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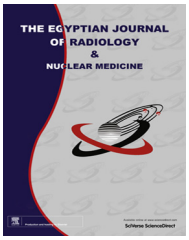

ORIGINAL ARTICLE

Angiographic mapping of AV fistula related vascular complications in ESRD via multislice CT; adjuvant role in correlation with CDUS

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KEYWORDS

ESRD;
CTA;
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Abstract *Background:* To evaluate the role and usefulness of Multislice CT angiography (CTA) and color Doppler US (CDUS) in assessment of vascular tree of AVFs and comprehensive evaluation of possible shunt complications in ESRD patients on hemodialysis.

Methods: Prospective analysis of vascular access related data was obtained from 30 patients (10 Male, 20 Female and age range 18–80 years) referred from hemodialysis unit via CTA and CDUS examination of the upper limbs. All patients were examined to identify the different types of fistula shunt related complications utilizing Doppler indices (PSV, EDV and RI) and different CTA 2D image reconstruction and 3D volume rendering techniques followed by surgical procedures as a gold standard within 2–7 days.

Results: The study showed 15 patients with shunt related complications; aneurysm 33.3% (10 patients) followed by venous thrombosis 23.3% (7 patients), and arterial steal syndrome 13.3% (4 patients), and finally venous hypertension 6.6% (2 patients). Considering surgery as a gold standard the sensitivity and specificity of CDUS and CTA, in detecting aneurysms and stenosis was 100% and 100% respectively. The detection of subclavian occlusion sensitivity and specificity by CDUS was 70% and 85% respectively on the other hand CTA sensitivity and specificity was 100% and 100% respectively.

Conclusions: The adjuvant diagnostic value of CTA with CDUS maximizes the evaluation of AV fistula related vascular complications approaching that of surgery.

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1. Introduction

The introduction of hemodialysis has prolonged the lives of patients with end-stage-renal disease (ESRD). To maintain them on long-term dialysis, vascular access procedures are required (1).

The long-term survival and quality of life of patients on hemodialysis (HD) are dependent on the adequacy of dialysis via an appropriately placed vascular access (2).

The upper extremities are most commonly used for dialysis access. An arteriovenous access (AVA) is created by connecting a vein to an artery (arteriovenous fistula or AVF) or by interposing a conduit, between an artery and a vein (arteriovenous graft or AVG). This provides a high flow circuit, which may be percutaneously cannulated for hemodialysis access when sufficiently mature. A matured AVF outperforms AVG, in terms of higher patency rates, freedom from infection and decrease in maintenance costs (3).

The creation and maintenance of a patent and well-functioning arteriovenous fistula (AVF) are essential for the maintenance of hemodialysis in patients with chronic renal failure. It has become a real challenge to nephrologists and vascular surgeons (4).

Complications associated with hemodialysis vascular access represent one of the most important sources of morbidity among end-stage renal disease patients (5).

After creation of access, periodic monitoring is recommended, since early detection of access dysfunction and subsequent intervention may help to reduce the rate of access failure (6).

Color-flow Doppler ultrasound is mobile noninvasive technique, accurate and sensitive method. It is available in most hospitals. The equipment is less expensive, requiring fewer personnel and less demanding facilities than angiography that provides direct visual imaging of the access and measurement of access flow (7).

MDCT is a fast, non-invasive, and accurate technique for diagnosing AVF complications. Radiologists familiar with these techniques can help to improve the prognosis and quality of life for hemodialysis patients (8).

2. Patients and methods

2.1. Study design and population

This prospective randomized controlled trial study included thirty patients meeting the study criteria out of 42 patients referred from the nephrology-dialysis-transplantation center to our department aged from 18 to 80 years and included 10 males and 20 females with an upper limb hemodialysis arterio-venous dysfunction, within a period of 8 months from December 2013 up to July 2014.

Nine out of 42 patients were examined only by CDUS and three out of 42 patients were examined only with CTA were excluded.

The thirty patients performed CDUS and CTA within 24 h followed by surgical procedures within 2–7 days. Agreement between CDUS and CTA results was performed. Then CDUS and CTA results were compared with gold standard surgery results.

2.2. Inclusion criteria

- Both male and female patients diagnosed as ESRD with an upper limb AVF for hemodialysis.
- Assessment of anatomy and blood flow of the already created fistula.
- Patients with suspected malfunctioning AVF e.g. dialysis needle puncture difficulties, enlarging aneurysms, suspected source of infection/abscess, thrombosed access, extremity swelling/edema or hand ischemia "steal".

2.3. Exclusion criteria

- Color Doppler ultrasound: No exclusion criteria.
- CTA: pregnancy is a contraindication.

2.4. Patient Assessment

Patient assessment must be performed before Evaluation of the Dialysis Access is performed. All Patients were subjected to:

(1) Explanation of the procedure to the patient (including table movements, voice messages, sensation of contrast injection and manner of breath holding in case of CTA), taking into consideration the age and mental status of the patient and to ensure that the patient understands the necessity for each aspect of the evaluation.
(2) Obtaining a complete history by interview of the patient and review of the patient's medical records. A complete history includes:
   - Personal identification (Name, Age, Sex).
   - Current medical status (including status of current dialysis)
   - Previous surgeries or invasive procedures involving the affected arm or neck
   - Current medications or therapies
   - Presence of any risk factors, recent or past surgery on the fistula/graft extremity.

(3) A clinical evaluation of the dialysis access should be performed:
   a. Determine access patency by the presence of a palpable thrill as well as the strength and consistency of thrill throughout the access.
   b. Provide a visual inspection of the limb and access site noting areas of redness, swelling, dilatation, presence of collateral vessels, and palpable prominent localized areas of pulsations (suggesting pseudo aneurysm).

(4) Patient positioning:
   a. **Color Doppler examination:** patient is most often supine, with arm relaxed and extended out to the side with area to be evaluated closest to the sonographer, or examined in the sitting position. Patient position should be optimized so that gravity helps to dilate the veins.
   b. **CT angiography:** patient is placed supine, with the AVF arm placed beside the body leaving a small gap between the arm and the body to avoid vein compression, while

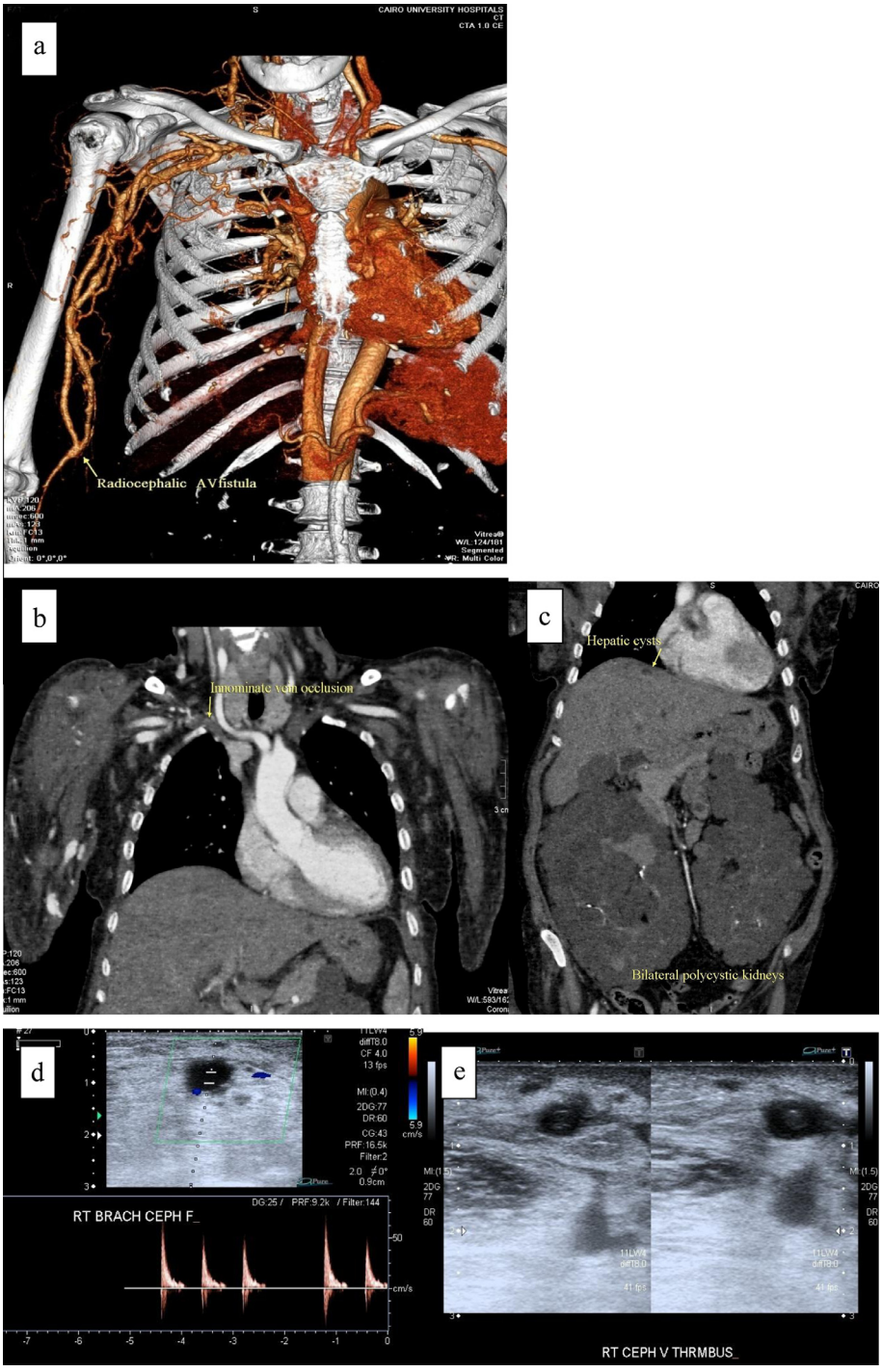

Fig. 1 (a–e): Female patient, 55 years old, known diabetic and hypertensive with renal failure due to bilateral adult type of polycystic kidney disease complaining of dilated veins on chest wall. (a) VRT and (b and c) coronal MPR CTA images revealed patent AVF communication, yet with no signs of arterialization of the venous side, totally thrombosed right innominate and subclavian veins with secondary venous collateralization along right upper limb and chest wall. Incidental findings of bilateral polycystic kidneys and multiple hepatic cysts detected. (d and e) CDUS revealed patent AVF with totally occluded incompressible thrombosed cephalic vein at the arm.

an IV catheter is placed in the opposite arm which is raised above the head to reduce artifacts. The reason we suggest the arm-down rather the arm-up position is that the arm-down position is the neutral position of the upper limb. When the arm is up, motion artifact is usually observed because the patients, who are usually older and have joint motion limitations, are uncomfortable. The contrast is injected into a peripheral vein in the opposite arm, thus avoiding any damage to the access site.

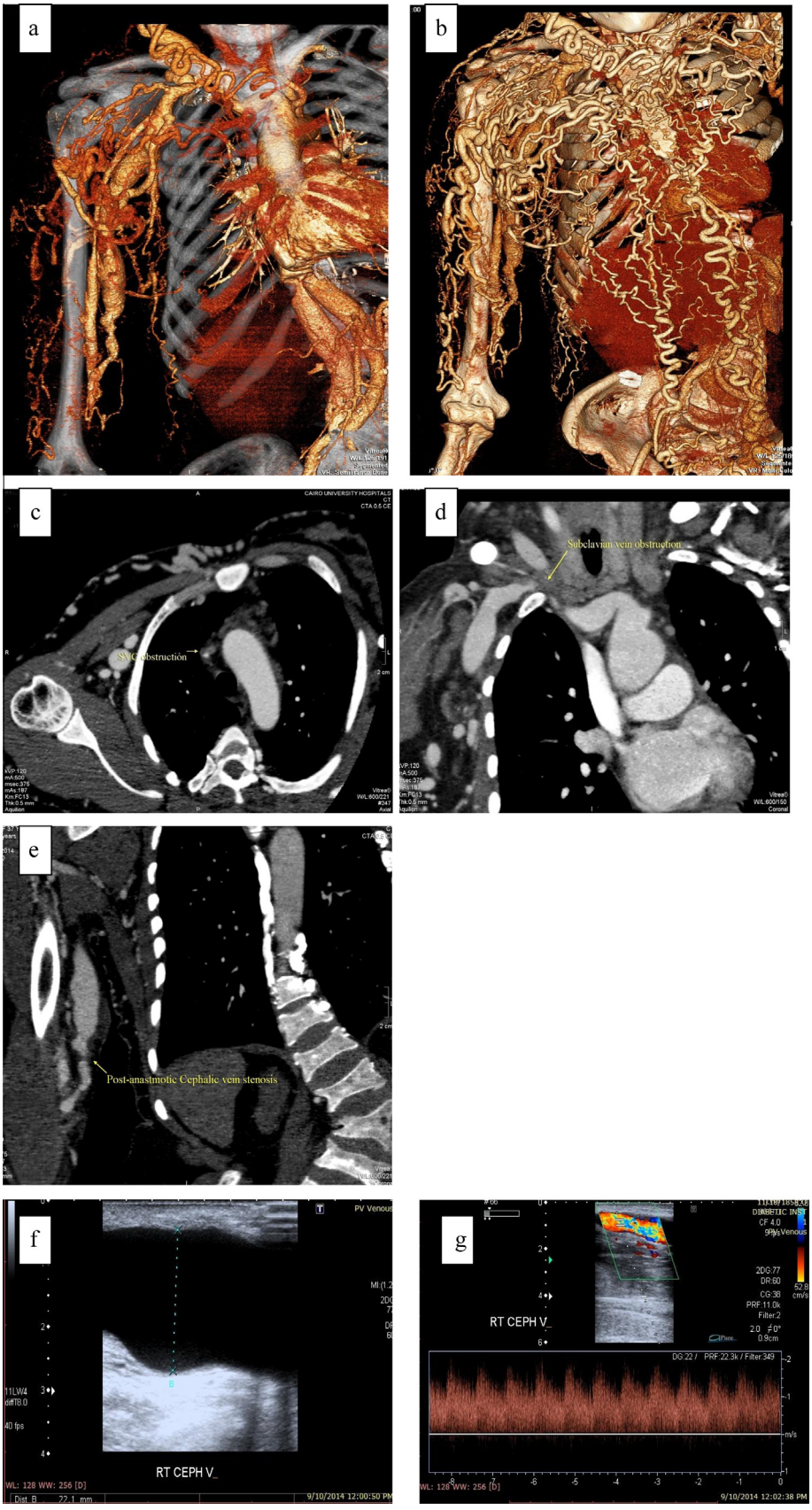

Fig. 2 (a–g): Female patient, 37 years old, with right brachiocephalic fistula complaining of swelling on medial aspect of the arm. (a and b) VRT, (c) axial and (d and e) coronal MPR CTA images revealed patent aneurysmal dilatation of the venous side of the fistula, immediately distal to the site of the fistula with SVC and right subclavian vein obstruction with secondary venous collateralization along chest wall and right upper limb as well as post-anastomotic cephalic vein stenosis. (f and g) CDUS shows aneurysmally cephalic vein (diameter = 2.2 cm), with arterialized waveform distal to the anastomotic site, indicating a well-functioning fistula.

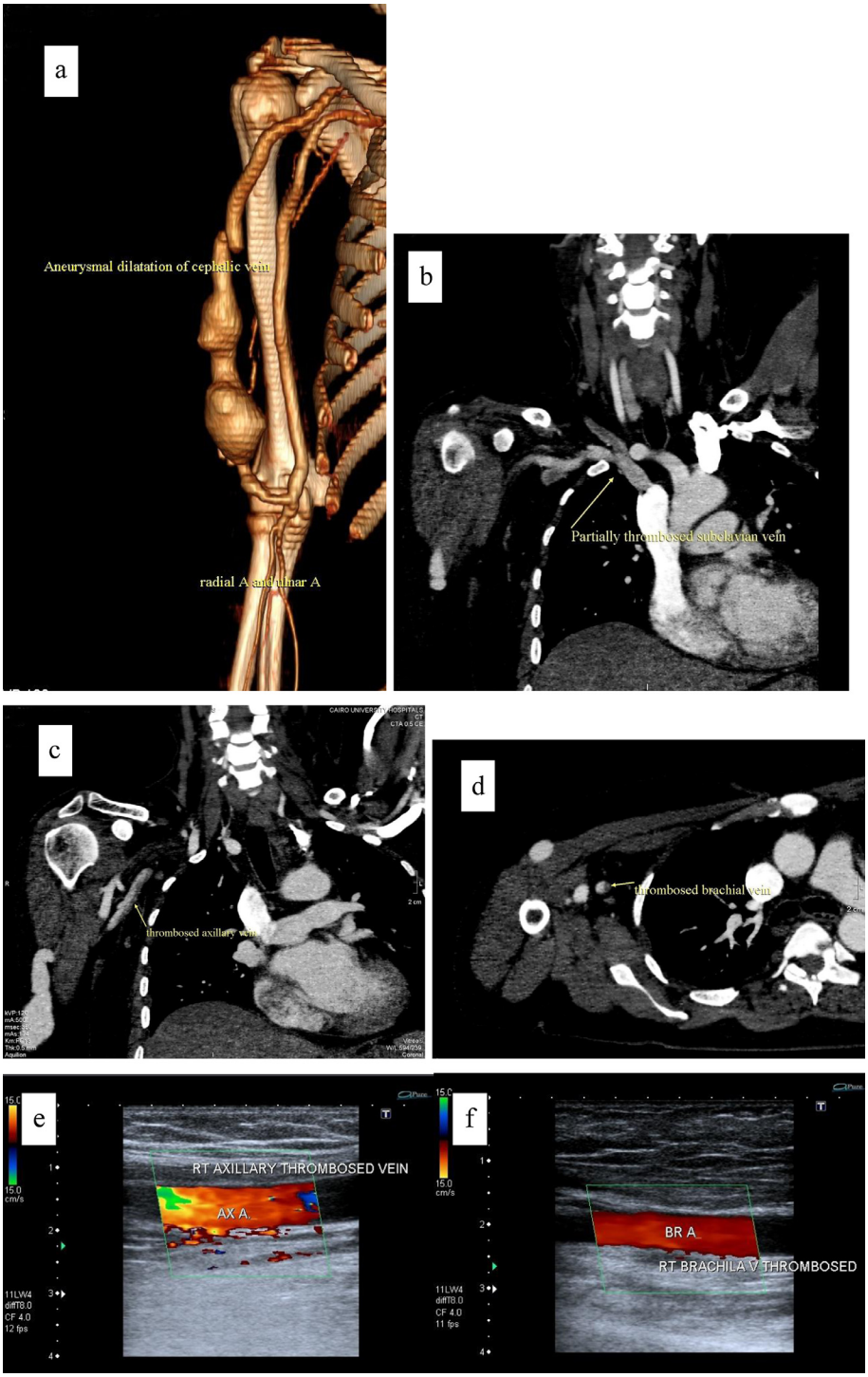

Fig. 3 (a–f): Male patient, 50 years old, with right brachiocephalic fistula complaining of swelling of the arm. (a) VRT, (b and c) coronal and (d) axial MPR CTA images showing two successive aneurysmal dilatations of the cephalic vein with partially thrombosed subclavian, axillary and brachial veins. (e and f) CDUS showing patent right axillary artery and thrombosed right axillary vein as well as patent right brachial artery and thrombosed right axillary vein.

2.5. Color doppler ultrasound procedure

(1) Use enough gel to facilitate visualization.
(2) Doppler ultrasound device was utilized (Elegra; Siemens Medical Systems, Erlangen, Germany) with linear array transducers (5–10 MHz) were used for superficial vascular imaging (the access itself) while curved and phased arrays transducers were used for deeper vascular imaging such as inflow arteries, central veins in the neck and shoulder, or in obese patients.
(3) All vessels were examined in both transverse and longitudinal planes using a representative grey-scale and color images.

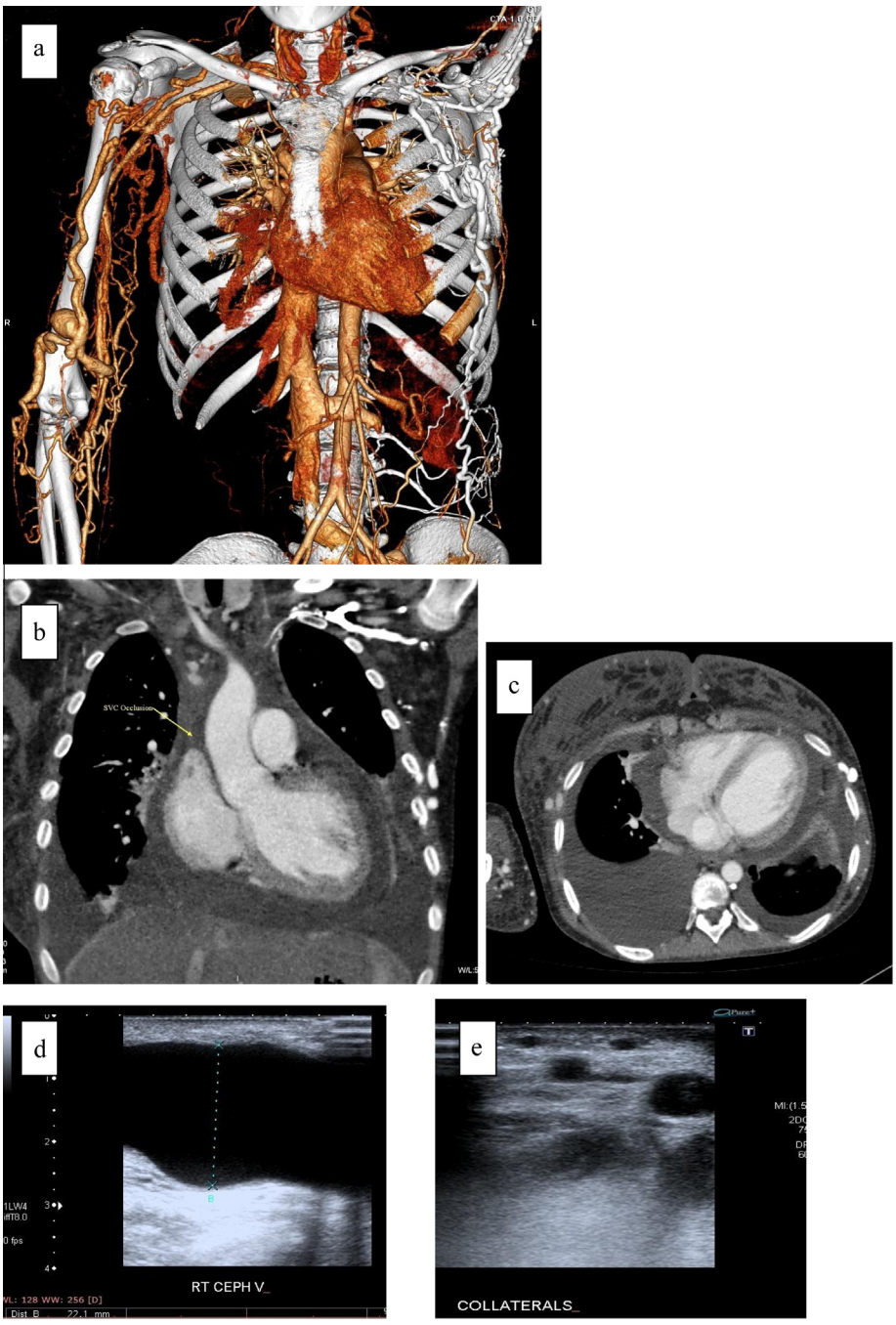

Fig. 4 (a–e): Female patient, 18 years old, with right brachiocephalic fistula complaining of localized swelling at puncture site with dyspnea and dilated veins on the chest wall. (a) VRT, (b) coronal and (c) axial MPR CTA images showing extensive venous collateralization along right upper limb, and a saccular pseudoaneurysm of the cephalic vein at the site of puncture as well as SVC occlusion, pericardial effusion and bilateral pleural effusions, with underlying right lower lobar segmental consolidation collapse. (e and f) CDUS showing aneurysmally dilated and patent right cephalic vein and multiple right upper limb venous collaterals.

(4) Venous study: arm is scanned from proximal to distal. Essential parameters to be measured: venous depth, internal diameter, compliance/ability to dilate, continuity with deep system, presence of stenosis/ thrombosis. Normal change of the signal during deep Inspiration and Expiration (Respiratory filling of the vein) indicates patency of the Superior Vena Cava.

(5) Arterial study: Standard arterial Doppler protocol should be used, with Doppler angle correct of less than or equal to 60 degrees, and parallel to vessel walls. Measured arterial parameters should include internal diameter, presence of calcifications or stenosis, thickness/disease of vessel wall, peak systolic velocity (PSV), end-diastolic velocity (EDV) and flow rate.

(6) Each of the following parameters was measured at the site of AV anastomosis, at the afferent artery and finally at the draining vein.
- PSV cm/s.
- EDV cm/s.
- RI (resistivity index): it reflects the grade of peripheral resistance and is represented by the following formula: RI = (PSV – EDV)/PSV.
- Volume of blood flow at the site of the anastomosis.

2.6. CT angiography protocol

The examination was done with sixty-four multidetector CT scanner (TOSHIBA Medical Systems, Aquillion, Japan).

Compared with central arteries, those of upper limb have a typical slow distal flow because of branching and decreasing diameter of vessels. Thus to opacify native arteries supplying the hand (as in case of AVF stealing blood to peripheral districts), a relatively low flow rate and long post-threshold delay are needed. The acquisition range extended from thoracic outlet to the end of fingers in a dynamic phase in which both the AVF arterial inflow and venous outflow tract up to the right atrium, are filled with contrast.

The bolus-tracking technique was employed, with a region of interest (ROI) placed at ascending aorta.

A post-threshold delay of about 10 s and a flow rate of 3 ml/s were used to obtain proper enhancement. When CT attenuation exceeded 150 HU in the ROI, scanning started in a cranio-caudal direction. 90 ml contrast medium was injected, then followed by 40 ml saline chase.

We tried to minimize patient exposure to contrast medium by scheduling CTA immediately before a dialysis session. We also excluded patients with histories of allergy to contrast. None of the 30 patients we studied experienced an allergic reaction, extravasation of contrast material.

2.7. CTA image interpretation and post-processing

Since hemodialysis AVF contains dilated, tortuous, and displaced vessels, it is difficult to realize its structure basing solely on axial images, although they are useful in evaluating the relationship with extra-vascular structures. Thus post-processing workstation was used for interpretation.

Two-dimensional (2D) image reconstructions, such as maximum intensity projection (MIP), multi-planar reformation (MPR), curved multi-planar reformation (cMPR), as well as 3D volume rendering (VR) techniques, were used interchangeably to complete the evaluation.

3. Results

The most common type of fistula was Brachio-cephalic (53.3%) followed by Radio-cephalic type (40%). Brachio-basilic fistula and Brachio-axillary synthetic graft types were the least common (3.3% for each type).

The study showed 15 patients with shunt related complications; aneurysm 33.3% (10 patients) followed by venous thrombosis 23.3% (7 patients), and arterial steal syndrome 13.3% (4 patients), and finally venous hypertension 6.6% (2 patients).

When considering agreement between both modalities (CTA and Doppler) in detecting various vascular complications Kappa statistics was utilized. Agreement between the two modalities will be based upon the agreement in detecting the type of complication i.e. did both modalities give the same type or not. So positive means that both modalities gave the same diagnosis of complication while negative means that both modalities did not detect complication or gave different diagnosis of complication (Table 1).

Results of Kappa statistic showed poor agreement between the two modalities in detecting the type of complication (kappa = 0.333), however the agreement was statistically significant (*P*-value = 0.014) (see Table 2).

Patent normal proximal vessels (subclavian artery and vein, axillary artery and veins and brachial artery and veins) were detected in all cases by Doppler (100.0%) and in 29 cases (96.7%) by CTA, while patent distal arteries (radial and ulnar arteries) were detected in all cases by Doppler (100.0%) and in only 20 cases (66.7%) by CTA (see Figs. 1–4).

The 10 cases of aneurysms and 3 cases of stenosis were diagnosed positive by the two modalities.

Subclavian vein occlusion was detected in 7 cases (23.3%) by CTA and only 4 out of the 7 cases were detected by Doppler (13.3%).

SVC occlusion was not detected by Doppler (0.0%) while it was detected in 4 cases (13.3%) by CTA.

Chest wall venous collateralization was not detected by Doppler (0.0%) while it was detected in 10 cases (33.3%) by CTA.

When surgery was taken as the gold standard the sensitivity and specificity of CDUS and CTA in detecting aneurysms and stenosis was 100% and 100% respectively. The detection of subclavian occlusion sensitivity and specificity by CDUS was 70% and 85% respectively on the other hand CTA sensitivity and specificity was 100% and 100% respectively. CDUS failed

Table 1 Agreement between CTA and Doppler modalities in detecting complication type.

CTA	Doppler		Kappa statistic	*P*-value
	Positive	Negative		
Positive	5	10	0.333	0.014*
Negative	0	15		

Brachio-cephalic fistulae showed statistically significantly higher prevalence of complications than Radio-cephalic fistulae.
* Significant at $P \leqslant 0.05$.

Table 2 Number of cases with different types of complications.

Type	Number
Complications	
Aneurysm	10
Stenosis	3
Subclavian vein occlusion	7
SVC occlusion	4
Innominate vein occlusion	2
Chest wall collateralization	10
Combined complications	15

to detected central SVC and innominate vein occlusion while CTA demonstrated 100% sensitivity and specificity in this category. CTA revealed partial limitation in detecting patency of distal radial and ulnar arteries due to steal phenomenon with sensitivity and specificity of 60% and 66.6% respectively (Table 3).

4. Discussion

Fistula failure is multifactorial (9). Age, female gender, presence of diabetic nephropathy, start of dialysis with a catheter and failure to wait for initial maturation of the AVF are risk factors and account for the majority of vascular access failures during hemodialysis (10). Arterial and venous stenosis, thrombosis (occlusive and non-occlusive), infection, aneurysm and pseudoaneurysm formation and arterial steal are relatively common abnormalities that can threaten or destroy access function (11).

In our study we found that number of female patients exceeded that of males being 10 male patients and 20 female patients representing 33.3% and 66.7% of all patients respectively.

In this study, we have found that most common AV fistulas were brachio-cephalic (53.3%), followed by radio-cephalic R-C (40%), brachio-basilic and brachio-axillary synthetic graft (3.3% for each of them), which is not similar to those found by Ahmed et al. (12) that showed 80% of AV fistulas to be radio-cephalic and 20% to be brachio-cephalic AV fistulas.

In our study, the complication rates were higher in the brachiocephalic group compared to the radiocephalic group, which is similar to the study of Azman et al. (13). Brachiocephalic fistulae may be preferred on the basis of adequate blood flow and low risk of thrombosis. Although radiocephalic fistulae have high incidence of thrombosis, they lower the risk for steal syndrome, aneurysm and extremity edema Azman et al. (13).

In our study, 10 (33.3%) were male and 20 (66.7%) were female with the ratio 2:1. Out of the 10 male patients, 4 (44%) developed complications while 11/21 (52.4%) female patients developed complications. These results showed that fistulas are less likely to be usable for dialysis in women than in men which correlates with the results of Miller CD et al. (14). One of the possible explanation is that vessels are of smaller caliber in women than in men, and therefore less likely to dilate sufficiently to sustain a blood flow adequate for hemodialysis.

The patients had mean and standard deviation values of renal failure duration of 6.5 ± (5.1) years which is lower than that calculated by Derakhshanfar et al. (15), which showed the mean and standard deviation values of fistula duration to be 3.0 ± (3.7) years.

Our study demonstrated that 15 patients had uncomplicated fistula (50%) and 15 patients had shunt complication (50%). The most frequent complications seen in our patients were aneurysm 33.3% (10 patients), venous thrombosis 23.3% (7 patients) followed by arterial steal syndrome 13.3% (4 patients) and venous hypertension 6.6% (2 patients). These results were in agreement with the study by Yu et al. (16).

The main etiology of ESRD observed in our study was diabetic or hypertensive nephropathy (46.7%) which is lower than that observed by Ahmed et al. (12) & Shemesh et al. (17) who found that 55% of their patients had ESRD secondary to diabetic or hypertensive nephropathy.

Our results showed that the frequency of complications was higher among patients with elbow and right-side AVFs and also among patients with a history of previously failed shunt, as detected by Salahi et al. (18).

The most common complications reported in our study were aneurysm (10 cases) and total thrombosis (7 cases) which is similar to the results of the study of Cavallaro et al. (19).

Stenosis of the hemodialysis vascular access is common and may lead to thrombosis and loss of the access (20). In the present study 3 cases had stenotic lesions, 2 at the venous side of the fistula and the other one at the anastomotic site with percentage of 10% which is lower to the results obtained by Daniel et al. (21).

One of the most frequent complications detected in our patients was aneurysm, which was more common in the elbow group (90%) than in the wrist group (10%), which is agreeable with the study by Yu et al. (16).

Suwitchakul (22) observed steal syndrome in 1.6% and 2% respectively while in our study its rate was 13.3%. Most of our patients with steal syndrome had brachiocephalic fistulae, which is consistent with Tordoir's (23) study.

Suwitchakul (22) reported wound infection in 4.4% and 2% while it was not found in any of our patients, as all examined fistulae were old.

Azman et al. (13) study stated that to create successful arteriovenous fistulae with long-term patency, appropriate veins of patients should be carefully preserved; thus initially a distal site should be preferred, and in case of failure the next fistulae should be created proximally. In case of failure of forearm fistulae, primary fistulae with autogenous veins should be tried at the upper arm first, and if this also fails, fistulae formation with synthetic grafts should be considered.

Table 3 Number of different findings determined at CDUS and CTA versus surgery (sensitivity and specificity).

	CDUS/CTA		Surgery	Sensitivity%		Specificity &	
	CDUS	CTA		CDUS	CTA	CDUS	CTA
Aneurysm	10	10	10	100	100	100	100
Stenosis	3	3	3	100	100	100	100
Subclavian vein occlusion	4	7	7	70	100	85	100
SVC occlusion	0	4	4	0	100	0	100
Innominate vein occlusion	0	2	2	0	100	0	100
Forearm artery patency	30	10	30	100	60	100	66.6

Our study and Cansu et al. (24) considered surgery as a gold standard. Both studies showed complete agreement between CDUS and multidetector CTA on one hand and surgical findings on the other hand in detection of aneurysms and pseudoaneurysm with sensitivity and specificity of 100% and 100% respectively.

Also our study showed complete agreement between CDUS and multidetector CTA versus surgical findings in detection of stenosis at the anastomotic site and at the venous side of the fistula with sensitivity and specificity each 100% however Cansu et al. (24) study showed CDUS sensitivity and specificity to be 74.2% and 90.6% respectively while CTA sensitivity and specificity to be 97.1% and 93.7% respectively.

Cansu et al. (24) stated that central region lesions can be difficult to evaluate accurately because the depth of the vascular structures and bone structures restricts investigation, in addition to the complex anatomy in patients with collateral development. As in our study, there is great difference between effectiveness of CDUS and multidetector CTA in detection of central vein lesions. CTA is superior and concordant with surgical findings in this issue.

Cansu et al. (24) study had shown that color Doppler ultrasound had detected only 1 case out of 5 cases of central vein stenoses, while the multidetector CTA had detected all the 5 lesions. In our study the color Doppler ultrasound could not detect any case of SVC (4 cases) or innominate vein (2 cases) occlusions.

Also, subclavian vein occlusion (7 cases) all were detected by CTA while color Doppler ultrasound detected only 4 out of the 7 cases, which is similar to the study of Doleman et al. (25) where CDUS was unable to identify more than one third of subclavian vein cases.

Heye et al. (26) extended the arm with AVF toward the superior part of the head in half of their cases, while in the other half they extended it over or to the side of the body. Following the extension of the arm with AVF toward the superior of the head, compression developed in proximal veins, and particularly the central veins in the thoracic inlet region. In our study the arm with AVF was pulled toward the contralateral side with the patient's body inside the gantry and a normal anatomical position established. We left a space between the arm with AVF and the body and so artifacts that might form from the body were prevented.

Our study has shown that color Doppler flow imaging is accurate for detecting, locating, and characterizing vascular complications at hemodialysis access sites. Considering the non-invasive nature and high sensitivity and specificity of this modality, some authors consider it the technique of choice for monitoring vascular access function. However, color Doppler imaging has a limited role in evaluation of central venous pathologies due to clavicle and sternum, also it is unable to perform angiographic mapping and it is an operator-dependent test (24).

The recent introduction of MDCT scanners has prompted wider use of CTA for assessing the vascular system. CT angiography (CTA) clearly depicts vessel abnormalities such as stenosis, thrombosis, aneurysms, pseudoaneurysms, calcifications, intimal thickening, stent ingrowth and perivascular complications e.g. seroma and hemorrhage (24).

The factor representing the most important limitation of MDCT angiography is that the patient is exposed to radiation during the procedure and the use of contrast material.

The combined use of the CDUS and CTA techniques will significantly raise the success rate in determination of all AVF lesions being nearly equal to the diagnostic value of surgery as a gold standard.

Conflict of interest

No conflict of interest is declared.

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