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Review

Standardized Methodology for Duplex Ultrasound Examination of Arteriovenous Access for Hemodialysis: A Proposal of the French Society of Vascular Medicine and the French-Speaking Society of Vascular Access

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Methods

Duplex ultrasound (DUS) is an essential tool for characterizing and monitoring arteriovenous (AV) access for hemodialysis. The aim of the work described here, requested by the French Society of Vascular Medicine in collaboration with the French-Speaking Vascular Access Society, is to propose a standardized methodology for performing and documenting DUS, taking into account the variety of AV access techniques and the problems routinely encountered. A steering committee reviewed the literature and selected the relevant references. A draft was prepared, and all items with missing or conflicting data were submitted to a Delphi consensus. The final document was discussed and approved by all participants. The principles of DUS evaluation of AV access consist of examination of the afferent artery, the anastomosis and the entire venous drainage system. DUS uses B-mode ultrasound, color flow, pulsed wave and power Doppler analysis. DUS can be used in a variety of clinical situations, which can directly influence the methodology of the examination and the interpretation of the results. Blood flow should be assessed as it correlates with the risk of thrombosis. The measurement should be adapted to the different anatomical and hemodynamic conditions encountered. Characterization of stenosis should take into account the residual diameter of the drainage vein and its hemodynamic consequences. Other complications can be assessed with a standardized DUS examination. When performed according to a rigorous methodology, DUS of the AV access allows a comprehensive assessment of its functionality and eliminates the need for further invasive diagnostic procedures.

Introduction

Arteriovenous fistula (AVF) and arteriovenous graft (AVG) complications are among the leading causes of morbidity in hemodialysis patients [1]. AV access monitoring involves a variety of techniques, among which duplex ultrasound (DUS) is critical because of its ability to provide an accurate anatomic and hemodynamic assessment of AV access [2,3]. The 2018 European Society for Vascular Surgery guidelines [4] on vascular access emphasize the role of DUS, but also question its reliability. Although several proposed methodological guidelines for this examination have been published previously, they are related mainly to the diagnosis of stenosis and do not cover the wide range of situations that may arise in this field [5–11]. In addition, there is no real consensus on the thresholds for the parameters of interest [12].

Our aim was to propose a standardized methodology for the DUS examination of AV access for hemodialysis, with a special focus on AVFs.

Methods

The French Society of Vascular Medicine (SFMV) and the French Society of Vascular Access (SFAV) jointly commissioned a steering committee to develop a methodology for the ultrasound examination

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of AV access for hemodialysis. This steering committee, composed of six vascular physicians with a long clinical experience in the examination of AV access, conducted a literature review. A narrative literature search was performed using Pubmed. From more than 467 articles corresponding to search terms such as duplex ultrasound and arteriovenous access or arteriovenous fistula, only 15 articles appeared to be of interest for this consensus. Other relevant literature was added through reference checking and manual searching. On the basis of the scientific data available at the time of writing (June 2019), a collaborative draft of the document was prepared. It also included input from the experts. The latter identified several questions for which there was a lack of references or conflicting data. To answer these open questions, the steering committee opted for a formalized consensus using the Delphi method [13]. Forty-one proposals were submitted to a review group consisting of a panel of 16 physicians from different specialties related to the topic (vascular physicians, radiologists, nephrologists and vascular surgeons).

Participants were asked to anonymously rate each proposal and indicate their level of agreement with the proposal using a 9-point scale. A score of 1 indicated complete disagreement, and a score of 9 indicated complete agreement. Participants were given the opportunity to add a comment to their response.

A proposal was considered:

- Appropriate if the median score was ≥7, and there was consensus among the rating group members.
- Inappropriate if the median was ≤3.5, and consensus was reached among the members of the evaluation group.
- Uncertain if the median was between 4 and 6.5 (indecision) or if consensus was not reached among the rating group members (all other situations).

In the first round, 30 of the proposals were validated. The 11 questions that did not achieve formal consensus in the first round were all canceled and reworded to be voted on again by the same panel of physicians with the same scoring instructions. In the end, 37 proposals were considered appropriate, as 4 remained undecided after the second round (Table S1, online only).

Because endovascular creation of an AVF (endoAVF) has become a new option since 2019, we performed a supplemental literature search on this topic to complete our duplex practice recommendations.

Comparison of Doppler ultrasound with other monitoring or diagnostic techniques was beyond the scope of our review.

Indications for duplex ultrasound

An initial evaluation of the AV access should be used as a reference throughout the follow-up period: prior to use of the AV access, after any surgical or endovascular repair and prior to return to dialysis in transplant patients. DUS is also indicated in cases of delayed AVF maturation, difficulty in use, abnormal dialysis parameters (*i.e.,* low blood flow, high venous pressure, recirculation) and abnormal clinical examination (Table 1). Intradialytic monitoring using dilution techniques can detect decreased blood flow and lead to DUS. Finally, DUS is particularly useful in self-care dialysis patients who do not have intradialytic monitoring of access flow [6,14,15].

Duplex ultrasound methodology

Prior to DUS, the patient should be interviewed regarding any dialysis-related issues, and a nude upper-body physical examination should be performed. Clinical examination helps to focus on suspected abnormalities and allows meaningful interpretation of DUS findings.

Table 1
Main pathological findings at clinical examination and the suggested corresponding pathology

Clinical signs	Suggested pathology
Rigid, pulsating draining vein, stronger thrill or bruit	Outflow stenosis
Excessively compressible draining vein	Inflow stenosis
Edema, upper limb peripheral cyanosis, venous collateral development in the shoulder or the hemithorax	Central vein stenosis or thrombosis
Localized inflammatory induration of the draining vein	Parietal thrombosis
Hand pain and cold hands including trophic changes in the fingers	Distal ischemia
Absent thrill	Complete thrombosis of arteriovenous fistula
Dystrophy or aneurysm in the draining vein	High flow

Patient setup and equipment

The operator should be seated in front of the patient or on the access side. The patient should be in a seated or semi-upright position.

Duplex ultrasound of the AV access should ideally be performed either just prior to dialysis or on the following day. DUS equipment must be capable of examining very superficial vessels and measuring extremely high velocities. A combination of two transducers is required. High-frequency transducers (up to 18–20 MHz) provide highly accurate characterization of the walls, lumen and surrounding tissue of target vessels. Blood flow velocity in the draining vein and feeding artery can be measured using a linear or micro-convex mid-frequency (5 MHz) transducer, which allows a high pulse repetition frequency (PRF) setting. This transducer is well suited for examining proximal veins in the axillary or supraclavicular fossae that are otherwise seen with lower-frequency convex or phased array probes. Several DUS modes can be used for different purposes:

- B-Mode should be used for tissue characterization.
- Color flow imaging (CFI) provides semiquantitative assessment of blood flow velocity and allows selection of an appropriate sampling window in pulsed-wave mode.
- Analysis of variance identifies areas of flow turbulence.
- Pulsed-wave imaging provides objective measurement of blood velocity and flow.
- Continuous-wave Doppler mode, available on some transducers, helps in the study of stenosis at very high velocities.
- Power mode, e-flow or b-flow imaging provides more refined characterization of hypo-echogenic endoluminal lesions such as intimal hyperplasia.

Duplex ultrasound examination

The baseline evaluation should include measurement of blood flow and resistance index (RI), as well as anatomic and hemodynamic evaluation of the afferent artery, anastomosis and draining vein.

Blood flow measurement

Blood flow through the AV access varies considerably from individual to individual. It is determined mainly by flow resistance and is closely related to the minimum diameter of the draining vein, the mean diameter of the afferent artery and the size of the anastomosis [16]. Therefore, blood flow is usually higher in proximal than in distal fistulas. It is measured by pulsed-wave DUS of the brachial artery and, if necessary, the axillary or subclavian artery. In cases of early division of the brachial artery, blood flow should be measured upstream of the division.

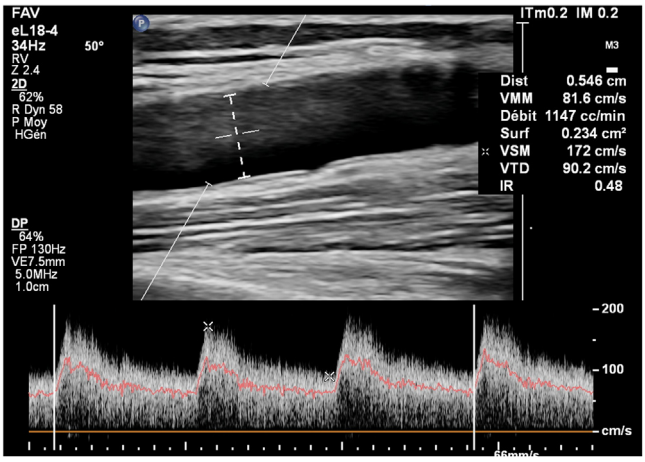

Figure 1. Brachial artery flow measurement.

Miscalculation of arterial caliber caused by atheromatous lesions, arterial dystrophy or significant pulsatility may result in measurement errors. Incorrect measurement of mean velocity is often related to flow turbulence caused by stenosis, parietal irregularity or tortuosity of the feeding artery. The ideal measurement site is a straight arterial segment of regular caliber with healthy, non-pulsatile walls and laminar flow. The transducer is oriented to obtain an insonation angle $\leq 60°$. The window size should encompass the entire arterial lumen to sample the total blood flow velocity. The arterial diameter should be measured from intima to intima (Fig. 1). At least three consecutive measurements from different appropriate sites are recommended [17]. These measurements must be consistent with each other and with clinical findings. Conflicting data reflect methodological shortcomings and should be excluded from the calculation of mean values.

Resistance index measurement

The RI reflects the overall level of vascular resistance throughout the AV access circuit. It is calculated from brachial artery velocity patterns (systolic velocity S minus diastolic velocity D divided by systolic velocity, or $[S - D]/S$).

Afferent artery examination

Stenosis can occur anywhere along the course of the artery, although the most common lesions involve the subclavian and antebrachial arteries, particularly in patients with diabetes. CFI is recommended to look for evidence of flow turbulence associated with a pathological increase in blood flow velocity.

An increase in flow velocity increases the hemodynamic consequences of stenosis. To quantify stenosis, the usual velocity criteria used to diagnose subclavian artery stenosis are not applicable. However, a prolonged systolic time interval in the brachial artery is an indirect but reliable sign of significant inflow stenosis.

Stenosis of the antebrachial arteries is easier to detect and quantify by comparing flow velocity at the site of stenosis and upstream or downstream.

Anastomosis examination

The surgical anastomosis should be evaluated by measuring its largest diameter. Evaluation of flow velocity, which is always very high at the anastomosis, is of little interest. Even if the anastomosis is well sized surgically, stenosis of the anastomosis may occur secondarily because post-operative remodeling may lead to stenosis, especially at the heel of the anastomosis.

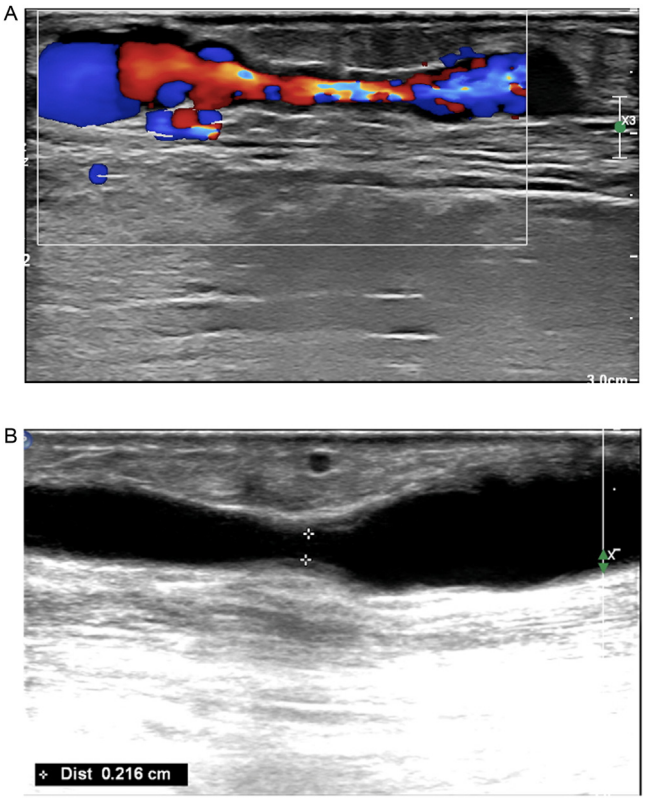

Figure 2. (a) Cephalic vein stenosis: color Doppler imaging. (b) Cephalic vein stenosis: B-mode imaging.

Draining vein examination

The DUS scan is used to look for signs of stenosis in the draining vein. Although venous stenosis is predominantly juxta-anastomotic, it can affect the draining vein anywhere, including the deep venous system.

B-Mode ultrasound detects any direct morphologic signs of stenosis, whereas CFI examines aliasing and flow turbulence, which indicate a pathologic increase in blood flow velocity (Fig. 2a). A compressibility maneuver of the draining vein by applying local pressure through the transducer helps to assess venous pressure, which increases upstream and decreases downstream of a stenosis. Persistent high pressure downstream of a stenosis suggests another stenosis downstream. Pulsed-wave Doppler imaging should be used to quantify the increase in flow velocity by measuring peak systolic velocity (PSV) and PSV ratio upstream and at the stenosis site.

Morphologic quantification of AVF stenosis is based on B-mode measurement of the smallest vessel lumen diameter as an absolute value [18] (Fig. 2b). The pathophysiologic mechanisms underlying stenosis can vary. Parietal fibrosis with wall shrinkage is clearly visible on B-mode imaging. Intimal hyperplasia involves hypo-echogenic parietal circumferential thickening, which is more clearly seen on CFI. Valvular fibrosis appears as an endoluminal diaphragm, sometimes difficult to detect on B-mode imaging, but as a filling defect in the venous lumen on CFI. Dissections and synechiae with irregular endoluminal trabeculae are visible on B-mode imaging. DUS can also identify kinking that may affect hypertrophic veins, extrinsic compression by false aneurysms and hematomas and sometimes calcifications.

Table 2
Ultrasound parameters used for venous stenosis quantification

Author(s), year	Modality of comparison	PSV (cm/s) F_{max} (kHz)	PSV ratio	Diameter (mm)	Blood Flow (ml/min)	RI
Tordoir et al. [32] 1989	Angiography	>12 kHz				
Older et al. [28] 1998	Angiography Stenosis > 50%	>400 cm/s	>3			
Doelman et al. [38] 2005	Angiography MRI	>375 cm/s		>50% decrease		
Chandra et al. [33] 2010	Angiography					
	<50%			>3		
	50%–75%			3–1.5		
	> 75%			<1.5		
Fahrtash et al. [18] 2011	Functional AVF vs. dysfunctional AVF			2.7		
Bandyk [17] 2013		> 400 cm/s	>2.5	<2–3		
Lomonte et al. [39] 2015	Main criteria		>2	50% decrease	<600 or 25% decrease	
	Secondary criteria			<2		
Itoga et al. [14] 2016	Angiography	>375 cm/s		>50%		
Vardza Raju et al. [34] 2013	Angiography stenosis >50%		>2			
Plato et al. [40] 2016	Angiography Stenosis > 50%	>400 cm/s	>2.25			
Ishii et al. [41] 2016	Vascular event (thrombosis/stenosis)		<1.85		<581.5	>0.56

PSV, peak systolic velocity; RI, resistance index.

Multiple stenoses may co-exist in close or distant anatomical locations. The location of the stenoses in relation to the anastomosis and puncture site should be described.

Diagnostic criteria

Flow and resistance index

There is no accepted definition of normal AVF flow. Ideally, it would be the minimum adequate for efficient hemodialysis and to maintain long-term patency of the AVF. In adults, flow is usually between 600 and 800 mL/min in distal fistulas and between 900 and 1200 mL/min in proximal fistulas [19]. Low blood flow is a major risk factor for thrombosis [20,21]. It is usually defined below the threshold of 500 mL/min, in which case corrective procedures (endovascular or surgical) for the AVF should be discussed [22]. However, an uncomplicated AVF with low blood flow may remain patent and functional in patients with constitutional small inflow arteries. Beyond this threshold, a decrease in flow of more than 25% from baseline may be a sign of significant stenosis [2].

High flow is usually defined as exceeding 1.5–2 L/min [23]. Relatively high flow may also be diagnosed when the cardiopulmonary recirculation rate (AV access flow/cardiac flow) exceeds 20% [24]. High flow is more common with proximal AV access. Assessment of the ability of the heart to withstand this high flow is recommended to detect signs of left ventricular hypertrophy [25].

Finally, we suggest that a flow less than 500 mL/min in distal fistulas and less than 600 mL/min in proximal fistulas is indicative of low blood flow, and conversely, a flow greater than 1500 mL/min is indicative of high blood flow.

The RI typically ranges from 0.40–0.60. Above 0.63, it has been considered a marker of AVF dysfunction, and above 0.7, a risk factor for thrombosis, but no precise threshold has been clearly defined [26,27].

Inflow arteries and outflow veins

Venous stenosis is defined as a localized decrease in the diameter of the draining vein. The ratio of vessel lumen diameter at the site of stenosis to that at the adjacent site is commonly used to radiologically quantify stenosis. However, several authors have reported that the characterization of venous AVF stenosis cannot be approached in this way [12–18]. Irregular draining vein diameter is the norm, especially when the AVF has been in use for a long time. For example, a 50% stenosis (the usual threshold for significant stenosis) may describe a minimal venous diameter of 3–6 mm, depending on whether the diameter of the reference draining vein is 6 or 12 mm. As a result, this method of quantifying stenosis has led to an incidence of 80% of patients with a functional and uncomplicated AVF being diagnosed with stenosis [28]. Not all stenoses affect AVF function or dialysis quality, nor do they systematically increase the risk of AVF thrombosis. Furthermore, two stenoses with identical residual lumen diameters may have very different hemodynamic consequences depending on the topography of the stenosis and the basal blood flow of the AV access [29].

Several studies comparing the performance of DUS and fistulography in the diagnosis of venous stenosis have reported good agreement [30–34]. Other studies have compared AVF ultrasound characteristics according to the presence or absence of complications [18,26] Several authors have attempted to define the DUS criteria that would justify prophylactic angioplasty in patients with asymptomatic stenosis [35,36]. Relevant measurable values in DUS are mainly the minimum lumen diameter of the draining vein, the peak systolic velocity at the stenosis site and the velocity ratio before and at the stenosis site [37]. Thresholds for AVF dysfunction vary from study to study (Table 2).

A rational analysis of AVF venous stenosis should include a combination of anatomic and hemodynamic parameters [36]. We recommend that venous stenosis be considered clinically significant (potentially responsible for AVF dysfunction) in the presence of a minimum draining vein diameter <2.7 mm and/or a PSV >5 m/s and/or a PSV ratio >4 [18,30,35,40]. Nevertheless, these values are indicative and should not be interpreted as a rough cut-off. The interpretation of duplex measurements must take into account the clinical context and include the overall characteristics of the AVF, especially the AVF flow, which is the best parameter for assessing the risk of thrombosis. In a recent study on AVGs, it was suggested that flow values be included to characterize venous stenosis. The authors defined borderline stenosis as a decrease in draining vein caliber >50% and a peak systolic velocity ratio >2. If these signs were present together with any of the secondary criteria—residual lumen diameter <2 mm, flow <600 mL/min or decrease in flow >25%—stenosis should be considered critical [42]. This distinction between borderline stenosis and critical stenosis (flow < 500 mL/min or decrease >25%, RI >0.7 or residual lumen diameter <2 mm) has been also validated for AVFs [43]. Furthermore, it is essential to identify the range of clinical issues involved, as they have direct implications on the strategy, surveillance or repair [39].

In daily practice, it is useful to differentiate between symptomatic stenosis, which is responsible for specific dialysis problems such as delayed AVF maturation, decreased dialysis efficiency, difficulty using

Table 3
Main thresholds

	Diameter (mm)	PSV (cm/s)	PSV ratio	Brachial artery flow (mL/min)
Significant venous stenosis	<2.7	>500	>4	
Venous stenosis of high risk of thrombosis	<2			<400 (distal AVF) <500 (proximal AVF)
Central venous stenosis			>2.5	
Arterial stenosis		>400	>3	
Venous aneurysm	≥20			

AVF, arteriovenous fistula; PSV, peak systolic viscosity.

the AV access or other complications, and asymptomatic stenosis, which still allows efficient dialysis. Among asymptomatic stenoses, DUS helps to identify those associated with a high risk of thrombosis. We suggest considering a residual lumen diameter <2 mm and a flow <400 mL/min in distal fistulas and <500 mL/min in proximal fistulas as parameters indicating a high risk of thrombosis. However, the assessment of thrombosis risk must consider combined parameters including blood flow, resistance index and all characteristics of the stenosis including minimum diameter, PSV, PSV ratio and location.

There are no specific velocity or diameter criteria for the diagnosis of central venous stenosis in the AV access. Velocity and diameter ratios >2.5 are recommended before and at the stenosis [44]. No diagnostic threshold has been validated for radial and brachial artery stenosis. Although stenosis is easily detected by the strength of aliasing and quantified by peak systolic velocity [39,45], we suggest considering PSV >4 m/s and PSV ratio >3 as criteria for arterial stenosis. However, we suggest that arterial stenosis should only be considered significant if it causes low blood flow and affects the quality of dialysis and/or induces ischemia.

Table 3 summarizes the network thresholds that are useful for better characterization of AFV complications.

Clinically oriented DUS

Low-flow AVF

In low-flow AVFs, DUS imaging should look primarily for signs of stenosis of the draining vein upstream of the arterial puncture site. Only very narrow venous stenoses will cause a significant decrease in AVF flow. DUS should then look for evidence of arterial stenosis. Sometimes low flow is simply owing to the small caliber of the feeding artery (Fig. 3). Small anastomotic size may be held responsible for low blood flow in the absence of other peripheral (venous or arterial stenosis, small-diameter afferent artery) or central (low blood pressure) causes.

High venous pressure

In AV accesses with high venous pressure, signs of stenosis of the peripheral draining vein downstream of the venipuncture site should be evaluated; moderate venous stenosis (lumen diameter ≥3 mm) may cause high venous pressure if the basal flow of the fistula is high.

Central venous stenosis ipsilateral to the AV access may also cause high venous pressure. Increased flow velocity is a direct sign of stenosis, easily seen in the axillary, subclavian and right brachiocephalic veins, but more difficult in the left brachiocephalic vein and superior vena cava. Indirect signs are more consistent: distention and pulsatility of the superficial and deep venous systems upstream of the obstruction, decrease or loss of flow modulation and development of collateral veins. In the presence of upper limb edema, cyanosis, collateral veins in the shoulder or hemithorax suggesting central venous stenosis, a complementary study to DUS should be suggested.

Difficulty to puncture

Difficulty in puncturing the AVF should first prompt a search for signs of arterial or venous stenosis and low blood flow. It can also occur in patent AVFs with normal flow but tortuous, deep, mobile or calcified draining veins and in the presence of perivenous soft tissue thickening. DUS helps to evaluate the course of the vein and its perivenous soft tissue, identify the most appropriate puncture sites and/or recommend superficialization of the draining vein.

Thrombosis

The occurrence of AVF thrombosis is often owing to lack of proper surveillance. Although clinical diagnosis of thrombosis is straightforward, we suggest that DUS should be used systematically if this examination does not delay declotting. DUS helps to determine the exact location and extent of the thrombosis and to identify one or more underlying stenoses (Fig. 4). Thrombosis that occurs in a stenosis-free AVF may be indicative of thrombophilia. The characteristics of the stenosis underneath the thrombosis may help determine angioplasty modalities after thrombectomy. In the case of a globally fibrotic vein, DUS imaging of both upper limbs may guide the choice of a new AV access site.

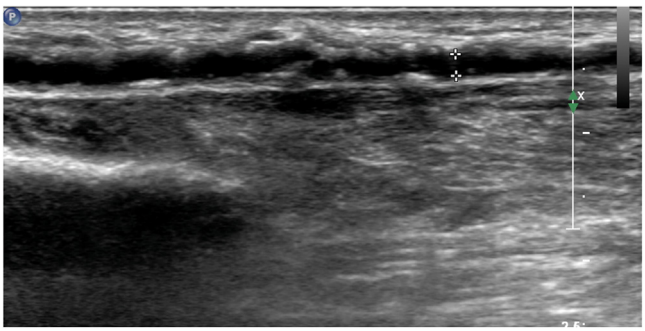

Figure 3. Atherosclerotic radial artery with a lumen diameter <2 mm.

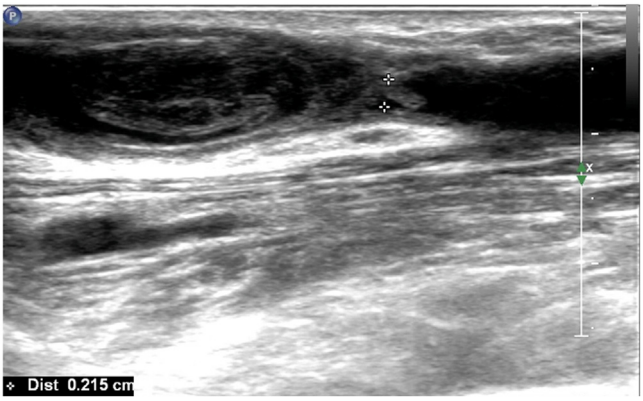

Figure 4. Cephalic vein thrombosis with an underlying stenosis.

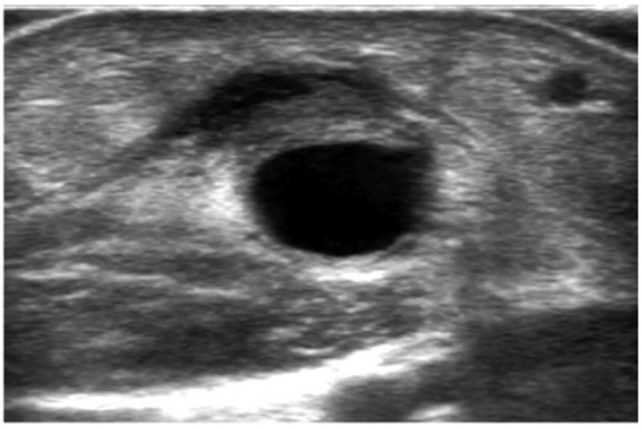

Figure 5. Subcutaneous perivenous hematoma.

Partial parietal thrombosis adjacent to the venous puncture site is common and should prompt a search for evidence of outflow stenosis.

Sometimes collateral veins compensate for segmental thrombosis of the draining vein. The AVF may then remain functional, provided there is adequate flow.

Perivenous soft tissues injuries

Perivenous hematoma is a common complication, especially in fistulas that are difficult to puncture (Fig. 5). DUS evaluates for complications such as active bleeding and compression of the vein.

A renitent or inflammatory tumefaction adjacent to the anastomosis after AV access creation at the elbow level may indicate a lymphocele, which appears on DUS as a perivascular collection of fluid with one or more anechoic and locally contained lacunae.

Aneurysms

Venous aneurysms, which are favored by repeated puncture at the same sites, have been defined as venous diameters ≥18 mm [46]. We suggest that 20 mm is a clearer threshold. DUS should measure the size of the aneurysm and follow its progression. We suggest measuring the distance between the lumen and the skin surface, which is paramount because patients with atrophic and ulcerated skin at the puncture sites are at risk of fatal hemorrhage. Mural thrombus within the aneurysm, often manifested by skin inflammation, is often the consequence of an outflow obstruction that should be sought.

Ischemia

Hand ischemia associated with AV access should be quantified by techniques such as plethysmography, laser photoplethysmography and/or finger Doppler velocimetry. Arterial pressure in the fingers and the ratio of arm to finger pressure should be calculated. Their cutoff values for ischemia are 60 mm Hg and 0.4, respectively [47]. DUS should evaluate AV access function (including AV access flow), look for signs of peripheral arterial disease, focusing on all forearm arteries, and assess for arterial steal [48]. For example, in proximal AV accesses, arterial steal may be seen with retrograde diastolic flow in the brachial artery downstream of the anastomosis and in the radial and/or ulnar arteries. Collateral arterial circulation may develop to the detriment of the periarterial elbow anastomotic ring, which contributes to the supply of the AVF. In radiocephalic AVFs, partial blood supply to the AVF from the ulnar artery via the palmar arch is the norm but may become symptomatic in patients with arterial disease.

Compression testing is recommended to assess the contribution of arterial steal syndrome to distal ischemia and to predict the efficacy and tolerability of any proposed surgical intervention. The effect of total or partial compression of the venous side of the AVF is measured on the arterial velocity pattern downstream of the anastomosis and on finger pressures. These tests mimic the effect of AVF ligation and flow reduction, respectively. In radiocephalic AVFs, elective compression of the radial artery downstream of the anastomosis simulates the effect of distal radial artery ligation, which is recommended when the ulnar artery and palmar arch are patent [49].

AVF surveillance

Duplex ultrasound can be used for the systematic screening of asymptomatic venous stenosis or restenosis, although there is still some controversy over this approach. It may help determine whether prophylactic angioplasty should be performed. A blood flow rate <500 mL/min or a reduction in blood flow ≥25% combined with a peak systolic velocity >400 cm/s or a velocity ratio >3 have been proposed as criteria for surgical intervention [35]. A recent meta-analysis suggests that prophylactic angioplasty is beneficial only in cases of low flow associated with DUS criteria for stenosis [50]. Recent recommendations from the European Society of Vascular Surgery confirm that DUS monitoring of fistulas associated with prophylactic treatment of stenosis could be considered to minimize the risk of thrombosis [4,51].

Arteriovenous grafts

In AVG, stenosis usually occurs at the graft-to-vein anastomosis as a result of intimal hyperplasia. CFI allows characterization of these hypoechogenic lesions. Repeated puncture is often responsible for damage to the graft wall leading to the formation of false aneurysms (Fig. 6). In the presence of sepsis, the periprosthetic tissue appears heterogeneous.

AVF in children

In children, the principles of DUS are the same as in adults, although children have small and compressible vessels that are prone to spasm, making it difficult to explore the AVF. Warming the limb and using a large amount of gel may help. The forearm can be immersed in a heated (37°C) water bath during DUS. Anastomotic stenosis is much more common in children than in adults but should be treated only if it causes low blood flow. There are no charts for flow rates in children, so it should be calculated by body surface area and adjusted to the average adult body surface area (1.73 m^2). Puncture problems are common in young children because of the dense layer of subcutaneous fat in the forearm.

Percutaneous AVF

For some years now, two devices have enabled the creation of percutaneous AVFs between the radial artery and vein or between the ulnar artery and vein with the WavelinQ system and between the proximal

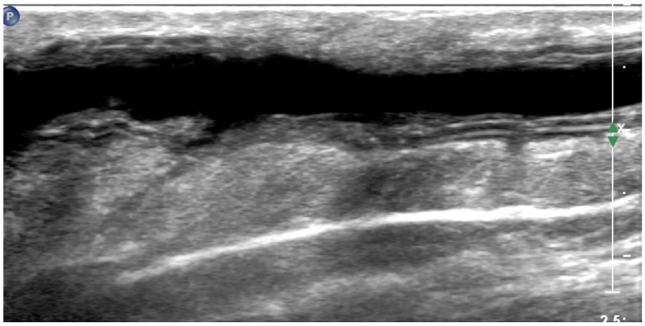

Figure 6. Partially destroyed wall of a prosthetic graft.

radial artery and venous perforator with the Ellipsys system. These endovascular AVFs are multidrainage fistulas that can drain into the cephalic vein, basilic vein and brachial veins, depending on the patient's anatomy. Duplex ultrasound is performed during the first month to assess fistula maturation, and usually a flow rate ≥500 to 600 mL/min is considered suitable for dialysis [52]. In case of delayed maturation or difficulty in canulation, duplex ultrasound should focus on analyzing the quality of the afferent artery and the anastomosis, looking for stenosis that could be treated by angioplasty. The venous drainage modalities of the endovascular AVF should be analyzed in order to propose different interventions such as deep vein coil embolization in the case of competing brachial vein, or transposition or elevation of the basilic vein in the case of basilic dominant flow [53,54].

Pre-operative examination

Although endovascular angioplasty is appropriate for most stenoses, some may warrant open surgery. We recommend the use of DUS prior to any AVF revision. It can help guide the choice between surgical and endovascular repair. For example, post- or juxta-anastomotic venous stenosis in forearm AVFs can be treated by proximalizing the anastomosis, especially in recurrent stenosis. DUS can help ensure that sufficient venous length remains for puncture. Recurrent stenosis of the cephalic arch and stenosis in a branched or plexiform cephalic arch can be treated by re-implantation of the cephalic vein into the axillary vein. DUS should be used to confirm that a brachial −basilic or brachial−brachial AVF was not feasible and to help determine the best re-implantation site. DUS can also identify kinking or external compression as the cause of stenosis and guide surgical treatment.

In all cases, pre-operative DUS provides critical information for planning surgical or endovascular intervention. Its reports should accurately describe the anatomic and hemodynamic characteristics of the AVF, the location and type of stenoses, potential anatomic variations of the vessels involved and even a map of the autologous graft material. For AV access-related hand ischemia, intra-operative functional testing such as digital pressure monitoring can be used to support the therapeutic strategy.

If the DUS data are sufficiently detailed, no further pre-operative radiologic imaging is required. In complex cases, ultrasound-guided skin marking may further improve the accuracy of the surgical procedure.

Prior to endovascular angioplasty, DUS helps to determine the most appropriate puncture site to access the stenosis and to select the appropriate balloon [55].

We recommend the systematic documentation of AV access mapping in addition to the DUS report, including AV access flow, RI, full description of all pathological findings with corresponding DUS imaging, diagnostic synthesis and eventually therapeutic proposal.

Conclusion

The DUS examination of AV access for hemodialysis requires a rigorous methodology while adapting to the clinical issues of the patient. Comprehensive knowledge of hemodialysis, surgical and endovascular therapeutic options is a prerequisite for any DUS for AV access. In this context, a well-performed DUS is the key to avoiding further imaging in the majority of cases. Although DUS can be very efficient in monitoring AV access, clinical examination and close monitoring of dialysis parameters should always be considered first.

Conflict of interest

The authors declare no competing interests.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ultrasmedbio.2023.07.007.

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