Role of color doppler ultrasound for assessment of arteriovenous fistula dysfunction in hemodialysis patients

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Background
and objective Arteriovenous fistulas (AVFs) are the vascular access of choice for hemodialysis with a lower incidence of complications and longer survival than prosthetic grafts or central venous catheters.
Our aim was to evaluate the role of color Doppler ultrasound (CDUS) in the detection and characterization of complications of AVF dialysis access.
Materials and methods
During a 9-month duration, we prospectively evaluated 25 patients with clinically suspected AVF complications using CDUS examination of the upper limbs. There were 11 (44%) males and 14 (56%) females, ranging in age from 8 to 70 years. All patients were examined after reconstruction of AVF for the assessment of vascular access complications. Doppler indices were measured in the afferent arteries, at the site of anastomosis, and the draining veins.
Results
All 25 patients had shunt complications. Venous thrombosis was the highest among all complication (*n*=12, 48%), followed by stenosis (*n*=11, 44%), aneurysm and pseudoaneurysmal formation (*n*=5, 20%), and infection (*n*=1, 4%). Four patients had more than one complication. Sixteen (64%) patients had complicated fistulas requiring further intervention, either surgical management [reconstruction of new fistula (*n*=3), ligation (*n*=1), graft (*n*=1), and superficialization (*n*=2)] or radiological intervention [percutaneous transluminal angioplasty (*n*=5), thrombectomy (*n*=2), and percutaneous transluminal angioplasty and thrombectomy (*n*=2)].
Conclusion
CDUS is a noninvasive diagnostic tool for early detection and localization of complications of AVFs that allows detection of possible causes of vascular access malfunction.

Keywords:
arteriovenous fistula, complications, Doppler, hemodialysis, ultrasound

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Introduction

The long-term survival and quality of life of patients with chronic end-stage renal failure on hemodialysis (HD) are dependent on the adequacy of dialysis via an appropriately placed vascular access. Arteriovenous fistulas (AVFs) are the preferred initial HD access owing to their longer patency than prosthetic arteriovenous grafts. However, arteriovenous grafts remain clinically important in patients whom AVFs are not feasible, and possibly in special populations such as the elderly. The creation and maintenance of a patent and well-functioning AVF have became a real challenge to nephrologists and vascular surgeons [1–3].

Complications associated with HD vascular access are considered one of the most important causes of morbidity among patients with end-stage renal disease. Access failure is usually owing to thrombosis associated with anastomotic or outflow vein stenosis. Multiple salvage procedures are required to restore functionality or creation of a new access [4,5].

Early detection of access dysfunction and subsequent intervention may help to decrease access failure rate. AVFs are constructed to be superficial, and they are easily accessible by Doppler ultrasound (DU). DU is very important in a patient-centered VA evaluation. It is mobile, cost effective, and noninvasive, and also, it provides morphologic and functional information of the access flow [6]. It can provide all aspects of vascular access care, including vascular mapping, maturation evaluation, and surveillance [7]. In addition to diagnosing the complications of AVFs, it can be also used to guide intervention procedures to correct the hemodynamic problems and prolong the access patency [8].

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The aim of this study was to evaluate the role of DU in detection and characterization of shunt complications and to determine further therapeutic options.

Patients and methods

Approval for this study was obtained from the institutional review board, and informed consent was obtained from all patients. During a 9-month duration, we prospectively evaluated 25 patients (11 males and 14 females), ranging in age from 8 to 70 years, with a mean±SD age of 51.56±15.524 years. All patients had chronic renal failure and were on regular HD. They were referred from the nephrology-dialysis center for assessment of HD arteriovenous dysfunction.

Clinical evaluation

A clinical evaluation of the dialysis access was performed in all patients before US examination:

(1) Access patency was determined by the presence of a palpable thrill, in addition to the strength and consistency of a thrill throughout the access.
(2) Visual inspection of the limb and access site to detect areas of swelling, redness as well as the presence of dilatation, collateral vessels and palpable prominent localized areas of pulsations (suggesting pseudoaneurysm) was done.

Before evaluation of the dialysis access by DU, the procedure was explained to the patient, and a complete history and review of the patient's medical records and current medical status (including status of current dialysis), history of previous surgeries or invasive procedures involving the affected arm or neck, current medications or therapies, recent or past surgery on the fistula/graft extremity, and history of venous thrombosis (including the central veins) were noted.

Patients with chronically occluded vascular access with failed surgical or interventional attempt were excluded from the study.

Doppler ultrasound examination

During DU examinations, the patient positioning was most often supine, with the arm relaxed and extended out to the side, with the area to be evaluated closest to the sonographer. The patient may be positioned in a Trendelenburg position with hands over the head or examined in the sitting position. Patient position should be optimized so that gravity helps dilate the veins.

DU examinations were performed using Elegra Siemens Medical Systems (Erlangen, Germany). Linear arrays transducers (5–10 MHz) were usually chosen for superficial vascular imaging and the access itself. However, curved transducers were utilized for deeper vascular imaging, such as central veins in the shoulder or the neck, the inflow arteries, or in obese patients.

Examination included the afferent artery, site of anastomosis, the draining veins as far as the subclavian vein as well as the arterial tree distal to the AVF in cases experiencing steal syndrome.

All vessels were examined in both transverse and longitudinal planes using gray-scale and color images. At first, the vessels were examined by B-mode to determine the site and type of the fistula, detection of wall echo pattern and dilatations, and measurement of the vessel's diameter. Then color images were obtained to assess the direction of blood flow. Finally, Doppler studies were performed, in the longitudinal orientation; the wall filter was set at 50–100 Hz; and the sample size was maintained below 5 mm and was located at the center of each vessel. The spectral waveform was angle corrected, and the Doppler angles of incidence were less than 60°. Then spectral waveforms were obtained at each level.

The following parameters were measured at the site of the afferent artery and AV anastomosis: the arterial diameter 2 cm proximal to the site of fistula and diameter of the fistula, peak systolic velocity (PSV), and end diastolic velocity. Then examination of proximal, mid, and distal outflow vein for diameters, patency, and mean velocities was performed. In the presence of stenosis, the degree of the stenosis was calculated. Waveforms and PSVs were documented in any area where velocity increase or turbulence was noted. Stenosis was diagnosed when there were reduction of the vessel diameter of more than 50% and an increase in PSV ratio (PSV in the stenotic area/PSV upstream the stenotic area) greater than 2 : 1 in the draining vein or greater than 3 : 1 in the anastomotic area [9–11].

US findings were compared with surgery and interventional radiological findings together with clinical and radiological follow-up.

Results

Among 25 patients with DU-detected complications, 10 (40%) patients had a brachiocephalic fistula, nine

(36%) patients had a radiocephalic fistula, and six (24%) patients had a brachiobasilic fistula. The duration of the fistula was less than 2 months in three patients, ranging from 2 to 6 months in two patients and more than 6 months in 20 patients. Twelve of the 25 patients had previous failure of AVF.

Color Doppler ultrasound (CDUS) provided a correct diagnosis of AV access complications in all cases. Venous thrombosis was the highest among all complication (*n*=12, 48%), followed by stenosis (*n*=11, 44% patients), aneurysmal dilatation (*n*=2, 8%), pseudo-aneurysmal formation (*n*=3, 12%), and infection (*n*=1, 4%), with 6 patients having more than one complications.

Among 11 patients with diagnosis of stenosis, 6 patients had stenosis at the fistula, 3 patients had central stenosis, and 2 patients had post-fistula stenosis. All patients had moderate to severe stenosis, with more than 50% diameter reduction of the lumen. The mean diameter of the stenotic area was 1.4±0.5. The mean pre-stenotic velocity was 72.32±29.47, and the mean interstenotic velocity was 243.85±70.42, with increase in PSV ratio greater than 3 : 1.

Six patients were diagnosed with minor complications, including arm edema (*n*=2), neuropathy (*n*=1), infection (*n*=1), and failure of maturation (*n*=2).

Sixteen (64%) of 25 patients had a complicated fistula that required further intervention. Surgical intervention was performed in seven (28%) patients, including reconstruction of a new fistula (*n*=3), ligation (*n*=1), graft (*n*=1), and superficialization (*n*=2). Radiological intervention was performed in nine (36%) patients, including percutaneous transluminal angioplasty (PTA) (*n*=5), thrombectomy (*n*=2), and PTA and thrombectomy (*n*=2). Central venous line was inserted in three (12%) patients. Six patients underwent conservative management.

Discussion

Vascular access problems remain the vulnerable point of modern HD [12]. For evaluation of access dysfunction, the initial, most practical and cost-effective method is physical examination [13,14]. US confirms the results of physical examination such as inflow stenosis and outflow stenosis. Moreover, it provides important information about the functional severity like brachial artery flow rates [9,15,16]. By combining the findings of US and physical examination, the treatment methods can be determined, such as angioplasty, revision surgery, or conservative management [8]. Moreover, Doppler US shortens angioplasty time, as it gives information on the stenosis site [17]. Thus, by the use of US more clinical needs are satisfied [8].

In this study, we evaluated the clinical utility of DU for early detection of complications in AV dialysis access.

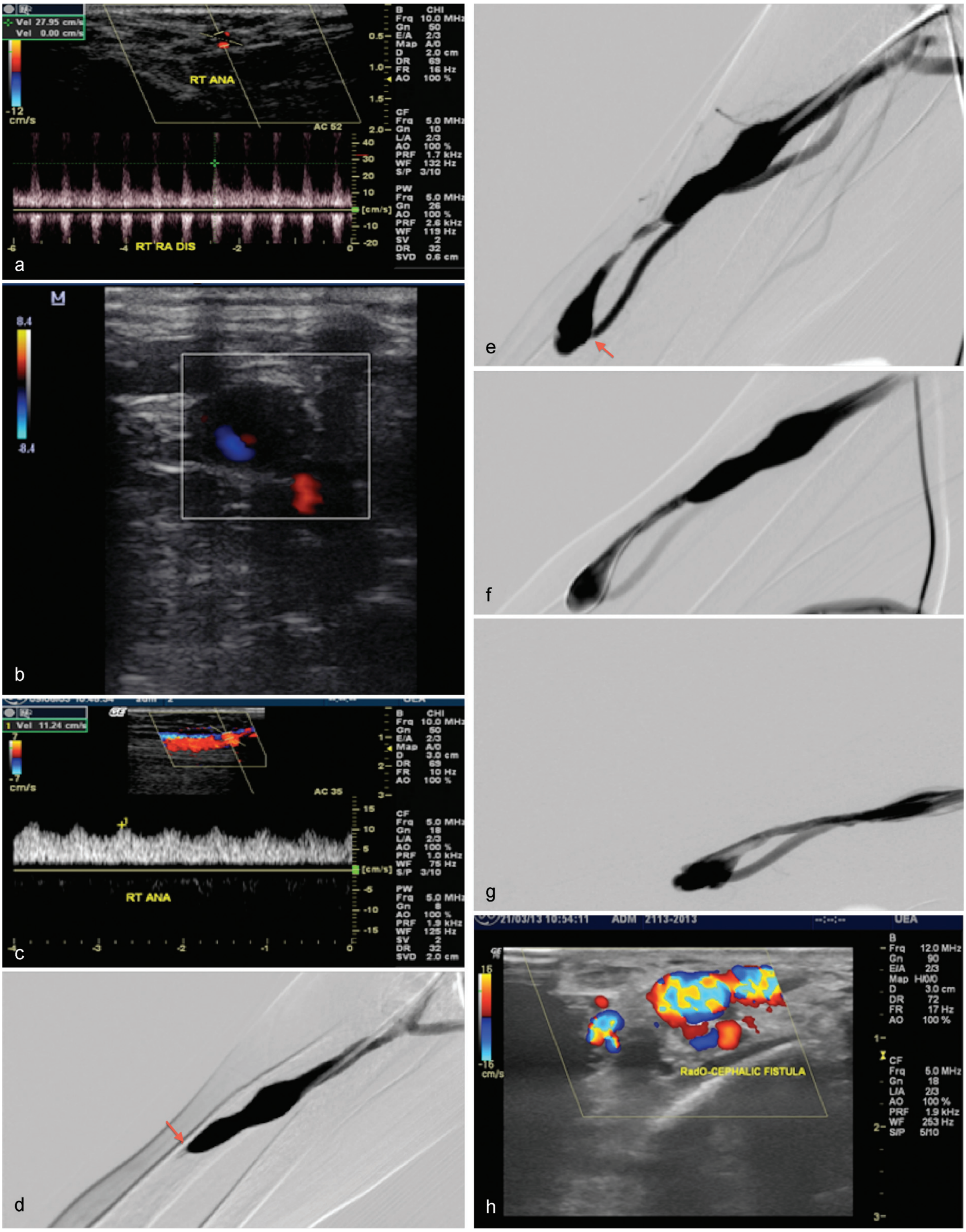
We found that the number of female patients exceeded that of males, with 14 female patients and 11 male patients, representing 56 and 44% of all patients, respectively. This correlates with the findings of the previous studies who found that fistulas are less likely to be usable for dialysis in female than in male patients [18,19]. This discrepancy in fistula could be explained by smaller arterial diameter in female than male patients, yet the venous diameters are not different, therefore less likely to dilate sufficiently to maintain a blood flow adequate for HD [18].

Among our study population, the most common shunt complication associated with HD was access thrombosis (*n*=12, 48%). Thrombosis is usually located in the arteriovenous anastomosis of the AVF. In our study, thrombosis was detected at the venous side of the fistula in all cases, diagnosis of thrombosis was established by absence of flow using color or pulsed Doppler together with hypoechoic or echogenic thrombus filling the lumen (Fig. 1).

Stenosis of HD vascular access is common and may lead to thrombosis and the loss of the access. Thus, detection of stenosis in AVF before thrombosis could offer a strategy to improve AVF survival by early intervention [20]. Stenosis in AVF develops more frequently in juxta-anastomotic location, up to 4 cm from the anastomosis [21,22]. Among 11 patients diagnosed with stenosis, two cases had post-fistula stenosis, six had stenosis at the anastomotic site, whereas three cases had central stenosis. This was in accordance with the finding of Tirinescu *et al.* [21], who performed a large observational study on 97 patients, and reported juxta-anastomotic localization of stenosis in most cases, in the forearm and in the upper arm AVF equally.

In AVF, stenosis is caused by the intimal or fibromuscular hyperplasia secondary to endothelial damage because of the pressure increase in the venous system. Recently, the diagnosis of stenosis relies on the PSV ratio in addition to measurement of the minimum diameter of the stenosed area in addition to PSV to differentiate true, significant, stenosis from borderline stenosis [23,24].

Figure 1



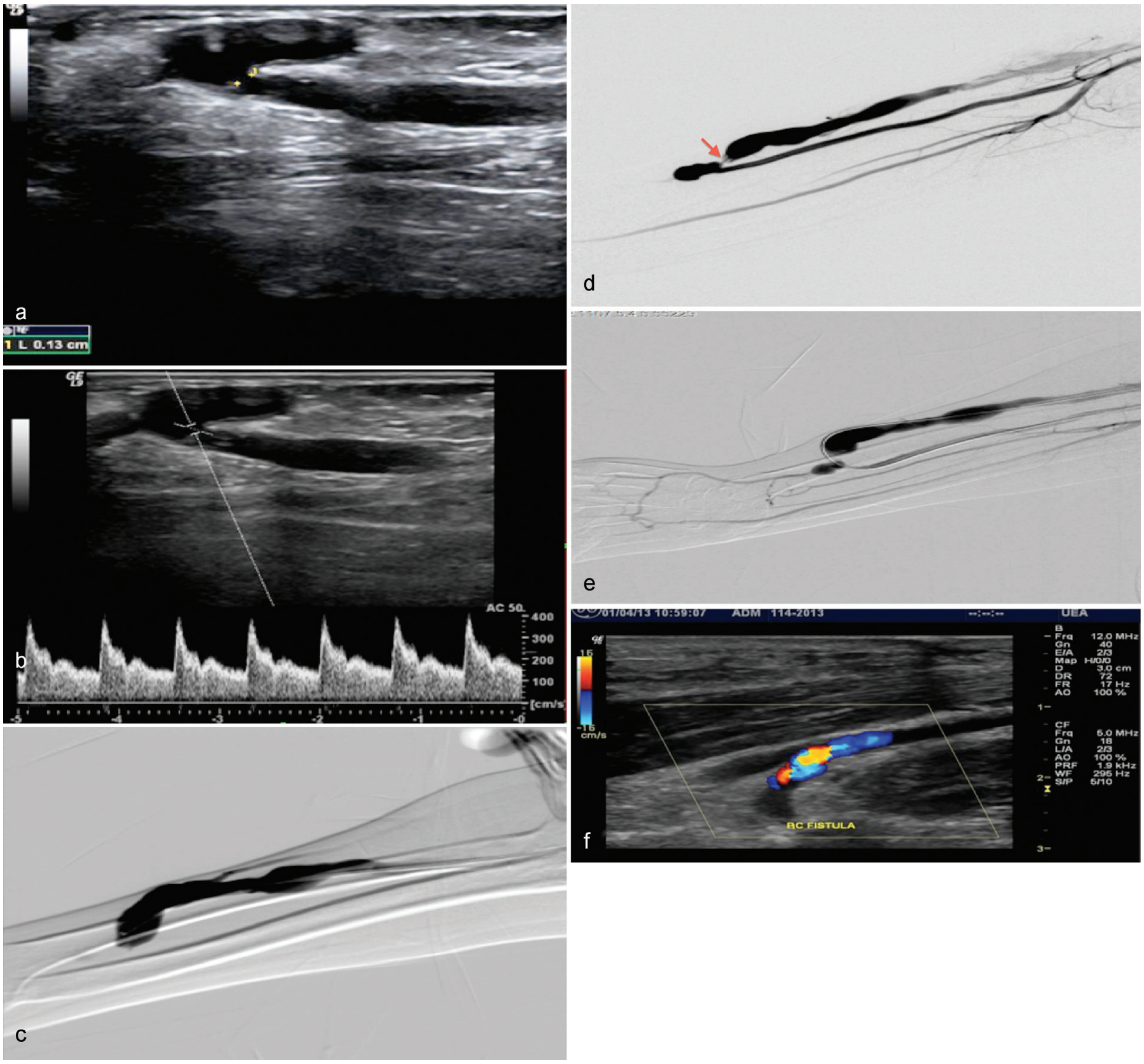
Cephalic vein thrombosis. A 42-year-old male patient with chronic renal failure and radiocephalic fistula construction for 9 years. DUS images demonstrate normal flow and wave pattern at the site of anastomosis (a). There is an echogenic thrombus in the cephalic vein with sluggish flow at the venous side distal to the thrombus (b–c). Digital subtraction angiography (DSA) image after injection of contrast from the venous side reveals complete occlusion of the cephalic vein with no passage of contrast to the arterial side (arrow) (d). Following repeated attempts of successful passage of the wire through the thrombus, the contrast crosses to the arterial side through the constructed RCF (arrow) (e). Finally, after repeated attempts of PTA using balloons of increasing sizes, the AVF restores its patency (50%) (f). Second session of PTA and repeated balloon dilatation performed after one month showing patent AVF (75%) (g), with postprocedure CDUS demonstrating patent radiocephalic fistula (h). AVF, arteriovenous fistula; CDUS, color Doppler ultrasound; DUS, Doppler ultrasound; PTA, percutaneous transluminal angioplasty.

In this study, we used PSV measurements and PSV ratios to diagnose access stenosis (Fig. 2). This was in agreement of the findings of Tordoir *et al.* [25] who compared DUS and angiography for the evaluation of native AVF. They found that PSV was the best diagnostic parameter with a sensitivity of 95% and a specificity of 97% [25].

False or pseudoaneurysms occur at the site of puncture or at the anastomoses. Puncture of an AVF either as part of standard dialysis needling or from intervention can result in prolonged bleeding and pseudoaneurysm formation. However, the mechanism of formation of true aneurysms in AVFs is less clear. This is may be attributed to also to repeated needling with consequent development of multiple small fibrous scars in the vessel wall that expand with time and result in localized aneurysmal areas [26,27].

The clinical finding of a pulsatile mass and a systolic murmur usually allows correct diagnosis of aneurysm and pseudoaneurysms. However, CDUS is of the utmost importance as it allows better estimation of the extent of aneurysm (less or more than 5 mm) size of its neck and degree of mural thrombosis. Additionally, CDUS can differentiate pseudoaneurysm from

Figure 2



A 45-year-old female patient with chronic renal failure for 5 years and radiocephalic fistula construction. CDUS images demonstrate severe anastomotic stenosis, where the fistula diameter measures 1.3 mm, and PSV at the fistula is 400 cm/s (a–b). Digital subtraction angiography (DSA) images after injection of contrast from the venous side demonstrate complete occlusion of the cephalic vein with no passage of contrast to the arterial side. After injection of contrast from the arterial side, the contrast crosses to the venous side and there is a significant stricture (arrow) (c–d). Following repeated attempts of balloon dilatation, there is adequate, but incomplete dilatation (e). CDUS after PTA demonstrates aliasing at the site of fistula suggesting, the presence of residual stenosis (f). CDUS, color Doppler ultrasound; DUS, Doppler ultrasound; PTA, percutaneous transluminal angioplasty.

hematomas as they have a typical 'to-and-fro' pattern [26].

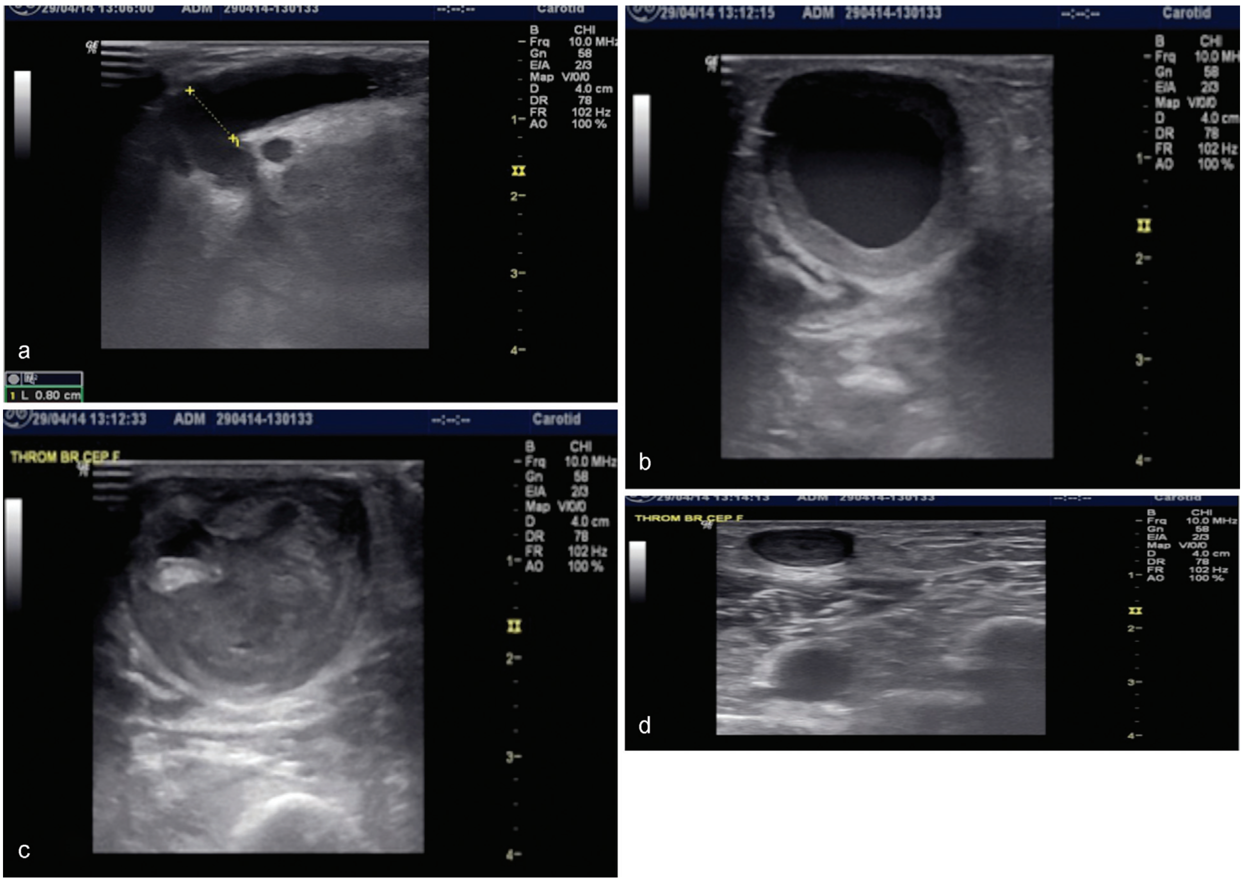
In this study, five (20%) patients had aneurysm and pseudoaneurysm: four at the venous side of the AVF, and one at the site of anastomosis. CDUS was useful to determine the extent of the aneurysm and evaluate the presence of luminal thrombus as well as to determine if the patient requires surgery or not (Fig. 3).

Tenderness and erythema along the access can indicate infection. An untreated access infection may lead to bacteremia, sepsis, hemorrhage, and if left untreated, possible death. In this study, only one (4%) patient had an infected AVF, because it is an uncommon complication.

The CDUS findings in this series were helpful to determine further therapeutic management in patients with AV dysfunction. Overall, 16/25 patients underwent further intervention; surgical intervention was performed in seven (28%) patients, whereas radiological intervention was performed nine (36%) patients. PTA was performed in five cases diagnosed with stenosis, and thrombectomy was performed in two patients, whereas two patients underwent combined PTA and thrombectomy. Cho *et al.* [7] recommended that if hemodynamically significant stenotic area was detected by US, the problem of vascular access can be treated. However, complete occlusion of the stenotic lumen elevates the risk of failure of angioplasty [7].The limitation of this study is the relatively small number of patients with selection bias including only patients with suspected AV dysfunction on physical examination. A larger study including all patients for surveillance of AVF is recommended.

In conclusion, CDUS is a noninvasive diagnostic tool for early detection of complications of AVFs that allows monitoring of the AVF blood flow and detection of possible causes of vascular access malfunction. Owing to its low cost and availability, it should be used as the first-line imaging modality for nonfunctional AVF.

Figure 3



Aneurysmal dilatation. A 53-year-old male patient. He had chronic renal failure and left brachiocephalic fistula for 1 year. Physical examination revealed painful arm swelling with suspected aneurysmal dilatation. CDUS images demonstrate aneurysmal dilatation of the cephalic vein and organized thrombus within (a–d). The patient underwent reconstruction of a new fistula. Surgery was preferred to angioplasty owing to the presence of thin-walled aneurysm with organized thrombus. CDUS, color Doppler ultrasound.

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Nil.

Conflicts of interest
There are no conflicts of interest.

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