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ORIGINAL ARTICLE

Role of Color Doppler Ultrasonography in Evaluation of Hemodialysis AV Fistula

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Abstract

Background: **A significant percentage of the Egyptian population is affected by end-stage kidney disease, which requires long-term hemodialysis. For patients receiving regular hemodialysis, the arteriovenous fistula is now the method most frequently employed to provide vascular access.**

Objective: **The current study's objective was to assess the role and utility of CDUS in assessing vascular access and identifying shunt complications for hemodialysis.**

Patients and methods: **This prospective, randomized controlled trial investigation has been carried out at the Health Insurance Hospital Nasr City's radio-diagnosis department. We included a sample size of thirty patients who needed an arteriovenous fistula in the upper limb for hemodialysis. Patients ranged in age from 8 to 70 and were both male and female.**

Results: **The majority of patients had normal vessel diameters. 6 patients (20%) have a BB fistula, 8 patients (26.7%) have an RC fistula, and 15 patients (50%) have a BC fistula. The study showed a mean age of AVF maturation occurs 2.17 ± 0.379 weeks after its 1st creation. Three patients had an uncomplicated 10% and 27 patients had shunt complications of 90%. The investigation revealed a significant percentage of venous thrombosis (12 patients, 40%), stenosis (9 patients, 30%), aneurysmal dilatation (6 patients, 20%), pseudoaneurysmal formation (3 patients, 10%), and finally steal syndrome (3.3%, 1 patient).**

Conclusion: **Early identification and repair of a failing hemodialysis fistula can improve the quality of hemodialysis treatment. For patients having AV dysfunction, the CDUS results from this series were useful in determining further treatment care.**

Keywords: Color doppler ultrasonography, Hemodialysis AV fistula, Complications of AVF

1. Introduction

Individuals experiencing end-stage renal disease (ESRD) depend heavily on hemodialysis to survive for a long time. Vascular access procedures are necessary to keep them on long-term dialysis.[1]

Dialysis access is most commonly gained through the upper limbs. By joining a vein to an artery (AV fistula or AVF) or by inserting a conduit, typically made of synthetic material, across an artery and a vein (AV graft or AVG), an arteriovenous access (AVA) is made. This creates a high-flow circuit that, when mature enough, could be percutaneously cannulated for hemodialysis access. In regards to higher patency rates, infection-free conditions, and cheaper cost of maintenance, a matured AVF outperforms AVG.[2]

A properly working vascular access has good flow of blood, excellent patency, and enables easy and repeatable cannulation using two needles. The arteriovenous fistula (AVF) offers the best longevity and the lowest mortality and morbidity. Yet, arteriovenous grafts continue to be clinically significant in older individuals for whom AVFs are not possible.[3]

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The vein distended successfully to form an arteriovenous fistula (AV) following surgical formation. Fistula goes through a remodeling process known as maturation. Even though these modifications are somewhat variable, they take place relatively quickly, leading to a fistula that may be used repeatedly and offer appropriate dialysis therapy.[4]

Periodic monitoring is advised following access creation since early access dysfunction discovery and subsequent treatment can assist in lowering the access failure rate. Since they are superficial and provide a thorough assessment by CDU, Doppler ultrasound is the primary imaging method for evaluating dialysis access circuits.[5]

Prior to surgery, vascular mapping for the creation of an AVF is made possible by color doppler ultrasonography, along with evaluation of the optimal time for puncture, early diagnosis of complications, and selection of the most effective treatment techniques for correction.[6]

Duplex ultrasonography is quickly becoming a crucial area of research, and its broad adoption in the future is going to have a significant impact on resources.[7]

It not only provides information on morphological characteristics but also assesses the inflow and outflow. Ultrasound is a low-cost, widely available imaging method that is non-invasive, does not use ionizing radiation, and does not use iodinated contrast medium.[8]

This study's objective was to assess the role of color Doppler ultrasound in pre-operative vascular mapping in hemodialysis arteriovenous fistula (AVF), assess the process of AVF maturation, and comprehensively evaluate possible shunt complications.

2. Patients and methods

This prospective, randomized controlled trial investigation has been carried out at the Health Insurance Hospital Nasr City's radio-diagnosis department. Thirty patients, aged 8–70, male and female, and needing an arteriovenous fistula in the upper limb for hemodialysis, were included in the sample size. The patients were referred by the nephrologist or hemodialysis unit at Health Insurance Nasr City Hospital within a 12-month period from August 2021 to July 2022.

Inclusion criteria: Patients who have been diagnosed with ESRD and require an AFV for hemodialysis include both male and female patients; patients with suspected malfunctioning AVF and requiring new creation of AVF at another site by the dialysis center; and follow-up patients for outcome.

Exclusion criteria: There were no exclusion criteria.

2.1. Equipment and supplies

Transducers could be curved, linear, or phased array with B-mode and Doppler mode ultrasound scanners that incorporate real-time display of both two-dimensional structure and motion with spectral analysis with or without color Doppler imaging and an imaging carrier frequency of at least 5–10 MHz with a minimum Doppler carrier frequency of 3.0 MHz.

2.2. Patient assessment

Prior to doing an assessment of the dialysis access, the patient must be assessed. All patients underwent the following:

Explain the process to the patient while keeping in mind the patient's age and mental state, and make sure the patient understands the importance of each part of the assessment.

Obtain a comprehensive, pertinent history by interviewing the patient or a representative of the patient and reviewing the patient's medical records. The present medical state (involving the state of present dialysis), history of prior operations or invasive procedures including the afflicted arm or neck, present drugs or treatments, recent or prior operations on the fistula/graft limb, as well as a history of venous thrombosis (involving the central veins) were noted.

Prior to CDUS examinations, all patients had a clinical assessment of their dialysis access. A thrill's ability to be felt throughout the access as well as its strength and consistency were used to determine its access patency. Visual examination of the limb and access site was performed to detect areas of swelling and redness, as well as the presence of collateral vessels, dilatation, and palpable conspicuous localized regions of pulsations (implying pseudo aneurysm).

2.3. Doppler ultrasound examination

Greyscale and color Doppler ultrasound machines featuring high frequency transducers (8–10 MHz) were used to perform CDUS examinations. Gloves, acoustic coupling gel, and skin wipes are standard equipment for ultrasound exams. Most frequently, the patient was positioned so that the area to be assessed was closest to the sonographer while lying on his or her back with an arm out to the side and relaxed. It is possible to examine the patient while they are sitting or in the Trendelenburg position with their hands over their heads. The patient's position ought to be optimized so that gravity can aid in vein dilation.

Examinations comprised the afferent artery, the anastomosis site, the draining veins up to the subclavian vein, and the arterial tree distal to the AVF in patients with steal syndrome.

Utilizing grayscale and color images, all vessels have been inspected in both longitudinal and transverse planes. First, the vessels have been inspected using B-mode to identify the site and type of the fistula; detection of wall echo pattern and dilations; and measurement of the vessel's diameter. Following that, color images have been acquired to evaluate the blood flow direction. Finally, Doppler studies were performed, in the longitudinal orientation. The wall filter has been adjusted to 50–100 Hz, and the sample size has been kept under 5 mm and placed in the center of every vessel.

Angle correction was applied to the spectral waveform, and the Doppler angles of incidence have been under 60°. Then, spectral waveforms were obtained at each level. The arterial diameter was 2 cm proximal to the site of the fistula and the diameter of the fistula, PSV, and EDV. The proximal, mid, and distal outflow veins were then examined for diameters, patency, and mean velocities. The degree of the stenosis was calculated when there was stenosis. Waveforms and PSVs were documented in any region where there was an increase in velocity or turbulence. Stenosis was diagnosed when the vessel diameter decreased by more than 50% and the PSV ratio increased (PSV in the stenotic region/PSV upstream of the stenotic region) to more than 2:1 in the vein that drains or more than 3:1 in the anastomotic region.

2.4. Methodology

Patients who have upper limb AVFs will have US Doppler exams every 12 months to detect late complications, which are summarized as follows.Clinical Signs and Symptoms of an Insufficient A-V Fistula like Poor of arterial flow with hemodialysis, thrill sensation, distal tingling, numbness and pain during hemodialysis, impaired fistula, clinical suspicion of infection and dilatation superficial veins. US mode Scan as site of fistula, type of fistula, afferent artery, arterial wall echo pattern, draining vein, diameter fistula, distance of fistula from skin, echogenic thrombus formation, aneurysm, pseudo-aneurysm, stenosis, hematoma, and steal phenomena or syndrome. Color and Power Doppler mode scan as normal blood flow, Yin-yang pattern, aliasing, black zone in the lumen, PSV cm/sec, TAMV cm/sec, blood flow volume ml/min, and the distal arterial tree have been checked in cases experiencing steal syndrome.

2.5. Statistical analysis

The Statistical Package for Social Sciences (SPSS) version 22 for Windows® (IBM SPSS Inc, Chicago, IL, USA) was used to code, process, and analyse the obtained data. To determine whether the data was normally distributed, the Shapiro-Wall test was used. Frequencies and relative percentages were employed to represent qualitative data. Use the Chi Square Test ($\chi 2$) to determine the difference between two or more sets of qualitative variables. Quantitative data has been presented as mean ± SD (Standard deviation). The independent samples *t*-test has been developed to compare two independent sets of normally distributed variables (parametric data). A *P* value of less than 0.05 has been regarded as significant.

3. Results

The study included 30 patients. It was conducted in radiology department of Health Insurance Hospital Nasr-City. Mean age of patients was 40.84 ± 9.984 (Mean ± SD) with minimum of 8 years old and maximum of 70 years old. fourteen of our sample were males and 16 were females (Table 1).

Among 30 patients with ESRD for AVF evaluation, 24 patients (80%) presented with poor of arterial flow with HD, 15 patients (50%) did not have thrill sensations and 9 (30%) patients had week thrill sensation, 1 patients (3.3%) showed distal tingling, numbness and pain during HD, 15 patients (50%) had impaired fistula and 9 patients (30%) had week impaired fistula, 1 patients (3.3%) showed clinical suspicion of infection, and 5 patients (16.7%) had dilated superficial veins (Table 2).

Among 30 patients with CDUS evaluated of AVF and detected complications, regarding the fistula site, 8 patients (26.7%) had brescia-cimino fistula, 1 patient (3.3%) had brachio-brachial fistula, 6 patients (20%) had upper arm basilic, and 15 patients (50%) had upper arm cephalic. Regarding the fistula type, 6 patients (20%) had brachio-basilic, 1 patient (3.3%) had brachio-brachial, 15 patients (50%) had brachio-cephalic, and 8 patients (26.7%) had radio-cephalic fistula. Regarding the draining vein, 6 patients (20%) had basilic vein, 1 patient (3.3%) had brachial vein, and 23 patients (67.6%) had cephalic

Table 1. Demographic characteristics of the study participants.

Patients variables	Numbers (%)
Sex	
Male	14 (46.7)
Female	16 (53.3)
Age	
Mean ± SD	41.84 ± 9.984
Median (IQR)	40(39.75–56)

vein. Regarding the afferent artery, 22 patients (73.3%) had brachial artery and 8 patients (26.7%) had radial artery (Table 3).

Additionally, 9 patients (30%) had weak blood flow, 15 patients (50%) had abnormal blood flow, 3 patients (10%) had a Yin-yang pattern, 23 patients (46) had a black zone in the lumen, 15 patients (30%) were aliasing, and 1 patient (2%) had abnormal results in examination of the distal arterial tree where PSV decreased in patients experiencing steal syndrome and increased with occluded fistula (Table 4).

Among 30 patients with CDUS evaluated through specific parameters including, mean of diameter fistula 9.90 ± 12.121 (Mean ± SD) with minimum 2 mm and maximum 45 mm, distance of fistula from skin 6.56 ± 4.272 (Mean ± SD) with minimum 3 mm and maximum 30 mm, PSV 25.66 ± 29.893 (Mean ± SD) with minimum 0 cm/s and maximum 90 cm/s, time averaged mean velocity (TAMV) 24.40 ± 28.638 (Mean ± SD) with minimum 0 cm/s and maximum 80 cm/s and blood flow volume rate 349.88 ± 732.409 (Mean ± SD) with minimum 0 ml/min and maximum 4775 ml/min (Table 5).

Table 2. Clinical symptoms and sign of insufficiency AVF.

Patients variables	Numbers (%)
Poor of arterial flow with hemodialysis	
No	6 (20)
Yes	24 (80)
Good	6 (20)
Thrill sensation	
No	15 (50)
Week	9 (30)
Distal tingling, numbness and pain during hemodialysis	
No	29 (96.7)
Yes	1 (3.3)
No	6 (20)
Impaired fistula	
Week	9 (30)
Yes	15 (50)
Clinical suspicion of infection	
No	29 (96.7)
Yes	1 (3.3)
Dilated superficial veins	
No	25 (83.3)
Yes	5 (16.7)

Table 3. AVF types of the study patients.

Patients variables	Numbers (%)
Brescia-cimino	8 (26.7)
Site of fistula	
Brachio-brachial	1 (3.3)
Upper arm basilic	6 (20)
Upper arm cephalic	15 (50)
brachio-basilic	6 (20)
Type of fistula	
brachio-brachial	1 (3.3)
brachio-cephalic	15 (50)
radio-cephalic	8 (26.7)
Basilic	6 (20)
Draining vein	
Brachial	1 (3.3)
Cephalic	23 (67.6)
Afferent artery	
Brachial	22 (73.3)
Radial	8 (26.7)

Table 4. Color and power mode US scan of the study patients.

Patients variables	Number (%)
No	15 (50)
Normal blood flow	
Week	9 (32)
Yes	6 (18)
Yin-yang pattern	
No	27 (90)
Yes	3 (10)
Black zone in the lumen	
No	18 (60)
Yes	12 (40)
Aliasing	
No	20 (70)
Yes	10 (30)
Distal arterial tree	
Normal	29 (27.7)
Abnormal	1 (3.3)

The total complications frequencies were 34 among 30 patients, venous thrombosis was found in 12 patients (40%), stenosis was found in 9 patients (30%), aneurysm was found in 6 patients (20%), pseudoaneurysm was found in 3 patients (10%), hematoma was found in 2 patients (6.7%), clinical suspicion of infection was reported with 1 patient (3.3%), and steal phenomenon/syndrome was found in 1 patient (3.3%) (Table 6) Figs. 1 and 2.

Table 5. Parameters of AVF of study patients by CDUS.

Parameters	Mean	SD	Median	IQR
Diameter fistula	9.90	12.121	5	4–6.5
Distance of fistula from skin	6.56	4.272	6	5–6
PSV	25.66	29.893	19	0–42.5
TAMV	24.40	28.638	16.5	0–41.5
Blood flow volume ml/min	349.88	732.409	154	0–379

IQR, interquartile range.

Table 6. Different complications of AVF of the study patients.

Patients Variables	Number (%)
Clinical suspicion of infection	
No	29 (96.7)
Yes	1 (3.3)
Venous thrombosis	
No	16 (60)
Yes	12 (40)
Aneurysm	
No	24 (80)
Yes	6 (20)
Pseudoaneurysm	
No	27 (90)
Yes	3 (10)
Stenosis	
No	21 (70)
Yes	9 (30)
Hematoma	
No	28 (93.3)
Yes	2 (6.7)
Steal phenomenon or syndrome.	
Yes	1 (3.3)
No	29 (97.7)

4. Discussion

The most frequent shunt complications linked to HD in our study population were access venous thrombosis (40%), and stenosis (30%). Thrombosis is usually found in the AVF's arteriovenous anastomosis. In our investigation, thrombosis was found at the anastomosis site and on the venous side of the fistula. Thrombosis was diagnosed by the absence of flow utilizing color or pulsed Doppler in conjunction with an echogenic or hypoechoic thrombus that filled the lumen.

Aneurysms occurred in 20%. An AVF's increased blood flow leads to a continuous increase in vessel size. When a fistula displayed a significant amount of aneurysmal alteration, downstream venous stenosis was suspected or associated with thrombosis. Skin thinning was carefully assessed because it may cause serious hemorrhaging, ulceration, and rupture. A sudden increase in a vessel's caliber (greater than 2 cm) is one of the characteristic sonographic features

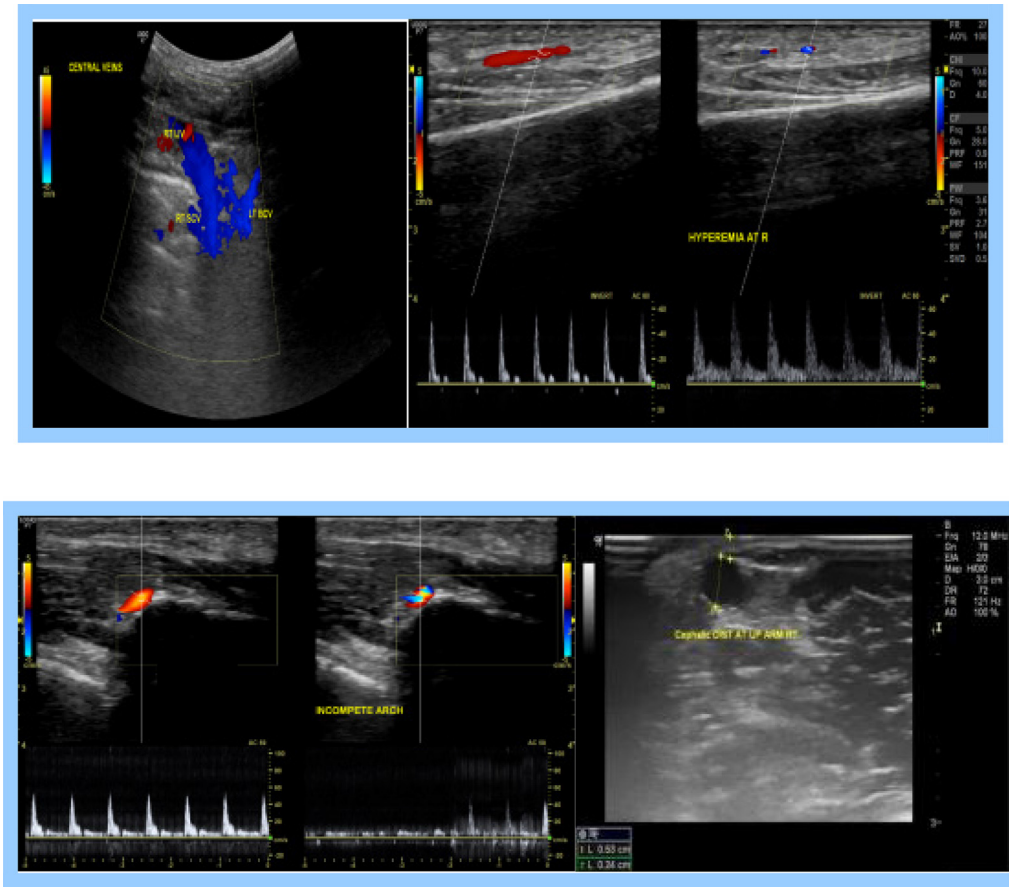

Fig. 1. Vascular mapping for normal arterial and venous duplex study with bilateral incomplete palmar arch of Female Patient 45 years old with CRF. (a) Patent central veins. (b) Normal arterial hyperemia response. (c) Duplex Allen test shows bilateral incomplete palmar arch. (d) patent compressible cephalic vein with average diameter 5 mm.

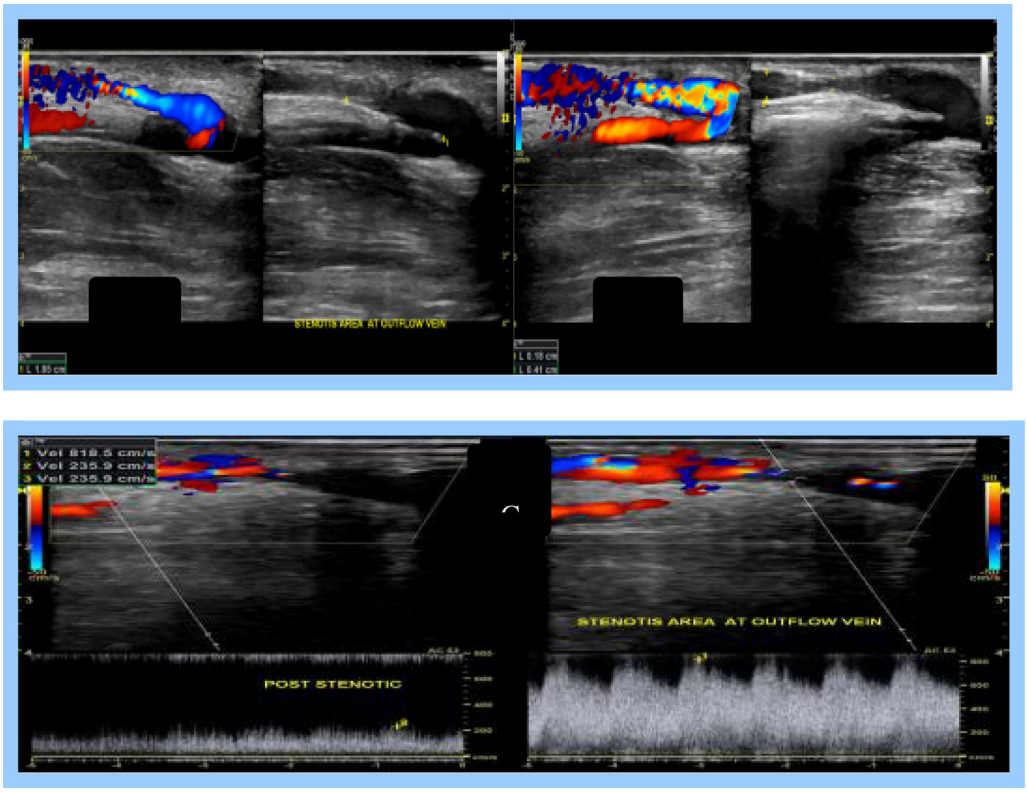

Fig. 2. Significant Juxta-anastomotic stenosis of right radio-cephalic fistula of Female patient 13 years old had right radio-cephalic fistula. (a) cephalic vein which show diameter reduction <50% with distance about 2 cm from the anastomosis at (juxta-anastomotic area) and measure about 1.6 mm at the narrowest area. (b) Focal aliasing and visible color bruit artifact at juxta-anastomotic area (the most common stenotic area. (c) Doppler study reveals monophasic low resistant flow with markedly elevated velocity measure 820 cm/s at stenotic area while post stenotic velocity measure 235 cm/s having a velocity ratio <3 (significant stenosis).

of vein aneurysms. Usually, sonography may identify thrombosis within an aneurysm.[9]

Pseudoaneurysms (10%) occurred at the anastomoses or the puncture sites. When an AVF is punctured, either naturally during dialysis or as a result of intervention, it causes persistent hemorrhage and the formation of pseudoaneurysms. It was less obvious how true aneurysms formed in AVFs, though. This could be due to repetitive needling, which led to the creation of numerous small fibrous scars in the walls of the vessels that expanded over time and produced localized aneurysmal regions.[10]

The proper diagnosis of aneurysms and pseudoaneurysms is usually made based on the clinical findings of a pulsatile mass as well as a systolic murmur. However, CDUS is of the most 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 pseudoaneurysms from hematomas as they have a typical "to-and-fro" pattern.[11] In this study, 30% of patients had aneurysms and pseudoaneurysms. CDUS was useful to determine the aneurysm's extent and evaluate the presence of luminal thrombus, as well as to determine if the patient requires surgery or not.

In this study, steal phenomenon or syndrome occurred in approximately 6% and 10–20% of patients with forearm and arm fistulas, respectively. It frequently occurs in fistulas with big anastomoses and lots of flow. Clinical symptoms and signs ranged from pallor, mild paresthesia, coldness, and pain during dialysis to more severe ones such as pain while at rest, palsy, ulceration, necrosis of tissues, and loss.

Steal syndrome happens when the radial artery section distal to the AVF anastomosis exhibits flow inversion. This indicates that the AVF is stealing blood from the hand/palmar arch. In both color and pulsed mapping, it is distinguished by a significant decrease in flow or a change in flow direction via the arterial segment distal to the AVF. In the ulnar artery, we can also detect a biphasic flow rather than the normal triphasic flow.[12]

When compensatory mechanisms for maintaining peripheral arterial perfusion are ineffective, the steal phenomenon becomes a steal syndrome. Age greater than 60 years, diabetes mellitus, and female gender

constitute risk factors for steal syndrome. The steal syndrome is distinguished by mostly acral necrosis and even loss of tissues, ulcerations, pain at rest, and pain during hemodialysis sessions. The difficulty is to detect individuals who are at risk for access-induced ischemic steal syndrome using CDU before creating the fistula.[13]

In this study, PSV of the ulnar and radial arteries decreased when the fistula was functional and afterwards elevated when it was blocked. When the velocity ratio (PSV fistula blocked/PSV fistula working) exceeded 2, steal syndrome was taken into consideration.

Approximately 20% of all AVF complications are infections, with perivascular cellulitis being the most prevalent infection and one that is typically treated easily. This infection appears as localized erythema and edema. An infection linked to anatomical defects, like aneurysms, hematomas, or abscesses, that need surgical removal and drainage, is even more dangerous.[14]

The formation of a hematoma, whether it is accompanied by active hemorrhage or not, may necessitate surgical examination of the wound. There are numerous situations which might arise. The functionality of the fistula could not be impacted by a hematoma if there was no active hemorrhage through the sutures. There's no surgical indication in the case of a small hematoma and the presence of the AVF's thrill; the patient is instead followed continuously. If the hematoma is bigger as well as the thrill is altered or missing, the hematoma should be evacuated, followed by the closure of the hemorrhage source and the repermeation of AVF. Occasionally, eliminating the hematoma can restore the thrill; if this doesn't work, the AVF can be thrombectomy, or perhaps a new AVF should be constructed.[15]

Hematoma was found in 6% and local infection in 3%. Infection was indicated by tenderness and erythema across the access. Untreated access infection results in bacteremia, sepsis, bleeding, and, if untreated, death.[16]

4.1. Conclusion

An AVF's anatomy and hemodynamics can be evaluated with CDUS, a noninvasive technique. This method can be employed at the bedside, is inexpensive, and has no known risks. The AVF lumen is defined by CDUS, which also makes it possible to define its dimensions and identify luminal encroachment. The procedure also offers valuable data to the surgeon, which may lead to an increase in the number of AVF reconstructions instead of new shunts.

Conflicts of interest

The authors declared that there were NO conflicts of Interest.

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