Role of perioperative vein diameter and flow volume change rate on predicting primary functional maturation of autogenous arteriovenous fistula

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Introduction
The patients on regular hemodialysis prefer the arteriovenous fistula (AVF) as their vascular access for dialysis. The goal of AVF surgery was to increase the proportion of dialysis patients who use native AVFs. The success of AVF surgery is mainly dependent on the upper limb's vasculature. Therefore, improved selection of the most appropriate procedure must be coupled with early access surveillance to determine which access would likely mature and when intervention might lead to access salvage.

Aim
This study aimed to determine the various vascular parameters (vein diameter and flow volume) both preoperatively and postoperatively at prespecified intervals – irrespective of other variables – for optimal hemodynamics of AVFs and their primary functional maturation.

Materials and methods
This prospective cohort study was conducted at Ain Shams University Hospitals on 80 patients with end-stage renal disease on regular dialysis submitted for autogenous AVF from November 2020 to November 2021.
Cephalic vein diameter, basilic vein diameter, as well as both brachial and radial artery diameters, flow, and peak systolic velocity from the wrist to the proximal upper arm were all measured using ultrasound with Doppler preoperatively and postoperatively at postoperative day 1 (POD 1), 6 weeks, and 3 months.

Results
In all, 80 patients (54 brachiocephalic BC AVF, 18 radiocephalic RC AVF, 8 brachiobasilic BB AVF) were evaluated with a mean age of 54.65±12.24. The male : female ratio was 1 : 1.1. The etiology of renal failure was diabetes related in 36.3%, and the remaining 73.7% were nondiabetic. The overall maturation rate was 81.25%, with 18.75% failure to mature rate. In comparison between different groups of fistulas, a significant difference was found in comparing the preoperative and postoperative vascular diameter and flow rates between the groups. The mean preoperative cephalic vein diameter in mature RC AVF was 2.59±0.55 mm with the mean flow volume at POD 1 being 265.83±61.46 ml/min. The mean preoperative cephalic vein diameter in mature BC AVF was 3.21±0.70 mm with the mean flow volume at POD 1 being 311.79±93.25 ml/min. The mean preoperative basilic vein diameter in mature BB AVF was 3.08±0.95 mm with the mean flow volume at POD 1 being 319.60±45.67 ml/min.

Conclusion
On the basis of this study, flow volume at POD 1 can be used as a predicting factor for RC and BB AVF maturation. Also, perioperative vein diameter change can be used as a predictor for RC AVF maturation. However, none of these parameters can be used as a predicting factor for maturation in BC AVF. Therefore, further studies of large size are recommended to standardize these parameters.

Keywords:
arteriovenous fistula, AVF maturation, Doppler ultrasound, flow volume, vein diameters

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Introduction

The arteriovenous fistula (AVF) is the most preferred vascular access in maintenance hemodialysis patients [1]. However, a significant proportion (up to 30%) of fistulae fail early, within 3 months of surgery [2]. Some

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fistulae thrombose in the first 24 h of the operation, usually due to technical errors, and others do not mature or become functionally usable as the blood flow through them is not sufficient enough for dialysis.

The cause of early failures is often unclear, although the status of the vessels is thought to play an important role. Small-sized, stenosed, or partially thrombosed cephalic and basilic veins or atherosclerotic or small-sized brachial and radial arteries have been suggested as possible causes [3]. Keeping these in view, it may be wise to perform preoperative mapping and a follow-up in the postoperative period with the help of a noninvasive, readily available, repeatable, reproducible, cost-containing method as ultrasound Doppler with color flow evaluation, which is helpful in assessing the outcomes of AV fistula creation. Here, we bring our approach and results of upper limb autogenous arteriovenous fistulas undertaken during the study period.

Aim

This study aimed to determine the various vascular parameters (vein diameter and flow volume) both preoperatively and postoperatively at prespecified intervals – irrespective of other variables – for optimal hemodynamics of AVFs and their primary functional maturation.

Materials and methods

Our prospective cohort study included 80 patients with end-stage renal disease (ESRD) on regular dialysis submitted for autogenous AVF from November 2020 to November 2021 at Ain Shams University Hospitals. Patients whose vascular anatomy did not promote the construction of a native AVF (on preoperative Doppler) were excluded. The criteria used for selection based on clinical examination included a modified Allens test and ultrasound study for vessel status of upper limb arterial and venous systems.

Inclusion criteria: ages 18–70 years, ESRD, and both sexes.

Exclusion criteria: peripheral vascular diseases, central venous diseases, hypotension, sclerosed or thrombosed superficial veins, and deep venous thrombosis in upper limbs; patients underwent primary assisted maturation.

Patients underwent detailed history taking and clinical assessment for possible native AV fistula creation. The study participants were informed about the protocol and the necessity of regular follow-up for the completion of the study, and written consent was taken. The authors certified that they had obtained all patient consents. In the form, the patients had permitted their images and other clinical data to be reported in the journal. The patients understand that their names will not be published, but anonymity cannot be guaranteed. The study was conducted after approval of the Institutional Research and Ethics Committee. The patients' upper limb vessel status, including arterial and venous systems, was recorded preoperatively and postoperatively by a Doppler ultrasound. The cephalic vein, basilic vein, brachial artery, and radial artery were imaged from the wrist to the proximal upper arm to note any stenosis/thrombus in the vessel. Both brachial and radial arterial flow were recorded. Follow-up after surgery was done on day 1, at 6 weeks, and at 3 months (maximum time interval required for AVF maturation), using a color Doppler ultrasound (Esaote MyLab40 with 10 MHz linear-array transducer, Genoa, Italy). Arteries were assessed for course, caliber, depth from the skin, flow direction, patency, and Doppler spectral wave patterns at the arm and the forearm.

Similarly, veins were evaluated at specific checkpoints. For ease of conceptualization, the examination follows blood flow, beginning with the feeding artery and moving through the anastomosis and draining vein. The examination should include the draining subclavian veins for stenosis or occlusion of this vein secondary to the previous temporary catheter. The native artery distal to the AVF is evaluated for patency, the direction of flow, depth from the skin, and flow characteristics like peak systolic velocity (PSV). The examination was performed in both longitudinal plane and transverse plane; spectral waveforms were obtained at each level with color Doppler, and flow volume across the fistula was calculated.

The formula used to calculate flow volumes is area×mean velocity×60, where area is the cross-sectional area of the blood vessel in square centimeters (as the vessel is cylindrical, its cross-sectional area is calculated as the square of the radius×3.14); mean velocity (in cm/s) is measured from the Doppler trace recorded at the site of measuring area, and 60 is the number of seconds in a minute [4].

As for the sampling site, the arterialized vein is punctured during hemodialysis, so the outflow vein of the AVF should be an ideal site for measuring the vascular access flow volume. However, measurements at this level are relatively imprecise because this vein can be easily compressed with the probe. In addition, its diameter varies widely due to its tortuous course and the presence of collateral circuits. These variations make it difficult to calculate the vessel's cross-sectional area with any degree of precision. Moreover, the calculation of the mean velocity is complicated by the turbulent flow that characterizes the venous side of the AVF [5]. For these reasons, measuring the flow volume at the inflow artery level improves accuracy and reproducibility. However, measuring the flow volume of a distal AVF at the level of the radial artery can lead to underestimation because a variable portion of the fistula flow (~25–30%) may come from the ulnar artery through the palmar arch. This 'reverse flow' occurs if the diameter of the anastomotic chamber is more significant than that of the artery that supplies the arterial blood to the fistula [6]. Therefore, in clinical practice, the brachial artery is the preferred site for measuring the flow volume of distal and proximal/proximalized AVFs, for several reasons. It is easy to sample and does not collapse under normal transducer pressures. In addition, just above the elbow crease, there is an oblique segment of the brachial artery, where the sample volume can be easily positioned at an appropriate insonation angle. Finally, its laminar flow allows one to record suitable tracings for precisely calculating the mean velocity [7].

A matured fistula was defined as a fistula used successfully for dialysis or incorporated in the K-DOQI Guidelines as 'the Rule of 6'. It identifies the ultrasound characteristics that confirm that a fistula is mature and, therefore, ready for use: a flow volume of 600 ml/min, an outflow vein diameter of more than 6 mm, and an outflow vein depth of less than 6 mm below the skin surface [8].

Statistical analysis

Statistical analysis was done using IBM SPSS software package version 20.0 (IBM Corp., Armonk, New York, USA). Qualitative data were described as percentages and numbers. The Kolmogorov–Smirnov test and Shapiro–Wilk test were used to verify the normality of distribution. Quantitative data were described using range, mean, SD, median, and interquartile range. Mann–Whitney *U*-test or Student's *t*-test, or Friedman test was used for analysis depending on the distribution of variables, and the χ^2-test or Fisher's exact or Monte–Carlo correction was used for comparing categorical variables; *P* value less than 0.05 was considered statistically significant.

Results

Our prospective cohort study was conducted on 80 patients with ESRD on regular dialysis for 12 months. The mean age of the patients was 54.65±12.24. The male : female ratio was 1 : 1.1. The etiology of renal failure was diabetes related in 36.3%, and the remaining 73.7% were nondiabetic. The comorbidities were hypertension in 77.5%, diabetes in 36.3%, ischemic heart disease in 22.5%, and hyperlipidemia in 36.3%, with none of them showing any statistically significant difference in terms of AVF maturation.

Of 80 fistulas that entered our study, there were 24 right-sided access and 56 left-sided access. Eighteen (radiocephalic fistula) RCF, 54 (brachiocephalic fistula) BCF, and 8 (brachiobasilic fistula) BBF as shown in Table 1 with an overall maturation rate of 81.25 and 18.75% failure to mature rate. Also, steal syndrome was detected in four cases while nine AVFs were thrombosed during the follow-up period.

As regards the radiocephalic fistula group, the maturation rate was 66.7%. The mean cephalic vein diameter in those mature fistulae was 2.59±0.55 mm preoperatively [with 1.38±0.47 mm increase at postoperative day (POD) 1] and 1.87±0.15 mm in those with a nonmature AVF (with 0.75±0.23 mm increase at POD 1). The mean flow volume of mature fistulae at POD 1 was 265.83±61.46 ml/min compared with 141.50±33.74 ml/min in those with a nonmature AVF as shown in Table 2.

As regards the brachiocephalic fistula group, the maturation rate was 88.9%. The mean cephalic vein diameter in those mature fistulae was 3.21±0.70 mm preoperatively (with 1.16±0.47 mm increase at POD 1) and 2.48±0.84 mm in those with a nonmature AVF (with 0.80±0.40 mm increase at POD 1). The mean flow volume of mature fistulae at POD 1 was 311.79 ±93.25 ml/min compared with 237.67±97.79 ml/min in those with a nonmature AVF as shown in Table 3.

Table 1 Number of patients with mature and nonmature AVF in each group

	Total AVF	Mature AVF	Rate of maturation	Nonmature AVF	Rate of FTM
RCF	18	12	66.7	6	33.3
BCF	54	48	88.9	6	11.1
BBF	8	5	62.5	3	37.5

AVF, arteriovenous fistula; BBF, brachiobasilic fistula; BCF, brachiocephalic fistula; FTM, failure to mature; RCF, radiocephalic fistula.

Table 2 Preoperative and postoperative parameters in the radiocephalic fistula (RCF) group

	Mature AVF		Nonmature AVF		
	Mean±SD	Median	Mean±SD	Median	*P* value
Preoperative cephalic vein diameter (mm)	2.59±0.55	2.50	1.87±0.15	1.80	0.001
Increase in vein diameter at POD 1	1.38±0.47		0.75±0.23		0.005
Flow volume at POD 1 (ml/min)	265.83±61.46	253.0	141.50±33.74	124.50	<0.001
Preoperative radial artery diameter (mm)	2.43±0.33	2.35	2.03±0.34	1.95	0.034
Flow velocity in radial artery (cm/s)	42.42±4.34	43.0	37.17±4.07	35.5	0.025

AVF, arteriovenous fistula; POD 1, postoperative day 1.

Table 3 Preoperative and postoperative parameters in the brachiocephalic fistula (BCF) group

	Mature AVF		Nonmature AVF		
	Mean±SD	Median	Mean±SD	Median	*P* value
Preoperative cephalic vein diameter (mm)	3.21±0.70	3.20	2.48±0.84	2.30	0.035
Increase in vein diameter at POD 1	1.16±0.47		0.80±0.40		0.058
Flow volume at POD 1 (ml/min)	311.79±93.25	299.5	237.67±97.79	196.0	0.071
Preoperative brachial artery diameter (mm)	3.50±0.61	3.60	3.56±0.39	3.60	0.794
Flow velocity in brachial artery (cm/s)	62.89±7.64	63.0	61.78±4.44	61.0	0.549

AVF, arteriovenous fistula; POD 1, postoperative day 1.

Table 4 Preoperative and postoperative parameters in the brachiobasilic fistula (BBF) group

	Mature AVF		Nonmature AVF		
	Mean±SD	Median	Mean±SD	Median	*P* value
Preoperative cephalic vein diameter (mm)	3.08±0.95	3.20	2.57±0.40	2.50	0.571
Increase in vein diameter at POD 1	1.22±0.94		0.67±0.35		0.393
Flow volume at POD 1 (ml/min)	319.60±45.67	333.0	184.33±34.93	204.0	0.036
Preoperative brachial artery diameter (mm)	3.50±0.61	3.60	3.56±0.39	3.60	0.794
Flow velocity in brachial artery (cm/s)	62.89±7.64	63.0	61.78±4.44	61.0	0.549

AVF, arteriovenous fistula; POD 1, postoperative day 1.

As regards the brachiobasilic fistula group, the maturation rate was 62.5%. The mean basilic vein diameter in those mature fistulae was 3.08±0.95 mm preoperatively (with 1.22±0.94 mm increase at POD 1) and 2.57±0.40 mm in those with a nonmature AVF (with 0.67±0.35 mm increase at POD 1). The mean flow volume of mature fistulae at POD 1 was 319.60 ±45.67 ml/min compared with 184.33±34.93 ml/min in those with a nonmature AVF as shown in Table 4.

In addition, our study showed that the mean preoperative radial artery diameter in patients with mature fistulae was 2.43±0.33 mm with a mean velocity of 42.42±4.34 cm/s, while the mean preoperative brachial artery diameter was 3.50 ±0.61 mm with a mean velocity of 62.89±7.64 cm/s as shown in Tables 2 and 3.

In comparison between different AV fistula groups, no statistical significance was found concerning age, sex, diabetes, hypertension, and ischemic heart disease. In contrast, a statistically significant difference was found concerning the preoperative and postoperative vascular diameter/flow rates between mature and nonmature groups in the overall AVF and radiocephalic AVF subgroup as shown in Tables 2 and 5.

However, the brachiocephalic AVF subgroup showed only a statistically significant difference in preoperative vein diameter between mature and nonmature AVF groups as shown in Table 3.

In addition, the brachiobasilic AVF subgroup showed only a statistically significant difference in POD 1 flow volume between mature and nonmature AVF groups as shown in Table 4.

Discussion

The prevalence rate of native AVF varies widely worldwide, and efforts to improve this rate must be continued. Several measures introduced in our practice,

Table 5 Preoperative and postoperative parameters in the overall AVF

	Mature AVF		Nonmature AVF		
	Mean±SD	Median	Mean±SD	Median	*P* value
Preoperative vein diameter (mm)	3.08±0.72	3.0	2.25±0.63	2.0	<0.01
Increase in vein diameter at POD 1	1.20±0.51		0.75±0.31		<0.01
Flow volume at POD 1 (ml/min)	303.91±86.62	295.0	188.53±77.35	180.0	<0.001

AVF, arteriovenous fistula; POD 1, postoperative day 1.

including preoperative vessel mapping and early postoperative surveillance, have increased the proportion of dialysis patients using native AVF [9].

It was suggested that duplex imaging be used to evaluate all patients before creating an AVF. Duplex ultrasound scanning is a promising method for establishing specific parameters of blood vessels because it is noninvasive and safe and may be used instead of venography and arteriography at facilities where this modality is available and reliable for venous and arterial assessment. This method has been recently used to visualize and measure arterial and venous vessel diameters, and a good correlation between preoperative determination and perioperative findings has been shown [10].

The results of our study revealed that the highest maturation rate was in the group that underwent brachiocephalic fistulae, 88.9%, which is consistent with the study of Manne *et al.* [11] and Navuluri *et al.* [12], which showed the same results. However, radiocephalic fistula is associated with substantial primary failure rates for many causes like atherosclerosis in uremia, which is associated with decreased PSV and reduced ability to increase the blood flow after fistula creation, as well as the inflammation associated with the uremia that influences the veins and their dilatation after fistula creation [13]. Also, in our study, the brachiobasilic fistula showed significant primary failure rates due to the limited number of patients who underwent brachiobasilic fistula in our study, which was different compared with the study by Abd El-Mabood *et al.* [14], which showed brachiobasilic AVFs with a substantially lower primary failure rate and less early thrombosis.

In our study, the maturation rate of radiocephalic fistula was 66.7% compared with 68.3 and 80% in the study of Dasari *et al.* [13] and Eldesouky *et al.* [15], respectively. The mean preoperative cephalic vein diameter with a mature radiocephalic fistula was found to be 2.59±0.55 and 1.87±0.15 mm in those with a nonmature AVF compared with the study by Brimble and colleagues, which was 2.52 and 2.23 mm, respectively. And the study of Dasari *et al.* [13] was 2.17 and 1.90 mm, respectively [16].

Furthermore, those mature fistulas had a mean blood flow volume in POD 1 of 265.83±61.46 ml/min, which was significantly higher in comparison to the study of Dasari *et al.* [13], which was 188.4 ml/min, which increased at 6 weeks postoperatively to 651.75 ±106.42 ml/min compared with 754.4±128.9 ml/min in the study by Hamada *et al.* [17].

In our study, a preoperative diameter of the proposed inflow radial artery less than 1.95 mm is associated with a higher failure rate in AVFs compared with less than or equal to 1.6 mm and less than 1.5 mm in a study by Simon and colleague and Manne and colleague, respectively [11,18].

PSV of the proposed inflow radial artery is easy to be measured and has also been evaluated as a predictor for the maturation of AVF. A PSV of at least 50 cm/s is suggested for fistula maturation. Lockhart *et al.* [19] found no difference in preoperative PSV between mature and nonmature fistulas and no increase in failure to mature rates with a PSV of less than 50 cm/s; however, our study found that preoperative PSV was 43 cm/s in those with a mature fistula, while it was 35.50 cm/s in patients with a nonmature fistula with statistical significance.

Compared with previous studies, our study's maturation rate of the brachiocephalic fistula was 88.9%, while 88.1 and 80% were in the study by Manne *et al.* [11] and Eldesouky *et al.* [15], respectively. The mean preoperative cephalic vein diameter with a mature brachiocephalic fistula was discovered to be 3.21±0.70 and 2.48±0.84 mm in those with a nonmature AVF, whereas Manne *et al.* [11] study showed comparatively lower results, 2.81 and 2.7 mm, respectively

In addition, those mature fistulas exhibited a mean blood flow volume in POD 1 of 311.79±93.25 ml/min, which was noticeably higher than those of 269.9 ml/min in the study by Manne *et al.* [11].

The mean diameter of the proposed inflow brachial artery in mature fistulas in our study was 3.50±0.61 mm compared with 4.9±1.0 and 4.0 mm in the study by Dasari *et al.* [13] and Ives *et al.* [20], respectively.

A study by Manne and colleagues showed a higher maturation rate for brachiobasilic fistula, 66.6%, than ours, 62.5%. In patients with mature brachiobasilic fistulas, the mean preoperative vein diameter was found to be 3.08±0.95 mm, closely similar to the study of Manne *et al.* [11], which showed results of 3.0 mm.

In addition, those mature fistulas had a mean blood flow volume in POD 1 of 319.60±45.67 ml/min, much higher than those in the Manne *et al.* [11] study, which was 261 ml/min.

Regarding complications, Steal syndrome was detected in 5% of patients in our study, while its incidence was 8.3% in the study by Eldesouky *et al.* [15].

Hence, the current study focused on demographic data, risk factors, arteriovenous diameter, preoperatively and PSV, flow volume, and diameter of the vessels at POD 1 and their effect on AVF patency.

Although some studies had found a correlation between age, sex, diabetes, and hypertension with outcomes of AVF, our study did not find any correlation between age, sex, and the presence of diabetes and hypertension with outcomes of AVF. Our study found a correlation between preoperative and postoperative vascular diameter/flow rates with AVF maturation.

Conclusion

On the basis of our study, flow volume at POD 1 can be used as a predicting factor for RC and BB AVF maturation. Also perioperative vein diameter change can be used as a predictor for RC AVF maturation. However, none of these parameters can be used as a predicting factor for maturation in BC AVF. Therefore, further studies with a larger sample size are recommended to standardize these parameters.

Limitations

This study has assessed only primary failures. Secondary failures are not evaluated because it requires a long-term follow-up, and the present study is a short-duration follow-up study. Other factors that affect the success of AVF, like the surgeon's performance, were not studied. Moreover, our study included a limited number of patients.

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Conflicts of interest

There were no conflicts of interest.

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