to evaluate for a second abnormality or insufficient dilatation. If there are accessory veins associated with stenosis, they are addressed by treating the underlying stenosis first. If no stenosis is present, the accessory veins can be treated with surgical ligation, coiled during angiography, or percutaneously occluded with minimally invasive image-guided ligation. For treatment of a deep draining vein, an incision can be made to allow the vein to rise closer to the surface, or superficial lipectomy can be performed. Successful superficialization may allow hemodialysis access maturation in 3 to 6 weeks.⁵³

Upper Extremity Examination for Graft Dysfunction

As part of a complete study, the graft should be evaluated with grayscale, color, and spectral Doppler imaging. Graft failure that is due to thrombosis is easily diagnosed by a physical examination, but ultrasound can be used. Differentiation of occlusive versus non-occlusive thrombosis can be made by color or power Doppler imaging. In a graft, the venous anastomosis is the most common site of stenosis. A PSV ratio

(anastomosis/graft 2 cm upstream) greater than 2:1 is used as a threshold to diagnose 50% stenosis at the venous anastomosis, and a 3:1 ratio suggests 75% stenosis.^{11,20} If there is a borderline PSV ratio suggesting stenosis, a PSV greater than 400 cm/s or visible narrowing greater than 50% can help make the diagnosis.²⁵ In another study, Doelman et al²⁷ used a PSV greater than 310 cm/s to detect stenosis with sensitivity and specificity of 95% (20 of 21) and 100% (10 of 10), respectively, at the venous anastomosis. A PSV measurement at the mid graft should be obtained. Likewise, the draining vein in the limb cranial to the graft should be evaluated with color Doppler imaging for signs of narrowing or aliasing. In regions of suspected narrowing in the draining vein of a graft, a PSV ratio (stenosis versus inflow venous segment 2 cm upstream) should be calculated with a 2:1 threshold ratio applied for diagnosis of stenosis in a manner similar to the draining vein of an AVF. The sites of any stenoses are documented, and the length of the stenosis is noted. Normal color Doppler findings are useful because they preclude the need for further imaging.⁵⁴

The arterial anastomosis of a hemodialysis graft has more variability in flow velocity relative to the upstream feeding artery than in a fistula. A PSV ratio greater than 3:1 should raise concern for stenosis at the arterial anastomosis of a graft, but there is lower specificity than at other locations.²⁰ Using a threshold PSV greater than 310 cm/s for detection of stenosis, the sensitivity and specificity have been reported to be 60% or less, respectively, at the arterial anastomosis.²⁷

Normal blood flow volumes within grafts are commonly higher than in AVFs, but flow rates of 500 to 1300 mL/min have been reported with graft stenosis. A blood flow volume less than 500 mL/min should lead to a fistulogram even if no anatomic etiology for the low blood flow volume is found.

The venous outflow should be followed into the subclavian vein to assess for stenosis. The central veins of the chest can also be examined. In the absence of any other etiology for access dysfunction, the central veins of the chest should be evaluated even if they were normal at the evaluation before graft placement, especially if there is reason to suspect central venous stenosis, such as arm swelling, shoulder collaterals, or a history of prolonged or multiple subclavian or internal jugular vein catheterizations. In some patients, multiple stenoses may be present; persistent slow flow after

treatment of an inflow stenosis may unmask a central abnormality. Close attention to detail is required because some central stenoses may be missed by an ultrasound evaluation.⁵⁴

An evaluation of the feeding artery should be performed in the same manner as done for the AVF evaluation described above. Reversal of flow in the distal artery may occur and is often asymptomatic, similar to patients with AVFs.

Grafts may have disruption/degeneration of the polytetrafluoroethylene material, and this may be directly visible on grayscale imaging. There may be associated hematoma adjacent to the area of disruption. If disruption of the graft material is suspected, the finding can be further evaluated by Doppler imaging to detect a PSA or graft degeneration. A patent PSA will appear anechoic with or without an associated mural thrombus with swirling of flow on color Doppler imaging and a yin-yang appearance within the sac, similar to the appearance of PSAs in other parts of the body.

Routine Ultrasound Monitoring of Functional Access

Controversy remains in the literature as to whether aggressive routine monitoring and angioplasty of hemodialysis access, especially in a graft, can prevent subsequent thrombosis and significantly extend patency and longevity.^{6,55-64} A recent Cochrane analysis suggests that correction of surveillance-detected stenosis in the absence of access dysfunction does not extend access longevity but may have promise in fistulas by reducing hospitalizations and catheter use.⁶⁵ Accordingly, the recent “ACCF/ACR/AIUM/ASE/IAC/SCAI/SCVS/SIR/SVM/SVS/SVU 2013 Appropriate Use Criteria for Peripheral Vascular Ultrasound and Physiological Testing, Part II: Testing for Venous Disease and Evaluation of Hemodialysis Access. A Report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force” guidelines suggest that routine surveillance is rarely appropriate for the asymptomatic functioning of a hemodialysis AVF or AVG.⁶⁶

Documentation

Accurate and complete documentation is essential for high-quality patient care. Written reports and ultrasound images/video clips that contain diagnostic information

should be obtained and archived, with recommendations for follow-up studies if clinically applicable, in accordance with the *AIUM Practice Parameter for Documentation of an Ultrasound Examination*.

Equipment Specifications

The ultrasound evaluation of the peripheral veins and arteries should include both real-time imaging of the vessels and their contents and an evaluation of the flow signals originating from within the lumen using grayscale as well as color and spectral Doppler imaging, with careful attention to the anastomoses and any area of perceived narrowing/stenosis or intraluminal echoes/thrombus. Grayscale imaging of the anastomosis is critical, as color Doppler imaging may obscure thrombus synechiae or overwrite focal narrowing, resulting in either overestimation or underestimation of stenosis. Real-time imaging should be conducted at the highest clinically appropriate frequency, realizing that there is a trade-off between resolution and beam penetration. This should usually be at a frequency of 7 MHz or greater, with the occasional need for a lower-frequency transducer, such as during insonation of the central veins. To determine flow rates, higher-resolution transducers are needed, preferably 9 to 15 MHz. In most cases, a linear transducer is preferable to obtain optimal images. The flow signals originating from within the lumen of the vessels should be evaluated with a Doppler frequency of 2.5 MHz or greater. A display of the relative amplitude and direction of moving blood should be available.

Imaging and flow analysis are currently performed with duplex ultrasound using range gating in the center of the vessel and angle correction with a Doppler angle less than 60°. Color Doppler imaging is used to detect aliasing that is indicative of stenosis and to facilitate the examination. Color and spectral Doppler examinations are also useful for evaluation of a PSA or non-occlusive thrombus. Appropriate gain and scale settings should be used. The wall filter should be chosen as appropriate for the vessel interrogated.

Quality and Safety

Policies and procedures related to quality assurance and improvement, safety, infection control, and

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

ALARA (as Low as Reasonably Achievable) Principle

The potential benefits and risks of each examination should be considered. The ALARA principle should be observed for factors that affect the acoustical output and by considering the transducer dwell time and total scanning time. Further details on ALARA may be found in the current AIUM publication *Medical Ultrasound Safety*.

Infection Control

Transducer preparation, cleaning, and disinfection should follow manufacturer recommendations and be consistent with the AIUM Guidelines for Cleaning and Preparing External- and Internal-Use Ultrasound Transducers Between Patients, Safe Handling, and Use of Ultrasound Coupling Gel.

Equipment Performance Monitoring

Monitoring protocols for equipment performance should be developed and implemented in accordance with the *AIUM Standards and Guidelines for the Accreditation of Ultrasound Practices*.

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