PICTORIAL ESSAY Cardiovascular Imaging

Arteriovenous fistulas and grafts for haemodialysis: what are they, how to examine them with ultrasound for preoperative mapping, monitoring and management of complications

Sofia Athanasiou, Demosthenes D. Cokkinos, Eleni G. Antypa, Ioannis Kalogeropoulos
Radiology Department, Evangelismos Hospital, Athens, Greece

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Abstract

Patients with end stage renal failure require vascular access in order to undergo haemodialysis. The two main types of vascular access are arteriovenous fistula (AVF) and arteriovenous graft (AVG), which are mainly imaged with ultrasound. This article reviews advantages and disadvantages of AVF and AVG and describes preoperative ultrasound mapping of arteries and veins for creating vascular access, as well as assessing fistula and graft adequacy. Surgical aspects and complications of both techniques, as well as their management are described.

Key words: Arteriovenous fistula; Arteriovenous graft; Haemodialysis; Ultrasound; Renal failure

Corresponding Author, Guarantor

Corresponding author: Sofia Athanasiou, Radiology Department, Evangelismos Hospital, 45-47 Ypsilantou, Athens 10676, Greece, Email: sofathanas122@gmail.com
Guarantor: Demosthenes D. Cokkinos, Radiology Department, Evangelismos Hospital, 45-47 Ypsilantou, Athens 10676, Greece, Email: demoscokkinos@gmail.com

1. Introduction

End stage renal failure is a major medical and social problem. Nearly two million people require haemodialysis worldwide with approximately 100,000 new cases of end-stage renal disease on an annual basis [1]. Patients with end stage renal failure need to receive dialysis treatments for toxin filtering from their vascular system. Dialysis requires access to the blood stream, gained by placing two needles in a vein, usually in the upper extremity. The first needle draws blood to the dialysis machine, where it is filtered, in order to return through the second needle to the blood stream. However, untreated veins cannot withstand repeated needle insertions. Therefore, it is necessary to surgically create a form of safe, long-term vascular access [2, 3]. The two types of this access designed for long-term use are: autologous arteriovenous fistula (AVF) and arteriovenous graft (AVG). Ultrasound is the commonest imaging examination for the assessment of all stages of AVF and AVG imaging: scanning includes preoperative screening of the arm arteries and veins before the creation of vascular access, assessment of their patency and adequacy, as well as imaging of potential complications.

2. Types of vascular access for haemodialysis

AVF and AVG are the two types of vascular access for long-term haemodialysis. Temporary central venous catheter (CVC) is another form of vascular access, which however is only recommended for short-term use, due to high risk of infection or stenosis [1].

AVF is a surgical connection between a native artery and a vein, usually in the wrist, the forearm or the upper arm. It is typically constructed with an end-to-side, vein-to-artery anastomosis, as this leads to better primary patency at six months with lower need of vein transposition and fewer puncture haematomas during follow-up compared to side-to-side or end-to-end anastomosis techniques [3, 4]. The most commonly used AVFs are created by anastomosing the radial artery to the cephalic vein (radiocephalic fistula) or by anastomosing the brachial artery to the cephalic vein (brachiocephalic fistula). Brachiobasilic fistulas are also commonly created by anastomosing the brachial artery to the basilic vein, but this fistula is located deeper in the medial aspect of the upper arm and requires transposition for use. The AVF mainly increases the flow by increasing the blood perfusion from the artery into the vein, making it grow larger and stronger and providing easy access to the blood vessels [5].

A novel alternative method for the creation of an AVF is by percutaneous endovascular access formation. Two different percutaneous devices currently exist:

The first device, (EverlinQ) is a dual catheter which enables access to the brachial artery and vein under ultrasound imaging with a micropuncture kit. Subsequently vascular sheaths are placed in the artery and veins and catheters are inserted, with magnets holding the artery and vein together. A radiofrequency electrode is deployed and, when activated, creates a fistula between artery and vein. Finally, the catheters are removed and the brachial vein is embolised with a coil, redirecting venous blood into the superficial systems.

The second system (Ellipsys) is a single catheter electrocautery device, where a retrograde puncture and access to the median cubital vein is achieved. A needle enters the perforating vein and is advanced to puncture the neighbouring radial artery under ultrasound imaging. A sheath is subsequently inserted and the device is introduced, achieving the distal electrocautery tip to be positioned in the radial artery and the proximal tip in the perforating vein. The device is employed, closing the electrocautery tips that hold the artery and vein together. Finally, the system is activated, electrocautery is performed and a fistula is created.

On the other hand, ageing of population with chronic kidney disease (CKD) in addition to venous injury during CKD stages depletes suitable superficial veins for AVF creation. In these cases, an AVG can be the alternative. According to the National Institutes of Health consortium, AVGs present various advantages, in order to reduce catheter use [6]. An AVG consists of a synthetic prosthesis implanted under the patient's skin, connecting the artery and the vein and providing needle placement access for dialysis [5]. Advances in biohybrid technology and tissue-engineered grafts provide a great opportunity to develop biocompatible graft materials with minimal tissue reactivity and thrombogenicity. Alternatively, xenografts (bovine carotid artery grafts) have proved to be comparable and, in many cases, better than conventional polytetrafluoroethylene (PTFE) material with lower rates of infection, abandonment and failure to maturation

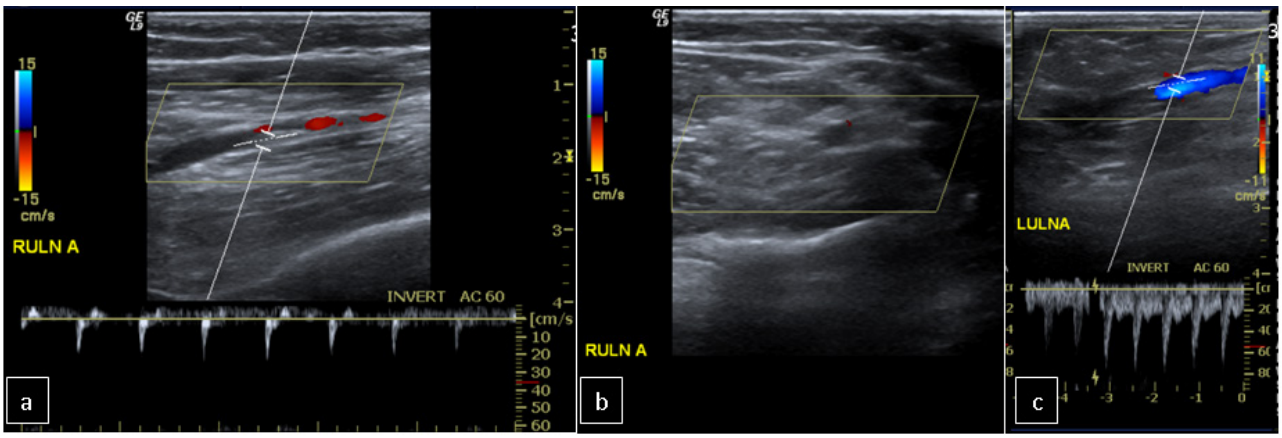

Fig. 1. *The right ulnar artery shows abnormal waveform and low velocities* ***(a)****. Slightly distal to image* ***a****, there is no blood flow, due to obstruction* ***(b)****. In comparison, the left ulnar artery* ***(c)*** *shows efficient blood flow.*

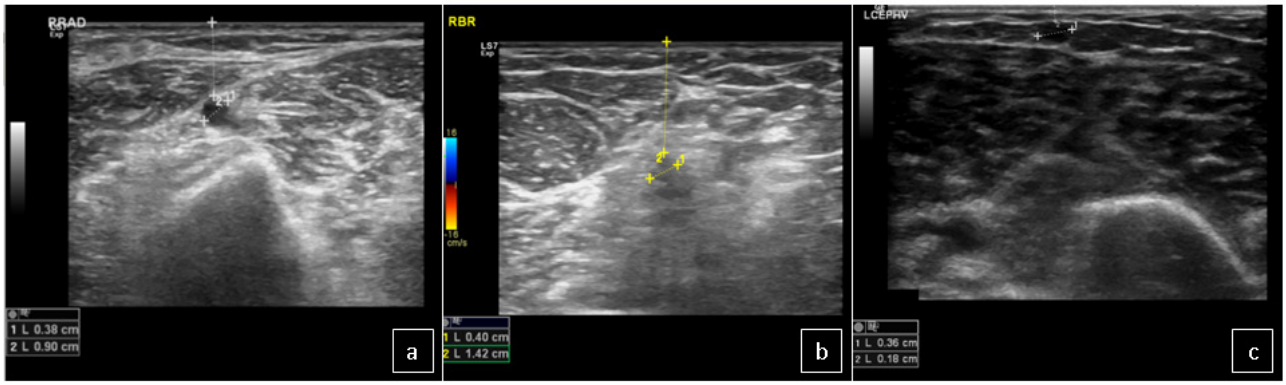

Fig. 2. *The radial artery* ***(a)****, the brachial artery* ***(b)*** *and the cephalic vein* ***(c)*** *are examined. Diameter and depth from the skin (between calipers) are calculated.*

when autologous AVF is not an option [6, 7].

3. Advantages and disadvantages of AVF and AVG

AVF formation is considered to be the best choice for vascular access, as it uses patient's arteries and veins without the need for artificial material. It provides adequate blood flow for dialysis, with high effectiveness and short treatment time. The risks of clotting or infection are lower in comparison to other forms of vascular access [1, 2]. AVF surgery is usually performed on an outpatient basis, under local anaesthesia, allowing for a rapid and easy recovery. AVF lasts more years than other forms of vascular access and can even last for decades [2, 5].

The main disadvantage of AVF is that its maturity requires several weeks (usually four to six weeks), before it can be used [2]. For this reason, patients with acute renal failure may need temporary vascular access until the fistula is suitable for cannulation. Unfortunately, in some cases, the AVF may fail to mature and the surgical process for its formation needs to be repeated. Finally, an AVF formation may not be feasible in patients with small or weak veins.

AVG provides a solution in the latter case and can be used two to four weeks after the placement. However, AVG may lead to an increased risk of thrombosis, aneurysms and infections. In addition, its duration is shorter than a native fistula and it will probably need to be eventually replaced [8-10].

The decision on using AVF or AVG is based, among others, on the patient's medical status (stage of CKD, life expectancy, body mass index, presence of comorbidities, psychologic concerns, etc.), anatomic considerations (availability of suitable vessels, presence of arterial disease), and if the patient is already on hae-

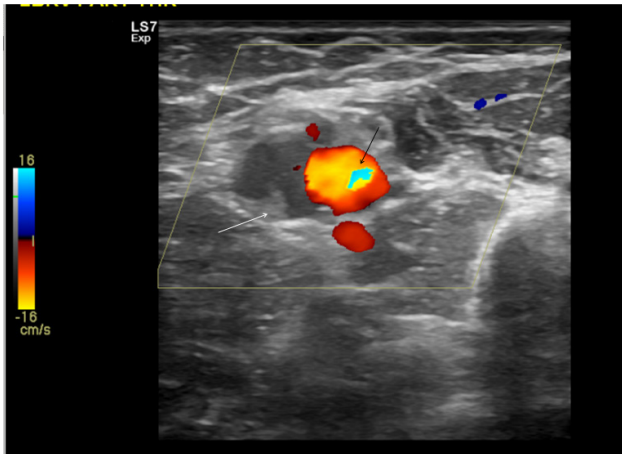

Fig. 3. *The brachial vein is partially thrombosed. The white arrow shows the peripheral thrombus. The brachial artery (black arrow) is patent.*

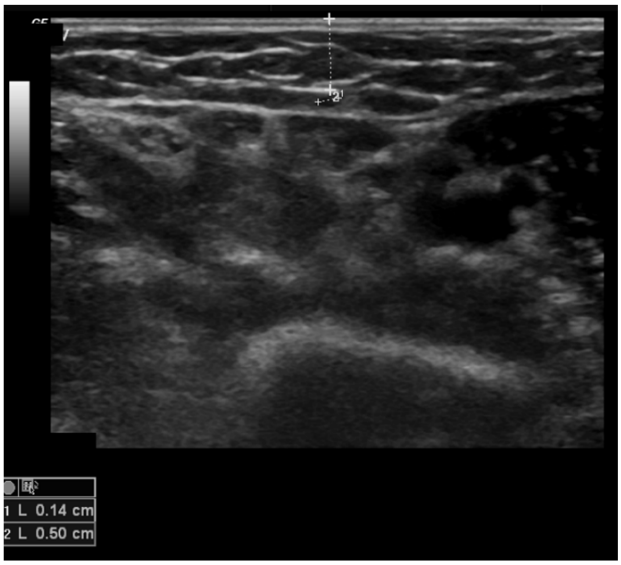

Fig. 4. *The cephalic vein (diameter of 0.14 cm) is very narrow. An AVF formation is not possible.*

modialysis, using a tunneled dialysis catheter [6]. Altogether, individualised and detailed patient history and examination are the fundamental elements for dialysis modality and type of access selection.

4. Preoperative ultrasound mapping of patient's arteries and veins

Preoperative assessment involves evaluation of both arterial and venous upper-extremity systems before access placement. One of three techniques may be used: physical examination, colour Doppler Ultrasound (CDUS) and angiography. Physical examination may be inadequate to identify suitable vasculature, particularly in obese patients or those with a history of prior vascular access, and is often supplemented with additional techniques, such as CDUS. Respectively, venography or another imaging modality such as computed tomography (CT), magnetic resonance imaging (MRI) or digital subtraction angiography (DSA) should be used when there is a risk of central venous stenosis. The effects of contrast agents (used in CT, MR and DSA) on renal function should also be taken into account when deciding on the most appropriate imaging technique [11, 12].

Preoperative vessel mapping by CDUS is the most useful and non-invasive imaging investigation, supplementary to history and physical examination, to determine the optimal dialysis access type and site [9]. CDUS examination for dialysis access planning gives information about both the arterial and the venous system. Mapping with CDUS increases significantly the success of AVF or AVG construction and patency and radiologists must be familiar with this technique in order to confirm correct diagnosis and detect potential problems [11].

Preoperative arterial CDUS should include evaluation of the subclavian, axillary, brachial, radial and ulnar arteries with grayscale and spectral Doppler imaging. CDUS allows the assessment of the arterial circulation of the arm based on a series of morphological and functional parameters [12]. Morphological aspects include vessel diameter, wall thickness, wall alterations, vessel course, and any obstructive lesions that may occur. Functional evaluation involves the assessment of blood flow and the artery's ability to dilate.

Initially, patency of all arteries should be noted and any obstruction should be reported **(Fig. 1)**. The artery that is to be used for AV communication must be of sufficient size (diameter >0.2 cm) to construct the fistula and to have adequate flow for maturation [9, 11]. The internal luminal diameter of the artery is measured at the level of the expected fistula creation. The presence of calcification is recorded and reported, since the surgical anastomosis can be difficult if significant concentric calcification is present. Arterial spectral waveforms should be assessed to screen for inflow or outflow disease and significant stenoses should also be reported. The arteries that are most commonly

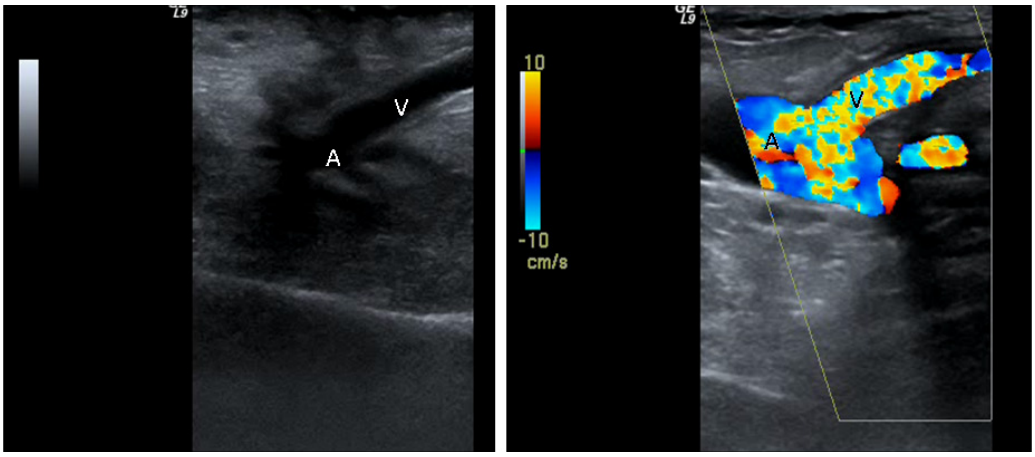

Fig. 5. *Normal end to side anastomosis of the vein (V) to the artery (A) on B-mode (left) and colour Doppler (right) ultrasound.*

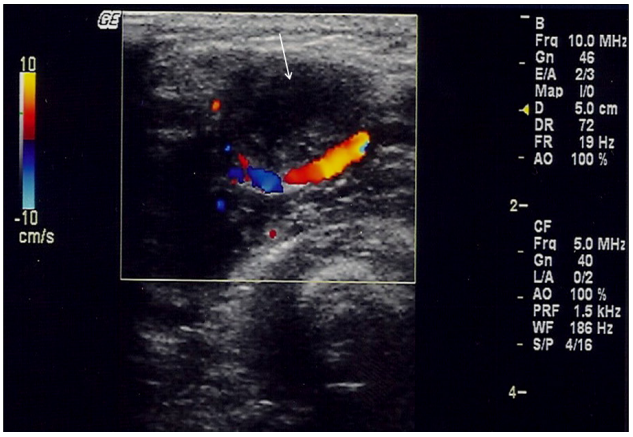

Fig. 6. *Thrombosis of the venous part of the fistula (arrow).*

used for AVF (radial, brachial) should be assessed for their diameter and depth from the patient's skin and these measurements should be included in the report **(Fig. 2)**.

Preoperative venous CDUS involves evaluation of the superficial and deep venous systems of the upper limb from the wrist up to the central veins (**Table 1**). Normal veins have a thin and smooth wall, an anechoic lumen, and are fully compressible. Several parameters can be helpful in deciding whether a superficial vein can be used to create an AVF. They include the appearance of the vein wall, the course of the vessel, its patency, caliber and distensibility, and the presence of collateral circuits [11, 12]. Any thrombosis should be noted **(Fig. 3).** As described, the forearm vein most commonly used for AVF creation is the cephalic vein. The anastomosis is usually created in the wrist, in the lower one-third of the forearm or in the middle of the arm. The cephalic vein is assessed for compressibility, possible thrombosis, diameter and depth from skin. A minimal inner luminal diameter of 0.25 cm is mandatory for any vein used for an AVF [13]. A very narrow vein **(Fig. 4)** can be a contraindication for an AVF and an AVG may need to be formed. There may be variations in the diameter used, based on clinical factors or surgical preference. The sites and length of any venous stenosis are noted. If a sclerotic (with extensive vascular calcifications present in patients with CKD) or thick-walled vein is shown, any abnormality should be mentioned [13, 14]. The distance from the skin of the venous part of the fistula should be less than 5-6 mm **(Fig. 2)**. If the vein lies deeper than this, it may be difficult to insert a cannulation needle [15]. In addition, it is important to ensure that at least 10 cm of the venous part lie within this depth, in order to guarantee sufficient space for placement of the two cannulation needles.

5. Surgical aspects and complications of AVF

As mentioned above, the two mainly used types of upper extremity AVF are the radiocephalic and the brachiocephalic fistula. A third, alternative choice is the brachiobasilic AVF. When selecting the patient's arm to form the fistula, it is prudent to avoid blood withdrawals or intravenous infusions, as well as to prefer the non-dominant arm. A vein diameter of more than 0.25 cm and an artery diameter of more than 0.2 cm are adequate and predictive of AVF maturation. The anastomosis may be performed end-to-side of the vein

Table 1. Vessels that need to be assessed for preoperative ultrasound mapping

Area to be scanned	Arteries	Deep and superficial veins
Subclavian area	subclavian artery	subclavian vein
Arm	axillary artery	axillary vein
	brachial artery	brachial veins
		cephalic vein
		basilic vein
Forearm, wrist	radial artery	radial veins
	ulnar artery	ulnar veins
		cephalic vein
		basilic vein

on the artery, latero-lateral, terminalised side-to-side, side-to end of the artery on the vein and end-to-end. The commonest pattern is the anastomosis of the vein side-to-end on the artery **(Fig. 5)** [16]. Proximal radiocephalic fistulas have fewer complications but similar midterm durability compared to brachiocephalic AVFs [17].

The most important complications of AVFs are lymphoedema, infection, aneurysm or pseudoaneurysm, congestive heart failure, steal syndrome, non-maturation of AVF, ischaemic neuropathy and thrombosis **(Fig. 6)** [18]. However, the most common pathophysiologic cause of vascular access failure is neointimal hyperplasia, which can cause stenosis or obstruction of the venous part of anastomosis. The commonest site of stenosis is within 3 cm from the AV anastomosis **(Figs. 7, 8)**. This mechanism is induced by different cells including myofibroblasts, vascular smooth muscle cells, endothelial cells involved in neovascularisation and inflammatory cells. Thus, the adjustment of myofibroblast formation, proliferation and migration is important in order to control neointimal hyperplasia that may subsequently cause fistula failure. It is crucial to gain information about early clinical symptoms of AVF dysfunction in order to prevent and adequately treat potential complications [19]. CDUS contributes not only to the creation of an AVF, but also for an early detection of complications. More precisely, morphological stenosis can be adequately assessed by following the vessel longitudinally with colour ultrasound, in order to detect narrowing of the lumen.

Doppler criteria for characterisation of a stenosis over 50% are:

a) Evident visual lumen narrowing,

b) Velocity increased by a factor of 3:1 distal to the stenosis, compared to 2 cm proximal to the anastomotic site in the feeding artery,

c) Doubling of peak systolic velocity in the draining vein [20].

Another serious but rare complication of AVFs is a pseudoaneurysm of the brachial artery. Clinically, it is presented as a pulsatile mass. On CDUS, the pseudoaneurysm shows the typical "Korean flag" image, characteristic of a pseudoaneurysm in any body artery, as well as the bidirectional blood flow inside the pseudoaneurysm neck. Pseudoaneurysms can be treated by compression, percutaneous thrombin injection, endovascular exclusion with covered stents, aneurysmectomy or surgical repair [21].

Additionally, dialysis access-related steal syndrome (DASS) has become a growing problem, more common in diabetic patients, which can potentially lead to severe hand ischaemia. This syndrome, caused by arterial insufficiency distal to the arteriovenous access

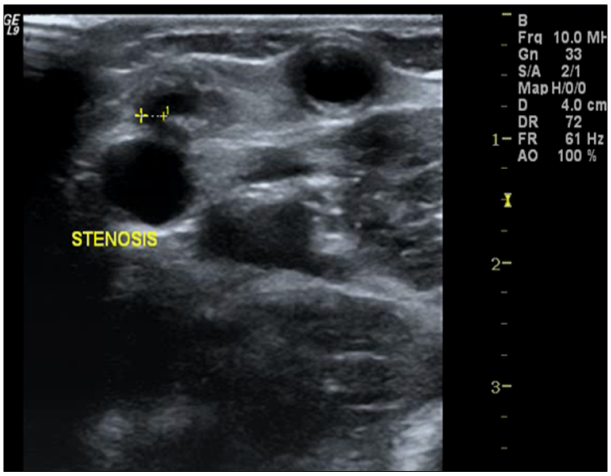

Fig. 7. Stenosis (between calipers) is noted in the anastomotic site.

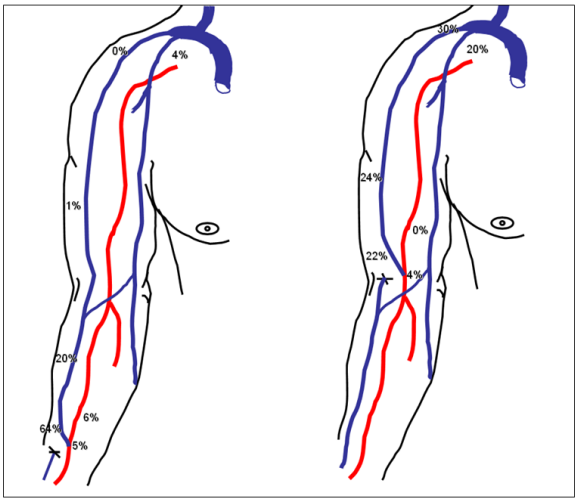

Fig. 8. AV fistula topography and frequency distribution of the commonest stenotic sites. Modified from [19].

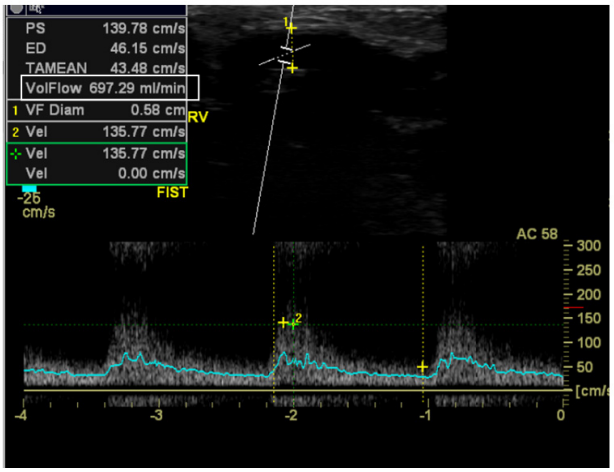

Fig. 9. A normal volume flow of 697.29 mL/min (inside rectangle) is calculated.

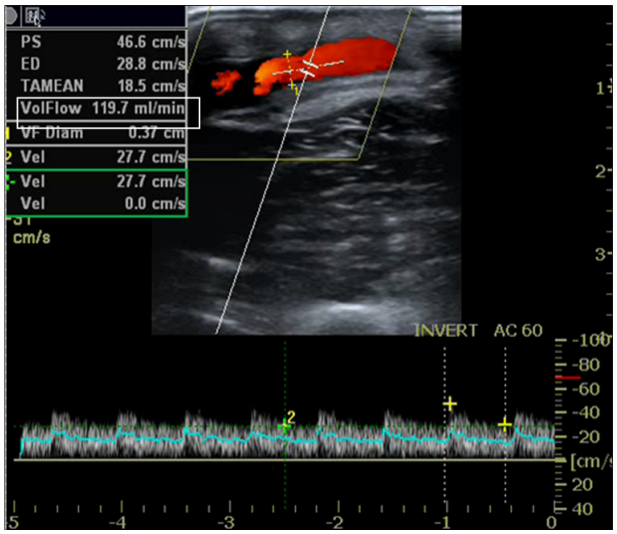

Fig. 10. A low volume flow of 119.7 mL/min (inside rectangle) is calculated.

due to diversion of blood into the access, is a potentially devastating complication. It is more frequent in patients with forearm and upper arm AVFs, as well as with prosthetic straight or loop grafts [22]. The choice of any intervention, if such is necessary, should be based upon the clinical features of the specific patient, stage of the disease, location of the arterial anastomosis and volume flow within the access [23].

A significant haemodynamic parameter of CDUS that can help examiners to determine whether the AVF is suitable for cannulation or whether it has failed to mature is volume flow. To calculate the volume flow inside the fistula lumen, a waveform at the venous part of the fistula is obtained, measuring velocity. Venous diameter is also estimated. Subsequently, volume flow is automatically calculated **(Fig. 9)**. A flow of at least 500-600 mL/min in the fistula artery is needed for a functional fistula. Of this volume, 350-450 mL/min is the minimal flow needed for the haemodialysis to be satisfactory, while 150 mL/min is minimally necessary in order to keep the fistula patent [15, 20]. If the volume flow is lower than the values above, a poorly

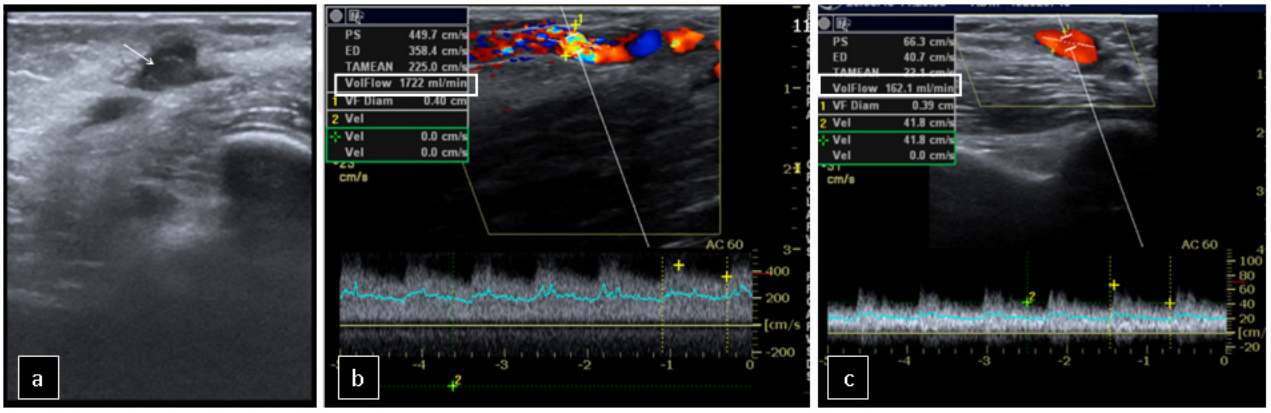

Fig. 11. *Brachiobasilic fistula shows partial thrombosis of the vein (arrow in* ***a****). Due to thrombosis, increased velocities are measured, resulting in false increase in volume flow (inside rectangle in* ***b****). In reality the volume flow is inadequate (inside rectangle in* ***c****).*

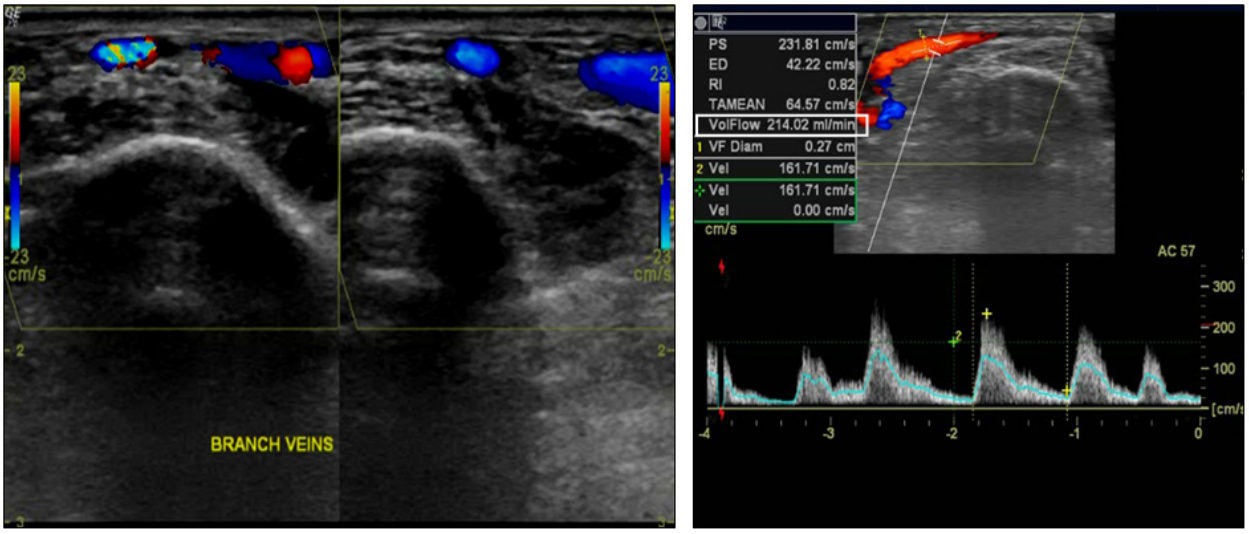

Fig. 12. *Volume flow is low (inside rectangle in the right image) due to the presence of accessory veins (left image).*

functioning fistula may result **(Fig. 10)**. Care should be taken to correctly measure volume flow, which may appear falsely increased due to thrombosis of the venous part. Thus, multiple measurements may be needed **(Fig. 11)**. The presence of accessory veins may also lead to low volume flow **(Fig. 12)**.

6. Surgery aspects and complications of AVG

Surgeons create an AVG by introducing a hollow synthetic tube in a looped configuration: one end is anastomosed to the side of an artery, while the other end to the side of a vein. The AVG is typically cannulated two to three weeks after its placement, after the surgical wound has healed. In the initial cannulation a 15-gauge needle is inserted at a 45° angle with a dialysis blood flow of 450 ml/min. A potential complication is thrombosis, which can be caused by stenotic lesions (primarily due to neointimal hyperplasia) developed inside the AVG. More than 90% of AVG thromboses are caused by stenotic lesions, suggesting that this anatomic abnormality is the cause of thrombosis [24]. The three factors predisposing to venous thrombosis (venous stasis, endothelial injury, hypercoagulability) are known as Virchow's triad. The first two factors are major causes of AVG thrombosis **(Fig. 13)**. The stenotic location is usually seen at the venous anastomosis, but may also be noted in the draining vein, central vein, feeding artery or within the AVG itself [25, 26].

AVG monitoring in order to identify thrombosis includes physical examination of the graft (abnor-

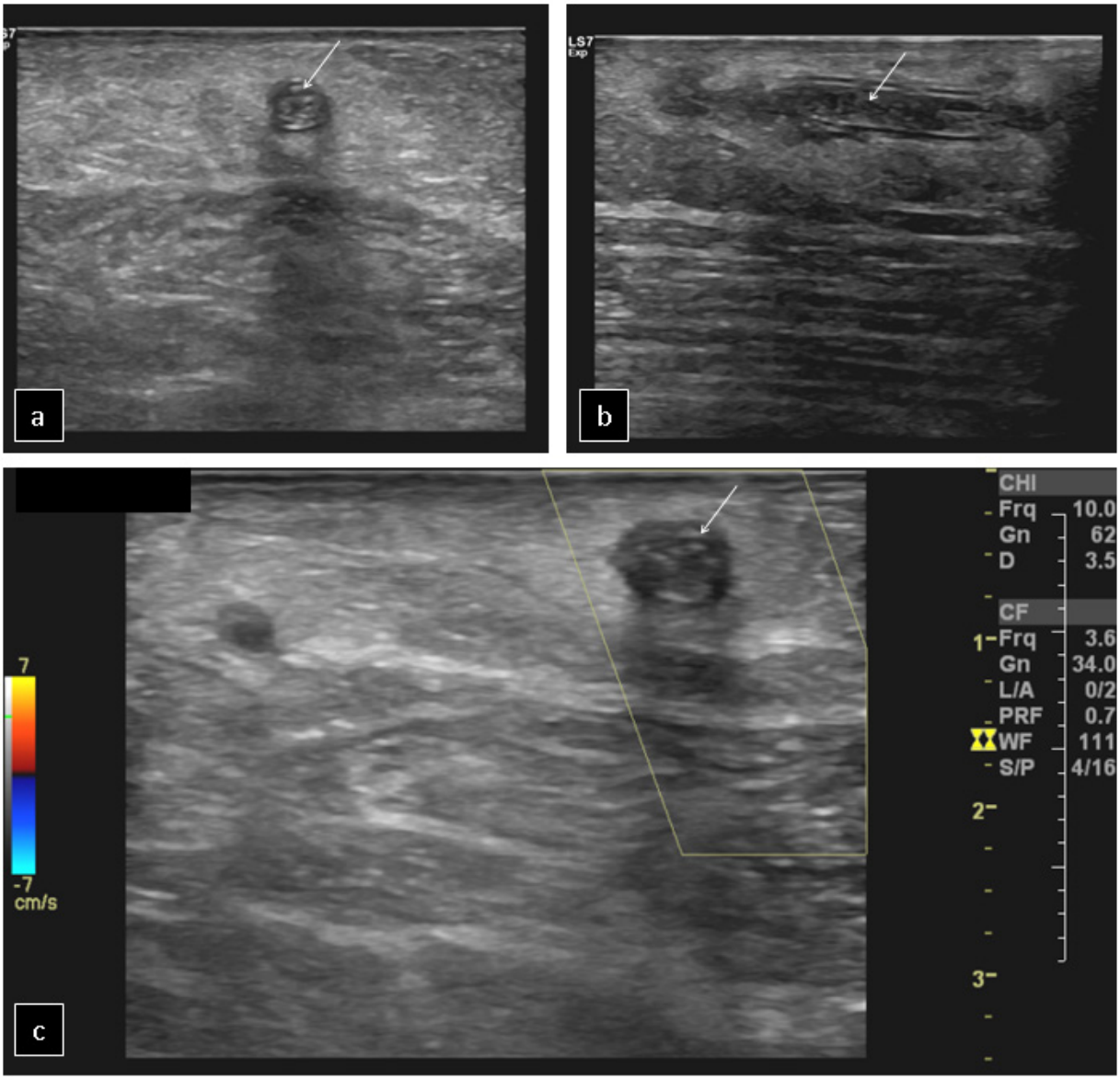

Fig. 13. *Echogenic thrombus (arrows) in the graft lumen is noted on transverse* ***(a)*** *and longitudinal* ***(b)*** *B-mode ultrasound. On colour Doppler* ***(c)*** *no flow is seen.*

mal bruit, oedema distal to the AVG) and observation during the haemodialysis session (difficulty in cannulation, prolonged bleeding from the needle puncture site). CDUS can show the location of stenosis in combination with a ratio of the peak systolic velocity on both sides of the stenosis being >2 [27].

An additional complication of AVG is bacterial infection, caused by repeated punctures and cannulations, in combination with the prosthetic segment, which is even more prone to infection. Infection usually presents as abnormal fluid or air collection around the AVG [27] and can be imaged by US **(Fig. 14)**.

7. Management of complications of AVF and AVG

AVF stenosis should be treated when the diameter decrease is higher than 50% or flow reduction, difficulties in cannulation, painful arm oedema, prolonged bleeding

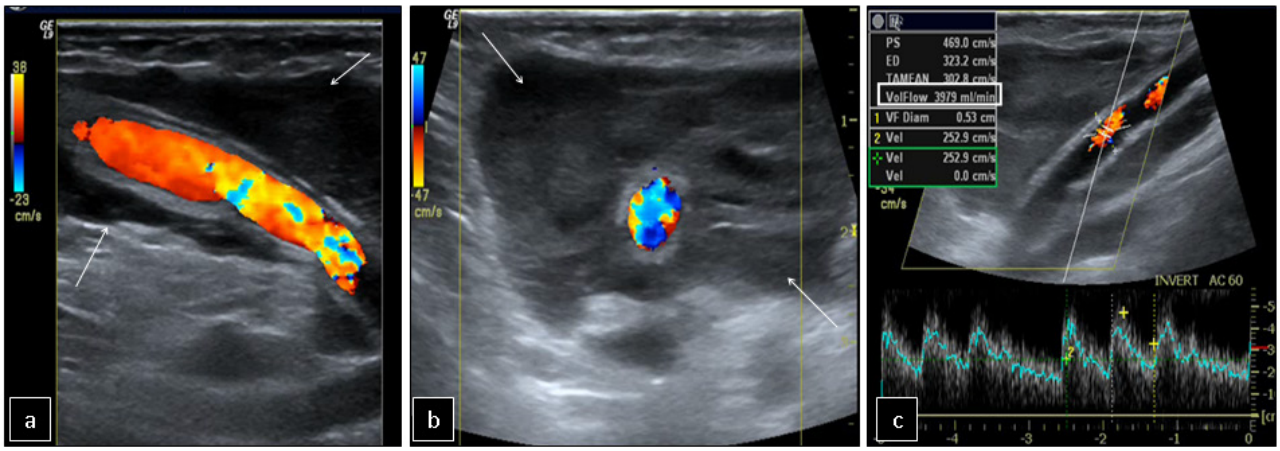

Fig. 14. *Echogenic fluid due to infection is seen around the synthetic graft lumen (arrows in* ***a, b****). Volume flow is high (inside rectangle in* ***c****).*

time after cannulation or after removal of the cannula and hand ischaemia, due to arterial inflow or distal stenosis, appear. Patients are examined by CDUS and fistulography. In this technique, access to the fistula is obtained through a brachial arterial puncture with a 21-gauge needle. Injection of 30 ml of contrast agent follows.

The feeding artery, arteriovenous anastomosis, draining vein(s) and central veins up to the right atrium are visualised. Once the stenosis is identified, percutaneous transluminal balloon angioplasty (PTA) is the gold standard for its treatment [28, 29].

An alternative to conventional surgical approach to haemodialysis access stenosis is the percutaneous approach, with PTA being an effective treatment with technical success rates up to 96.3% of stenosis and clinical success up to 97.2% [30]. However, some stenoses cannot be treated with conventional balloon angioplasty. In these cases, cutting balloons or ultra-high pressure balloons (up to 32 atm) or drug eluting balloons can be used [30].

Graft thrombosis should be treated without delay and within the first 48 hours, at least before the next dialysis session. Treatment techniques include surgical thrombectomy and interventional thrombolysis. Surgical thrombectomy is performed with a thrombectomy catheter. Interventional treatment with the use of thrombolytic agents such as tissue plasminogen activator (t-PA) and PTA constitutes an effective treatment method for dysfunctional AVG [29, 30].

8. Conclusion

AVFs and AVGs for treating patients with end stage renal failure are commonly examined in clinical practice. Ultrasound is an examination technique commonly used in this task. The sonographic studying of AVFs and AVGs includes all stages, from preoperative mapping of arm arteries and veins for their creation, assessment of their functional adequacy, to detecting and managing their complications. Following a specific examination protocol, as outlined in this article, ensures covering of all these aspects. **R**

Conflict of interest

The authors declared no conflicts of interest.

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