



# The role of hemodialysis access duplex ultrasound for evaluation of patency and access surveillance

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**Contributions:** (I) Conception and design: N Fendrikova-Mahlay; (II) Administrative support: None; (III) Provision of study materials or patients: None; (IV) Collection and assembly of data: A Saati, D Puffenberger; (V) Data analysis and interpretation: None; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

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**Abstract:** The rise in prevalence of end stage renal disease (ESRD) and the impact on health care resulted in increasing focus on delivery of vascular access. Hemodialysis vascular access is the most common renal replacement therapy method. The vascular access types include arteriovenous fistula, arteriovenous graft, and tunneled central venous catheters. Vascular access function remains an important outcome measure with significant impact on morbidity and health care cost. The survival and quality of life of patients on hemodialysis is dependent on the adequacy of dialysis through proper vascular access. Early detection of failure to mature vascular access, stenosis, thrombosis, and aneurysm or pseudoaneurysm formation remains crucial. Ultrasound can help identify complications, even though ultrasound evaluation of the arteriovenous access is less well defined. Some published vascular access guidelines support ultrasound for detecting stenosis. The evolution of ultrasound has improved throughout the years, both multi parametric top-line systems and hand-held systems. Ultrasound evaluation is inexpensive, rapid, noninvasive, and repeatable, it is a powerful tool used for early diagnosis. The ultrasound image quality still depends on the skill of the operator. Careful attention to technical details is needed and avoidance of several diagnostic pitfalls is necessary. This review is focused on the role of ultrasound for hemodialysis access surveillance, evaluation of maturation, detection of access complications, and aid with cannulation.

**Keywords:** Arteriovenous fistula; Arteriovenous graft; Hemodialysis Access; Ultrasound; Access Complication

Submitted Mar 14, 2022. Accepted for publication May 19, 2022. Published online Jun 15, 2022.

doi: 10.21037/cdt-22-129

**View this article at:** <https://dx.doi.org/10.21037/cdt-22-129>

## Introduction

The prevalence of end stage renal disease (ESRD) in the United States had tripled between 1990 and 2018 rising to 2,382 per million, with up to 1,685 per million population requiring dialysis treatment (1). Previous vascular access creation guidelines had encouraged a strategy of initially pursuing autologous vascular access, i.e., “fistula first”. This approach was supported by a belief that autologous fistula has relative patency benefits compared with prosthetic bridge graft. These dogmas have fallen into a question recently as more evidence emerges that dialysis fistula are associated with high rates of non-maturation and prolonged

central venous catheter (CVC) dependency. For this reason, the most recent guidelines suggest that a patient centered approach described as the End Stage Kidney Disease Life Plan may be the best strategy (2). The ultimate clinical goal is to maximize the uninterrupted use of the vascular access circuit. Mitigating access circuit complications reduces patient morbidity and overall health care expenditure, also improved quality of life. Monitoring and surveillance programs are essential for early detection of vascular access dysfunction and to maintain adequate dialysis circuit clearance and avoid access circuit thrombosis.

Monitoring for signs of access system dysfunction by physical examination of both arteriovenous fistula (AVF)

and arteriovenous graft (AVG) is strongly recommended by Kidney Foundation Dialysis Outcomes Quality Initiative (KDOQI) (3). Clinical monitoring is done by physical exam through inspection, palpation and auscultation. Other modalities of monitoring include laboratory studies in the dialysis unit; (I) measuring dialysis adequacy by urea reduction ratio or  $Kt/V$ ; (II) monitoring for difficulty cannulation and prolonged bleeding after needle withdrawal; (III) AV access flow measurement by ultrasound dilution method, dynamic and static venous pressure, and imaging for stenosis (3).

While there is insufficient evidence to recommend routine surveillance imaging of the vascular access circuit, the dialysis access duplex ultrasound has two potential roles: (I) a diagnostic adjunct complimenting clinical findings and physical examination in the patient with fistula dysfunction, especially to distinguish cannulation issues from “flow” related issues; (II) the postoperative evaluation of arteriovenous (AV) access to assess maturation, volume flow, adequacy of access circuit for use and to establish a baseline function for a relative comparison over time. Ultrasound may also provide the diagnosis of the source of dysfunction by direct visualization of sites of stenosis or concomitant flow measurements, although the yield of ultrasound for detection of central venous stenosis is limited (4,5).

## Surveillance

Routine screening with ultrasonography to assess maturation or complication is not currently a standard practice. There is evidence to suggest that selective and clinically driven ultrasound use, when performed for signs or objective findings of dysfunction, may provide a patency benefit in AVF but probably not AVG (4). Routine ultrasound screening of AVFs early after placement, when combined with clinical inspection, helps to identify significant vascular stenosis in the absence of physical exam findings and may reduce non-maturation rates (4).

Prospective and retrospective trial comparing performance of ultrasound in detecting significant stenosis and measuring access blood flow by Tessitore *et al.* revealed that duplex ultrasound parameters of luminal diameter less than 2 mm and/or a downstream peak systolic velocity (PSV) greater than 400 cm/s have a good accuracy of 85% and a positive predictive value (PPV) of 93% for angiography-proven significant stenosis  $\geq 50\%$  (6). Doelman *et al.* compared color Doppler ultrasonography to digital subtraction angiography to assess access blood flow and

reported sensitivity of 91% and specificity of 97% to accurately detect access stenosis. Stenosis was considered significant if PSV was greater than 310 cm/s for an AVG or 375 cm/s for an AVF, or narrowing of 50% or more at the point of maximal stenosis at grayscale imaging (7). Tuka *et al.*, defined AVG stenosis as a combination of  $>50\%$  lumen reduction and peak systolic ratio (PSR)  $>2$  together with at least one of the additional criteria including residual diameter  $<2.0$  mm, blood flow  $<600$  mL/min, or the blood flow reduction of  $>25\%$  (8).

For AVF blood flow values  $<500$  mL/min were considered predictive of access dysfunction (9). Clinical practice guidelines for vascular access by the American Journal of Kidney Diseases 2006 made a Grade A recommendation to refer patients for evaluation and treatment when access flow rate was less than 600 mL/min in AVG and less than 400–500 mL/min in AVF (2). Whereas, the Society of Vascular Surgery 2008 suggested performing a duplex ultrasound in accesses that display signs of dysfunction or abnormal routine surveillance (Grade 2, very low quality evidence) (10). KDOQI expert opinion found it reasonable to use duplex ultrasound to verify physical exam to help determine direction of flow and AV access evaluation for aneurysm or pseudoaneurysm.

However, routine surveillance of the AVF or AVG in asymptomatic patients to improve access patency was not recommended by the KDOQI (3). In a 3 year follow up randomized controlled multicenter open labeled trial Aragoncillo *et al.* found that vascular access blood flow (Qa) based surveillance combining Doppler ultrasound and ultrasound dilution to standard monitoring reduces the frequency of thrombosis and is cost effective in assuring patency in autologous AVF (11). The criteria for intervention included 25% reduction in Qa, Qa  $<500$  mL/min or significant stenosis with PSV more than 400 cm/s or PSV pre-stenosis/stenosis ratio higher than 3. Grogan *et al.* found presence of critical stenosis after arterialization in 54% of patients with primary AVF on postoperative surveillance with color duplex ultrasound (12). Authors reported sensitivity, specificity and accuracy to detect hemodynamically significant stenosis of 93%, 94% and 97% respectively, and proposed to consider color duplex ultrasound to identify and correct flow limiting stenosis to improve long-term patency. Turbulence and PSV ratio of  $\geq 3:1$  was used to identify stenosis at the anastomotic site whereas PSV ratio  $\geq 2:1$  was used to detect stenosis within the fistula.

At present, preemptive intervention to correct AV access

stenosis not associated with clinical indicators of access malfunction is not recommended (3). For borderline stenosis within polytetrafluoroethylene (PTFE) grafts, a watch and wait strategy with delaying angiographic intervention and repeating examination after 6–8 weeks was found safe by Tuka *et al.* (8). A Cochrane review analysis suggested that correction of surveillance-detected stenosis in a functional AV access does not extend access longevity and patency (13). Special consideration including the process of care and practice patterns are important when implementing a new monitoring program. Mauro *et al.*, found that in patients with AVG, duplex ultrasound done at 3 months then every 6 months postoperatively improved 5-year secondary patency in surveillance group compared with historical control group (14).

The American Institute of Ultrasound Medicine listed the following indications for hemodialysis access ultrasound: (I) inadequate hemodialysis blood flow 500–600 mL/min or decrease 25% interval of blood flow; (II) ipsilateral upper extremity edema or pain after access or during hemodialysis; (III) delayed maturation >6 weeks of AVF; (IV) suspected pseudoaneurysm, stenosis, soft tissue infection or adjacent fluid collection; (V) decreased or absent thrill or abnormal bruit; (VI) follow-up after an intervention; (VII) signs or symptoms of digital ischemia, (VIII) access collapse; (IX) prolonged bleeding >20 min from access site; (X) unexplained decrease in the delivered dose of hemodialysis; (XI) repeated difficult cannulation; (XII) thrombus aspiration; (XIII) elevated venous pressure greater than 200 mmHg on a 300 mL/min pump; (XIV) elevated recirculation time greater than 15% (15).

### Maturation

One clinical definition of the mature AVF is a structure that is usable for hemodialysis at a hemodialysis flow rate of 300 to 350 mL/min at 12 dialysis sessions in 1 month (16). A mature AVF must be easily palpable and support cannulation. AVF usually changes rapidly after placement, with 55% of forearm and 83% of upper arm AVF's achieving at least 50% of the 6-week blood flow rate measurement at 1 day (17). Full maturation of an AVF may take 6 weeks to 3 months. If progressive AVF maturation is not clinically identified in the first 4–8 weeks, an ultrasound examination may be performed to assess for stenosis, minimum vein diameter, and maximum depth from the skin to surface. Timely diagnosis of fistula stenosis with US and early therapeutic

fistulogram may enhance maturation when the culprit lesion is identified and treated.

A multicenter NIH hemodialysis fistula maturation study evaluated early anatomic changes using US at day 1, week 2, and 6 weeks with centralized interpretation, and found the value of measuring vein diameter and fistula flow rate at 2 weeks in the early identification of fistulas that are unlikely to develop optimally at 6 weeks (17). Robbin *et al.*, indicated that measurements at 2–4 months are highly predictive of fistula maturation and adequacy for dialysis (18). Kudlicka *et al.* found that duplex Doppler ultrasound examination of AVG early after creation can identify those at substantial risk for stenosis and access loss (19). A primary outcome of the ongoing multicenter observational surveillance of AVF using ultrasound study (SONAR) aims to examine a role of Doppler ultrasound surveillance protocol to detect potentially correctable early problems in fail-to-mature fistulas (20).

### Access aneurysms

Ultrasound surveillance provides a useful noninvasive modality for the assessment of AV access wall integrity, the presence of aneurysms and pseudoaneurysms and perivascular fluid collection. Studies have found that the prevalence of aneurysmal degeneration of AVF ranges between 5% to over 60% (21). An aneurysm of the AVF defined as any segment dilation of >18 mm was proposed by Valenti *et al.* The authors established the universal classification to guide management. According to the proposed classification, type 1 aneurysm is defined as the dilation along the length of the vein (1a) or post-anastomotic segment (1b), type 2—as a “camel hump” appearance with two distinct aneurysms, type 3—as complex aneurysms not fitting other groups, type 4—as a pseudoaneurysm (22). Another classification system published by Balaz *et al.* described arteriovenous access aneurysm by an enlargement of all three vessel layers with a diameter of more than 18 mm included type 1 aneurysm without stenosis, type 2 with significant stenosis (>50%), type 3 with partial thrombosis (<50% lumen), type 4 with complete thrombosis (23).

### Cannulation

Normal use of any arteriovenous access involves repeated cannulation with 14–16 gauge needles. One approach to reduce traumatic injury is the “rope ladder” technique

<b>AVF or AVG stenosis</b>			
Patent	Absence of significant velocity shift or stenosis (i.e., <50%)		
<b>For lesions within AVF or AVG or at venous anastomosis</b>			
50–99% stenosis	2:1 ratio or PSV doubling from the proximal adjacent segment with visual narrowing on grey scale and/or color image		
<b>For lesions at arterial anastomosis only of AVF or AVG</b>			
50–99% stenosis	3:1 ratio or PSV tripling from the inflow artery approximately 2 cm upstream from arterial anastomosis		
<b>Volume Flow</b>			
	Adequate	Marginal	Inadequate
AVF	>700 mL/min	500–700 mL/min	<500 mL/min
AVG	>800 mL/min	600–800 mL/min	<600 mL/min

**Figure 1** Cleveland Clinic Dialysis Access Evaluation, Cleveland Clinic Non-Invasive Vascular Laboratory Protocols + Procedures. AVF, arteriovenous fistula; AVG, arteriovenous graft; PSV, peak systolic velocity.

which involves serial rotation of the cannulation point. This approach notwithstanding, repeated site puncture and/or extravasation after needle removal may lead to the development of pseudoaneurysm. Portable Doppler ultrasound was recommended by the Spanish clinical guidelines on vascular access in all hemodialysis units to guide successful cannulation to reduce errors during needle cannulation (24). Schoch *et al.*, found the ultrasound guided cannulation promoted higher quality and decreased cannulation damage (25). Use of US for routine cannulation needs to be evaluated with respect of the cost efficiency, availability of point of care ultrasound modalities and other factors including time and local expertise.

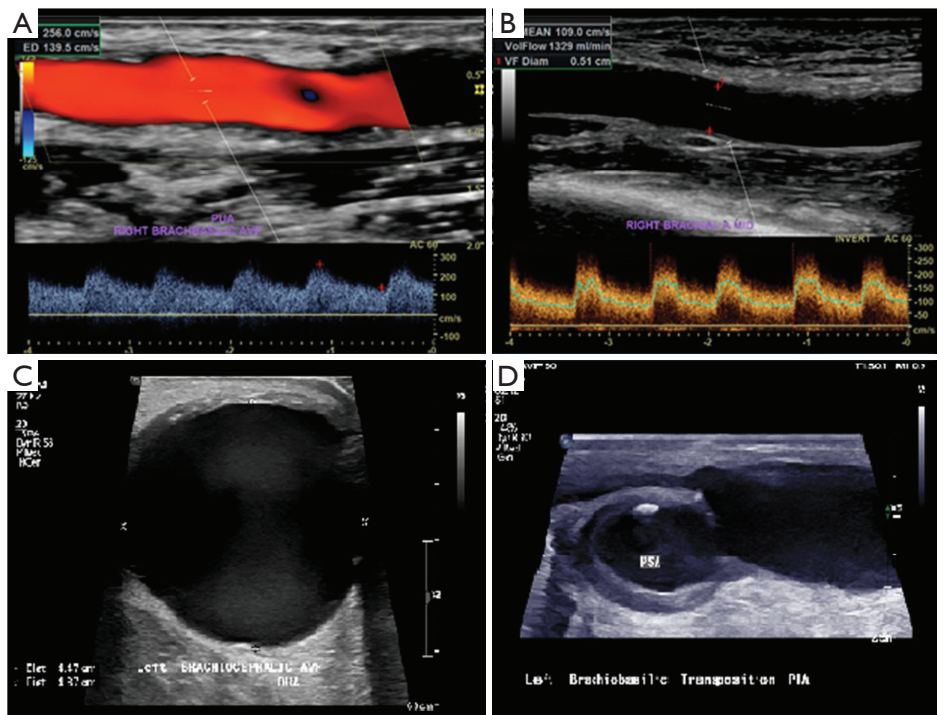
### **Cleveland Clinic hemodialysis duplex ultrasound protocol/criteria (Figures 1,2)**

At the Cleveland Clinic, we follow our published hemodialysis monitoring and surveillance protocol. An abridged tabular version is provided in *Figure 1*. Indications for AVF duplex include but not limited to loss or decreased palpable thrill, decrease flow rate during dialysis, failure of access to mature, edema of affect limb (after access placement or dialysis), suspected pseudoaneurysm or

adjacent fluid collection, presence of prominent collateral veins (upper arm, chest, neck) and/or ischemic symptoms of upper extremity suggestive of steal phenomenon. A high frequency transducer is utilized for the examination with appropriate settings. The inflow artery, inflow anastomosis, graft, outflow anastomosis and outflow vein are interrogated documenting any areas of stenosis or occlusion in addition to recording peak systolic velocities and luminal diameters. For AVF's, three volume flow measurements are obtained at mid brachial artery avoiding any area of stenosis, calcification, or tortuosity. For AVG's, volume flow measurements are obtained within the proximal, mid and distal segments of the graft itself.

### **Conclusions**

The noninvasive vascular ultrasound plays an important role in maintenance and surveillance of the existing hemodialysis access circuit. It is a valuable diagnostic adjunct when utilized to complement clinical evaluation and physician examination. Evidence continues to evolve regarding the role of ultrasound surveillance in various access types and details such as ideal timing and cost effectiveness warrant further implementation, outcomes, and cost analysis research.



**Figure 2** (A) Patent brachio-basilic AVF, (B) AVF adequate volume flow, (C) AVF Aneurysm, (D) pseudoaneurysm with thrombus. AVF, arteriovenous fistula.

## Acknowledgments

*Funding:* None.

## Footnote

*Provenance and Peer Review:* This article was commissioned by the editorial office, *Cardiovascular Diagnosis and Therapy* for the series “Endovascular and Surgical Interventions in the End Stage Renal Disease Population”. The article has undergone external peer review.

*Conflicts of Interest:* All authors have completed the ICMJE uniform disclosure form (available at <https://cdt.amegroups.com/article/view/10.21037/cdt-22-129/coif>). The series “Endovascular and Surgical Interventions in the End Stage Renal Disease Population” was commissioned by the editorial office without any funding or sponsorship. LK served as the unpaid Guest Editor of the series. LK is a consultant to COOK Medical, Gore Medical and 3M Boston Scientific and received payment from Gore Medical and 3M Boston Scientific. DP attends the ACP (America College of Physicians) assisting with POCUS (point of

care ultrasound) sessions. ACP covers expenses and small honorarium. AS attended ACP Annual Meeting April 2022. The authors have no other conflicts of interest to declare.

*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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**Cite this article as:** Saati A, Puffenberger D, Kirksey L, Fendrikova-Mahlay N. The role of hemodialysis access duplex ultrasound for evaluation of patency and access surveillance. *Cardiovasc Diagn Ther* 2023;13(1):190-195. doi: 10.21037/cdt-22-129