The effect of immediate postoperative increase in blood flow velocity in predicting maturation of arteriovenous fistula for dialysis

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Background
Doppler ultrasonography is the main imaging modality for hemodialysis arteriovenous fistula (AVF) as it is safe, accurate, and noninvasive. Published literature related to the utility of early postoperative ultrasound in predicting AVF maturation is scarce. With the KDOQI guidelines recommending an AVF first catheter last approach, the quest to increase AVF maturation is of utmost importance. This study aims at measuring blood flow immediately postoperatively and assessing its predictive role in AVF maturation.
Methods
We correlated the ultrasound parameters with maturation in newly created AVFs measured preoperatively, immediately postoperatively, 6 weeks, and 3, 6, and12 months postoperatively. Both demographics and vascular parameters were compared between the group of patients whose AVFs successfully maturated and those whose AVFs did not. Primary endpoint was AVF maturation; secondary endpoints included patency, functional success, and predictive value of increased vein blood flow on fistula patency.
Results
A total of 50 procedures were performed; the mean age was 52.12 years (±6.58). The overall technical success rate was 86% (43) and 39 (90.7%) of them were functionally mature according to KDOQI guidelines for maturation. Primary patency was 93.02%, 92.7%, and 88.89%; and the primary-assisted patency was 97.7%, 95.12%, and 91.67% at 3, 6, and 12 months, respectively.
Receiver-operated curve (ROC) showed a cutoff value of 322.8 ml/min increase in blood flow above which the AVF is more likely to become mature.
Binary logistic regression showed that arterial depth greater than 3.92 mm, arterial flow velocity greater than 88 ml/min, preoperative average vein diameter of greater than 2.5 mm, arterial flow velocity of greater than 73 ml/min immediately postoperatively, and average vein diameter of greater than 3.94 mm immediately postoperatively were significant predictors of successful maturation at 6 weeks postoperatively (P values 0.001, <0.0001, <0.0001, <0.0001, and <0.0001, respectively).
Conclusion
Immediately postoperative flow measurement is a reliable parameter that can be used to predict successful fistula maturation, especially if flow velocities exceed 326.15 ml/min.

Keywords:
arteriovenous fistula, Doppler ultrasound, predictors of maturation, vascular access for hemodialysis

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Introduction

An estimated13.4% of the worldwide population is currently suffering from chronic kidney disease; 10.6% of whom are of stages 3–5[1].

Hemodialysis is the most commonest form of renal replacement therapy, accounting for approximately 69% of all renal replacement and 89% of all dialysis procedures undergone, with nearly four million patients around the world currently surviving on renal replacement therapy[2].

Consequently, the need for hemodialysis is increasing with a prevalence reaching up to 121/million population in Europe[3].

Autogenous arteriovenous fistulas (AVFs) have been shown to provide optimal vascular access for the majority of patients on chronic hemodialysis. The National Kidney Foundation Dialysis Outcomes Quality Initiative (KDOQI) developed renal care guidelines, including clinical practice recommendations and outcome goals for vascular access[4]. According to these guidelines, autogenous AVFs have the lowest rate of thrombosis, require the fewest interventions, and provide the longest access survival; however, a substantial proportion of the autogenous AVFs fail to mature adequately for dialysis use. AVFs are associated with an average failure rate of 23–28%; therefore, determinants of success and maturation of the AVF have been the cornerstone of many research projects [5–8].

Postoperative ultrasound measurements have been used to predict AVF clinical maturation in several, single-center series, using brachial or radial artery, or target vein inner diameter measurements, and blood flow measured in variable artery and vein locations, which consequently limits comparability. Early AVF clinical maturation criteria focused on both AVF blood flow and diameter[8,9].

Subsequent KDOQI guidelines proposed the ultrasound criteria for AVF maturation of 600 ml/min blood flow, 0.6 cm diameter, and less than 0.6 cm depth from the skin at the 6-week post-AVF creation[4].

Moreover, further procedures have been tried to accelerate AVF maturation such as balloon-assisted maturation either primarily during AVF creation, or sequentially postoperatively with equivocal results [10,11].

This study aims at exploring the effect of an increase in flow in the venous side of autogenous AVF as a predictor for maturation.

Materials and methods

This is a prospective cohort study conducted between February 2021 and February 2022. Convenience sampling from all patients with chronic renal failure who attended the outpatient clinics at El Demerdash University Hospital and El Sahel Teaching Hospital was performed. Sample size was calculated using PASS 11.0 and based on a study carried out by Polimanti *et al.*[12]. A sample of 50 patients achieved 80% power to detect a difference of 0.2200 between the area under the receiver-operated curve (ROC) curve (AUC) under the null hypothesis of 0.5000 and an AUC under the alternative hypothesis of 0.7200 using a two-sided z-test at a significance level of 0.05000. The data were discrete (rating scale) responses. The AUC was computed between false-positive rates of 0.000 and 1.000. The ratio of the standard deviation of the responses in the negative group to the standard deviation of the responses in the positive group is 1.000.

Ain Shams University ethics committee approval was obtained, and an informed consent was taken from every patient before recruitment. The inclusion criteria were all patients of more than 18 years of age who were willing to participate and provide informed consent with a minimal vein diameter of 2 mm without tourniquet application and a minimal arterial diameter of 1.5 mm and arterial blood flow of more than 40 ml/min, in addition to freedom from any cardiac condition that would deem the patient unsuitable for AVF creation (ejection fraction between 50% and 70% on preoperative echocardiography) to avoid high cardiac output heart failure. Exclusion criteria were anatomically unsuitable patients for autogenous AVF, patients with congestive cardiac failure, patients with known central venous occlusion, pregnancy or lactation, coagulation disorders, active or metastatic carcinoma, and patients with high risk for surgery or those who refuse surgery or participation in the study.

Patients meeting inclusion criteria were selected and had a baseline preoperative duplex mapping for both upper limbs to evaluate patency of both superficial and deep venous systems, in addition to diameter, depth, and blood flow in the designated inflow artery as well as the planned vein conduit at the intended site of anastomosis, 3 cm proximal to it and 6 cm proximal to it. This was repeated immediately postoperatively as well as 6 weeks postoperatively.

History and clinical examination were performed on all patients and recorded, Allen's test was routinely performed to detect the dominant artery in case of planning for distal forearm or wrist fistula. The nondominant hand was preferred if anatomically suitable.

Baseline demographic and clinical data, including age, gender, prior coronary artery or peripheral vascular diseases, and body mass index were ascertained by means of direct patient interviews and chart review.

Primary endpoint was AVF maturation, which was determined through venous duplex findings at 6 weeks postoperatively consistent with KDOQI guidelines [4]. Secondary endpoints included AVF patency, functional success of the fistula defined as successful cannulation, and subsequent completion of three successive full hemodialysis sessions without the need to use central venous catheters, and predictive value of increased vein flow on fistula patency. Primary failure was defined as impalpable thrill and absence of blood flow in the AVF at 6 weeks postoperatively.

Statistical analyses

Statistical analysis was conducted by SPSS x8 (SPSS, IBM, Chicago, IL, USA). Descriptive statistics were used for patient demographics; χ^2test was used to compare demographics between patients with failure of maturation and those with completely mature AVF. *T*-test was used to compare the means of an increase in blood flow following AVF creation as well as other noncategorical data. ROC curve was plotted to deduce cutoff values of vein blood flow immediately postoperatively as well as the increase in blood flow associated with successful fistula maturation. *P* values are considered significant if less than 0.05.

Our prognostic models evaluated the probabilities of AVF clinical maturation based on ultrasound measurements at the designated assessment times, conditional on patient survival without AVF thrombosis before the assessment times.

Results

A total of 50 procedures were performed. The mean age was 52.12 years (±6.58), 24 (48.0%) of the patients were males and 26 (52.0%) were females; 28 (56.0%) had a history of previous vascular access procedures, 18 (36.0%) were diabetic, 7 (14.0%) were hypertensive, and 8 (16.0%) patients had a history of ischemic heart disease not significantly interfering with the overall cardiac function. Overall, 25 (50%) radiocephalic and 25 (50%) brachiocephalic procedures were done (Table 1).

Four (8%) patients had the procedures on the right side and 46 (92%) on the left; 47 (94%) procedures were performed under local anesthesia, and three (6%) were performed under regional anesthesia. Mean operative time was 68.2 min (±12.28), mean length of arteriotomy was 5.44 mm (±0.5), and mean venotomy was 6.34 mm (±0.48) long (Table 1).

Overall, the technical success rate was 86% (43 AVFs) and 39 (90.7%) of them were functionally mature according to KDOQI guidelines for maturation

Table 1 Patients' demographics, baseline clinical data, operative details, outcome, complications, and follow-up

Demographics	Number (50)
Age	
Mean±SD	52.12±6.58
Range	41–65
Gender	
Male	24 (48.0%)
Female	26 (52.0%)
Diabetes mellitus	
No	32 (64.0%)
Yes	18 (36.0%)
Hypertension	
No	43 (86.0%)
Yes	7 (14.0%)
Ischemic heart disease	
No	42 (84.0%)
Yes	8 (16.0%)
Duration of dialysis	
Median (IQR)	203.50 (21-790)
Range	7–1800
History of previous access	
No	22 (44.0%)
Yes	28 (56.0%)
Anesethia	
Local	47 (94.0%)
Regional	3 (6.0%)
General	0
Type of procedure	
Radiocephalic AVF	25 (50%)
Brachiocephalic AVF	25 (50%)
Duration of operation in minutes	
Mean±SD	68.20±12.28
Range	45–95
Length of arteriotomy in mm	
Mean±SD	5.44±0.50
Range	5–6
Length of venotomy in mm	
Mean±SD	6.34±0.48
Range	6–7
Side	
Right	4 (8.0%)
Left	46 (92.0%)
Palpable thrill immediately postoperatively	
Yes	50 (100%)
Perioperative complications	Number (%)
Bleeding	
No	48 (96)
Yes	2 (4)
Thrombosis	
No	43 (86)
Yes	7 (14)
Steal	
No	50 (100)
Venous hypertension	
No	50 (100)
Seroma	
No	49 (98)
Yes	1 (2)

(*Continued*)

Table 1 (*Continued*)

Demographics	Number (50)		
Infection			
No	50 (0)		
Functional success			
No	7 (86)		
Yes	43 (14)		
Failure to maturate at 6 weeks			
No	4 (9.3)		
Yes	39 (90.7)		
Outcome	Number (%)		
Primary patency at 3 months postoperative			
No	3 (6.98)		
Yes	40 (93.02)		
Primary assisted patency at 3 months postoperative			
No	1 (2.3)		
Yes	42 (97.7)		
Primary patency at 6 months postoperative			
No	3 (7.3)		
Yes	38 (92.7)		
Primary assisted patency at 6 months postoperative			
No	2 (4.87)		
Yes	39 (95.12)		
Primary patency at 12 months postoperative			
No	4 (11.11)		
Yes	32 (88.89)		
Primary assisted patency at 12 months postoperative			
No	3 (8.3)		
Yes	33 (91.67)		
Follow-up	3 months *N* (%)	6 months *N* (%)	12 months *N* (%)
Puncture site hematoma			
No	41 (95.35)	40 (97.56)	36 (97.30)
Yes	2 (4.65)	1 (2.44)	1 (2.70)
Infection			
No	43 (100)	40 (97.56)	36 (97.30)
Yes	0	1 (2.44)	1 (2.70)
Focal puncture site stenosis			
No	41 (95.35)	39 (95.12)	36 (97.30)
Yes	2 (4.65)	2 (4.88)	1 (2.70)
Anastomotic stenosis			
No	43 (100)	41 (100)	37 (100)
Thrombosis			
No	42 (97.67)	41 (100)	35 (94.59)
Yes	1 (2.33)	1 (2.44)	2 (5.41)
Rupture			
No	43 (100)	40 (97.56)	37 (100)
Yes	0	1 (2.44)	0
Venous hypertension			
No	43 (100)	41 (100)	37 (100)
Steal phenomenon			
No	43 (100)	41 (100)	37 (100)

(Table 1). At 6 weeks postoperatively, seven AVFs were thrombosed, and four AVFs failed to maturate according to KDOQI guidelines, three of which matured after 2 more weeks without the need for intervention, and one required balloon-assisted maturation. By 2 months, all of the delayed maturation fistulae could be used for two-needle punctures for dialysis.

Primary patency was 93.02% (40 AVFs), 92.7% (38 AVFs), and 88.89% (32 AVFs); and the primary-assisted patency was 97.7% (42 AVFs), 95.12% (39 AVFs), and 91.67% (33 AVFs) at 3, 6, and 12 months, respectively (Table 1).

At 3 months postoperatively, one patient had a puncture site stenosis for which he had a successful venoplasty, and two patients had thrombectomy for thrombosed AVFs followed by venoplasty, one of which failed to be salvaged.

At 6 months postoperatively, one patient had an infected hematoma related to a puncture site that was presented by AVF rupture and was surgically ligated. In addition, two patients had successful venoplasty for puncture site stenosis.

At 12 months postoperatively, one patient developed puncture site stenosis for which veinoplasty was tried and was not successful. This warranted surgical correction through resection and end-to-end anastomosis of the AVF. Two patients had thrombosed AVFs, one of whom had a trial of thrombectomy, and the other patient had extensive cellulitis and infection over a puncture site hematoma that was not responding to antibiotics with subsequent preemptive AVF ligation.

The mean preoperative arterial diameter was 3.3 mm (±1.16), mean preoperative arterial depth was 4.76 mm (±1.41), and the mean preoperative arterial blood flow was 90.6 ml/min (±9.34). With regard to vein parameters, mean preoperative average vein depth was 2.93 mm (±1.45), mean preoperative average vein diameter was 2.57 mm (±0.25), and the mean preoperative average venous blood flow was 3.45 ml/min (±0.89) (Table 2, Fig. 1).

The immediately postoperative mean arterial diameter was 3.8 mm (±1.16), and the flow velocity was 75.62 ml/min (±9.34).

Mean average vein depth was 3.58 mm (±0.5), 4.02 mm (±0.52), 4.12 mm (±0.62), 4.3 mm (±0.65), and 4.2 mm (±0.93) immediately postoperatively, and at 6 weeks, 3 months, 6 months, and 12 months postoperatively, respectively (Table 2, Fig. 1).

Mean average vein diameter was 4.01 mm (±0.46), 5.68 mm (±0.64), 6.56 mm (±0.52), 7.18 mm (±0.48),

Table 2 Vessels' parameters

	Preoperative	Immediately postoperative	6 weeks postoperative	3 months postoperative	6 months postoperative	12 months postoperative
Artery at the site of anastomosis						
Depth (mm)						
Mean±SD	4.76±1.41	—	—	—	—	—
Diameter (mm)						
Mean±SD	3.30±1.16	3.80±1.16	4.07±1.17	—	—	—
Flow velocity (ml/min)						
Mean±SD	90.62±9.34	75.62±9.34	70.39±9.47	—	—	—
Vein at the site of anastomosis						
Depth (mm)						
Mean±SD	2.87±1.31	3.60±0.53	3.92±0.57	—	—	—
Diameter (mm)						
Mean±SD	2.56±0.28	4.10±0.44	5.73±0.62	6.68±0.57	7.26±0.48	7.89±0.5
Flow velocity (ml/min)						
Mean±SD	3.54±1.27	366.36±85.04	649.62±153.50	—	—	—
Vein 3 cm proximal to the site of anastomosis						
Depth (mm)						
Mean±SD	2.93±1.45	3.59±0.51	4.05±0.52	—	—	—
Diameter (mm)						
Mean±SD	2.58±0.26	4.01±0.47	5.67±0.68	6.55±0.54	7.18±0.48	7.87±0.48
Flow velocity (ml/min)						
Mean±SD	3.44±0.97	347.76±83.43	636.38±153.73	—	—	—
Vein 6 cm proximal to the site of anastomosis						
Depth (mm)						
Mean±SD	3.00±1.60	3.54±0.49	4.09±0.49	—	—	—
Diameter (mm)						
Mean±SD	2.57±0.25	3.93±0.48	5.65±0.63	6.45±0.51	7.09±0.54	7.8±0.56
Flow velocity (ml/min)						
Mean±SD	3.38±0.90	340.80±85.16	624.20±152.08	—	—	—
Average vein measurements						
Depth						
Mean±SD	2.93±1.45	3.58±0.50	4.02±0.52	4.12±0.62	4.3±0.65	4.2±0.93
Diameter						
Mean±SD	2.57±0.25	4.01±0.46	5.68±0.64	6.56±0.52	7.18±0.48	7.8±0.46
Flow velocity (ml/min)						
Mean±SD	3.45±0.89	351.64±84.49	636.73±153.05	728.3±148.17	828.17±82.05	908.06±186.75

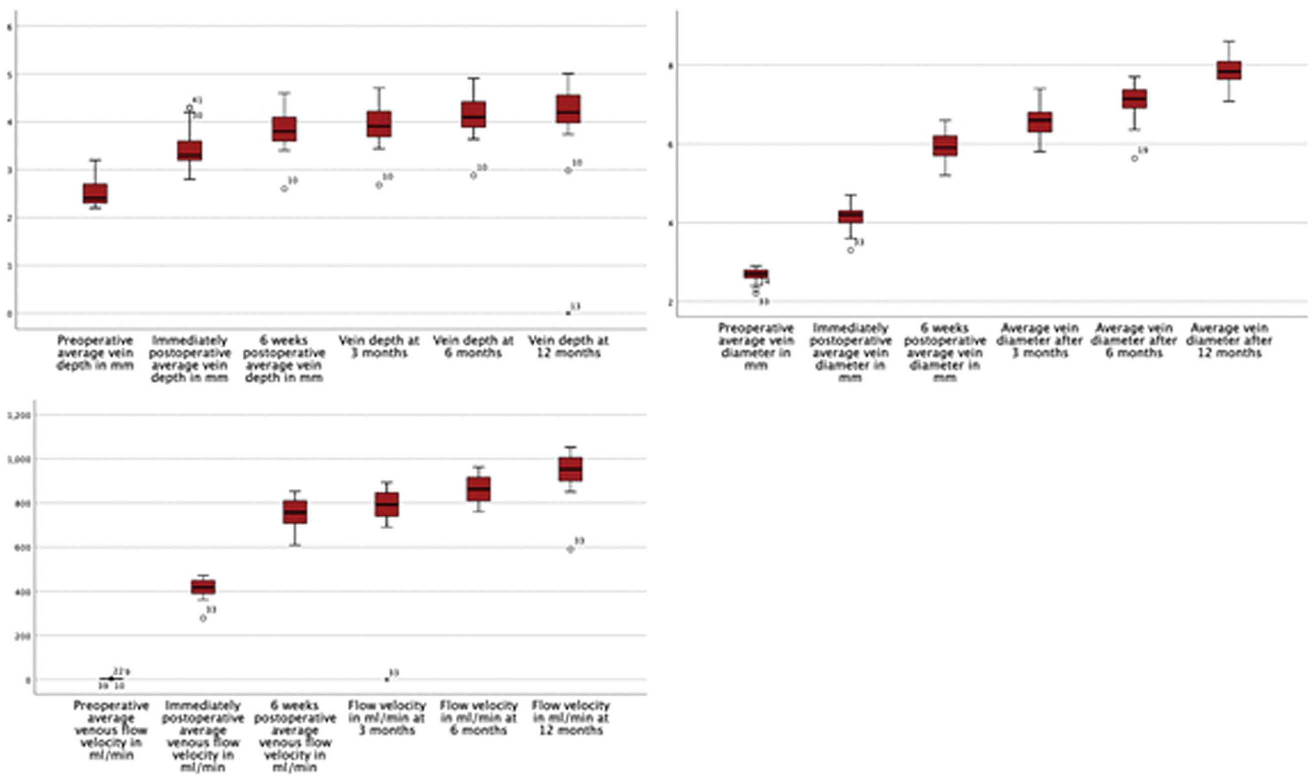
and 7.8 mm (±0.46) immediately postoperatively, and at 6 weeks, 3 months, 6 months, and 12 months postoperatively, respectively (Table 2,Fig. 1).

Mean average vein flow velocity was 351.84 ml/min (±0.5), 4.02 ml/min (±0.52), 4.12 ml/min (±0.62), 4.3 ml/min (±0,65), and 4.2 ml/min (±0.93) immediately postoperatively, and at 6 weeks, 3 months, 6 months, and 12 months postoperatively, respectively (Table 2, Fig. 1).

With regard to demographics, there was no statistically significant difference between patients who had successful fistulas and those who did not, with the exception of diabetes, which was more associated with failure with a P value of 0.04 (Table 3). There were statistically significant differences between the primary failed and technically successful AVFs with regard to the site of the AVF and thrombosis rate (P value 0.004, and <0.0001, respectively). No other statistically significant differences were found between the two groups concerning background medical data and baseline laboratory results (Table 3). To eliminate technical failure as a confounding factor and to better predict maturation, only AVFs with proven technical success defined as palpable post-anastomotic thrill and freedom from thrombosis on venous duplex were examined for maturation, with the subsequent exclusion of the primarily failed AVFs from the regression model.

There were also statistically significant differences in mean values of preoperative venous and arterial parameters between patients with technical success and those who had primary failure concerning preoperative arterial depth, diameter and flow

Figure 1



Boxplot representations of increase in average vein depth, diameter, and flow velocity by time.

velocity, preoperative average vein diameter, immediately postoperative arterial diameter and flow, and immediately postoperative vein depth, diameter, and flow (*P* values 0.02, <0.0001, <0.0001, <0.0001, <0.0001, <0.0001, <0.0001, respectively) (Table 3).

There were no statistically significant differences between successfully matured AVFs (39) at 6 weeks and those who did not (4 AVFs) with regard to patients' demographics, operative details, and complications with the exception of more association of brachiocephalic AVFs with successful maturation (*P* value 0.04). Primary assisted patency at 3 months and primary patency at 12 months were also significantly higher in the successfully matured at 6 weeks group (*P* values 0.01 and 0.03, respectively) (Table 4). Preoperative arterial parameters showed statistically significant higher depth, diameter, and flow in patients with successful AVF maturation at 6 weeks postoperatively (*P* values 0.002, <0.0001, and <0.0001 respectively), as well as immediately postoperative diameter (*P* value <0.0001). Preoperative average vein diameter, immediately postoperative average vein diameter, and immediately postoperative venous blood flow were also significantly higher in the successfully matured group with *P* values of less than 0.0001, less than 0.0001, and 0.004, respectively (Table 4, Fig. 1).

At 6 weeks postoperatively, arterial and venous depth and flow velocities were significantly higher in the successfully matured group (*P* values 0.035, 0.013, 0.006, <0.0001, respectively) (Table 4).

Immediately postoperative increase in average vein diameter of 1.5 mm (±0.19) was found in the successfully matured group compared with 0.93 mm (±0.39) in the unsuccessful maturation at 6 weeks (*P* value <0.0001), and an increase in blood flow of 371.59 ml/min (±64.95) was found in the successfully matured group compared with 230.58 ml/min (±54.29) in the unsuccessfully matured group (*P* value <0.0001) (Table 4).

At 6 weeks postoperatively, the mean vein diameter increased by 3.3 mm (±0.28) in the successfully matured group compared with 2.77 mm (±1.39) in the unsuccessful maturation group, and the mean vein blood flow increased by 690.76±82.40 ml/min in the successfully mature group compared with 457.29±20.48 ml/min in the successfully mature group with a *P* value of <0.0001 (Table 4).

Table 3 Comparison between demographics, lab results, operative details, complications, and vessel measurements preoperatively, immediately postoperatively, and 6 weeks postoperatively between the primary failure group and the technically successful group

	Primary failure	Success		
	N=7	*N*=43	Test value	*P*
Demographics				
Sex				
Male	2	21		0.42a
Female	5	22		
Diabetes				
No	4	21		0.04a
Yes	3	22		
Hypertension				
No	2	19		0.17a
Yes	5	24		
ISHD				
No	7	35		1a
Yes	0	8		
Preoperative investigations				
HB: g/dl				
Mean±SD	10.30±0.98	10.56±1.01	–0.635	0.528b
TLC: 10^3/μl				
Mean±SD	7.57±1.27	7.58±2.41	–0.011	0.992b
PLT: 10^3/μl				
Mean±SD	315.71±65.81	330.49±77.81	–0.474	0.637b
Eosinophils				
Mean±SD	0.20±0.00	0.20±0.02	0.400	0.691b
Urea: mg/dl				
Mean±SD	149.43±16.51	145.42±28.61	0.359	0.721b
Creatinine: mg/dl				
Mean±SD	5.49±1.01	5.47±0.82	0.046	0.963b
ALT: u/l				
Mean±SD	23.43±2.99	21.84±4.84	–3.382	0.661b
AST: u/l				
Mean±SD	23.57±2.51	22.98±5.44	–3.520	0.651b
PT: sec				
Mean±SD	13.14±0.90	13.37±1.40	–0.418	0.678b
Aptt: sec				
Mean±SD	29.29±2.87	30.09±4.67	–0.442	0.661b
INR:				
Mean±SD	0.93±0.11	0.92±0.12	0.138	0.891b
CRP: mg/l				
Mean±SD	1.49±0.47	1.12±0.64	1.428	0.160b
Operative details				
Time of operation in minutes				
Mean±SD	67.14±11.13	68.37±12.57	–0.243	0.809b
Length of arteriotomy in mm				
Mean±SD	5.43±0.53	5.44±0.50	–0.064	0.949b
Length of venotomy in mm				
Mean±SD	6.29±0.49	6.35±0.48	–0.321	0.750b
Anesthesia				
Local	7 (100.0%)	40 (93.0%)		
Regional	0	3 (7.0%)	0.520	0.471a
General	0	0		
Time of operation in minutes				
Mean±SD	67.14±11.13	68.37±12.57	–0.243	0.809b
Length of arteriotomy in mm				
Mean±SD	5.43±0.53	5.44±0.50	–0.064	0.949b
Length of venotomy in mm				

(*Continued*)

Table 3 (*Continued*)

	Primary failure	Success		
Mean±SD	6.29±0.49	6.35±0.48	−0.321	0.750b
Side				
Right	1 (14.3%)	3 (7.0%)	0.437	0.509a
Left	6 (85.7%)	40 (93.0%)		
Site of the fistula				
Radiocephalic	7 (100%)	18 (41.9%)	8.140	0.004a
Brachiocephalic end to side	0	25 (58.1%)		
Complications				
Bleeding	0	2 (4.7%)	0.339	0.560a
Thrombosis	7 (100%)	0	50.000	<0.0001a
Steal	0	0	NA	NA
Venous hypertension	0	0	NA	NA
Seroma	1 (2.3%)	0	0.166	0.684a
Infection	0	0	NA	NA
Failure to maturate	4 (9.3%)	0	0.708	0.4a
Pseudoaneurysm	0	0	NA	NA
Anastomotic Rupture	0	0	NA	NA
Anastomotic stenosis	0	0	NA	NA
Preoperative parameters				
Artery at the site of anastomosis				
Depth (mm)				
Mean±SD	4.02±0.17	3.22±0.29	0.856	0.002b
Diameter (mm)				
Mean±SD	1.78±0.13	3.55±1.06	−4.390	<0.0001b
Flow (ml/min)				
Mean±SD	75.86±6.72	93.02±7.28	−5.839	<0.0001b
Average vein measurements				
Depth				
Mean±SD	2.64±0.38	2.99±1.55	−0.579	0.566b
Diameter				
Mean±SD	2.23±0.08	2.64±0.24	−4.508	<0.0001b
Flow (ml/min)				
Mean±SD	3.27±0.48	3.48±0.93	−0.586	0.561b
Immediately postoperative measurements				
Artery at the site of anastomosis				
Diameter: mm				
Mean±SD	2.28±0.13	4.05±1.06	−4.390	<0.0001b
Flow ml/min				
Mean±SD	60.86±6.72	78.02±7.28	−5.839	<0.0001b
Average vein measurements				
Depth				
Mean±SD	3.61±0.28	3.56±0.52	0.254	0.801b
Diameter				
Mean±SD	3.14±0.45	4.12±0.41	−5.759	<0.0001b
Flow ml/min				
Mean±SD	233.85±12.94	375.07±64.79	−3.047	0.004b

[a]=χ^2test. [b]=Independent *t* test. NA, not applicable.

On performing ROC to determine the sensitivity and specificity of blood flow increase immediately after hydrostatic dilatation in predicting AVF maturation, the area under the curve was 0.780 and a cutoff value of 322.8 ml/min increase in blood flow above which the AVF is more likely to become mature according to KDOQI guidelines (sensitivity value was 0.756 and 1; specificity was 0.250). This implies that an increase in vein blood flow after hydrostatic dilatation is a fair test when it comes to sensitivity and specificity regardless of the site of measurement (Fig. 2).

Binary logistic regression was performed to investigate the predictors for successful AVF maturation at 6 weeks postoperatively, which showed that patients older than 46 years of age (*P* value 0.002, OR 31,

Table 4 Association of demographics, preexisting medical conditions, operative complications, and patency rates as well as mean parameters' comparison between the patients whose arteriovenous fistus were successfully mature at 6 weeks and those who were not

	Fistula maturation at 6 weeks		
	No	Yes	*P*
Demographics			
Gender			
Male	1	19	0.611a
Female	3	20	
Diabetes			
No	1	20	0.609a
Yes	3	19	
Hypertension			
No	1	19	0.611a
Yes	3	20	
ISHD			
No	4	33	1a
Yes	0	6	
Operative details			
Side of the operation			
Right	1	2	0.3a
Left	3	37	
Type of operation			
Radiocephalic	4	16	0.04a
Brachiocephalic	0	23	
Anesthesia			
Local	4	37	0.76a
Regional	0	2	
Complications			
Bleeding			
No	4	38	0.83a
Yes	0	1	
Steal			
No	4	39	—
Venous hypertension			
No	4	39	—
Seroma			
No	4	38	0.92a
Yes	0	1	
Infection			
No	4	39	—
Pseudoaneurysm			
No	4	39	—
Anastomotic rupture			
No	4	39	—
Anastomotic stenosis			
No	4	39	—
Primary patency at 3 months postoperative			
No	1	2	0.16a
Yes	3	37	
Primary assisted patency at 3 months postoperative			
No	1	0	0.01a
Yes	3	39	
Primary patency at 6 months postoperative			
No	1	2	0.067a
Yes	3	35	
Primary assisted patency at 6 months postoperative			
No	1	1	0.28a
Yes	3	36	

(*Continued*)

Table 4 (*Continued*)

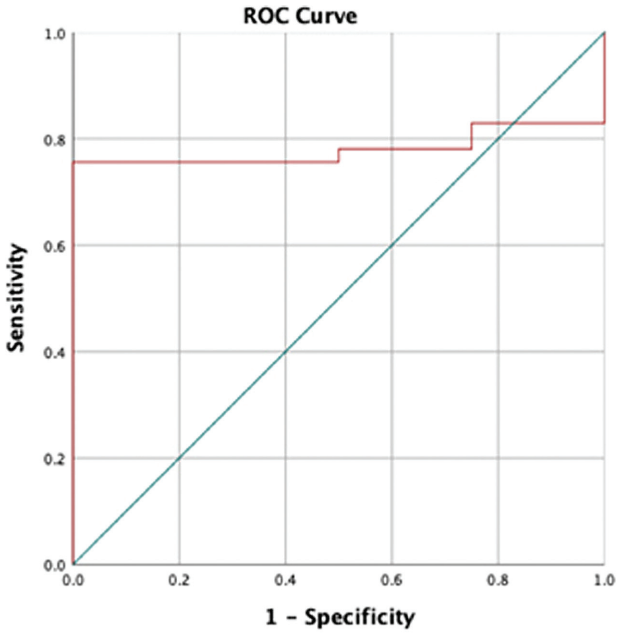
	Fistula maturation at 6 weeks		
Primary patency at 12 months postoperative			
No	2	2	0.03a
Yes	2	30	
Primary assisted patency at 12 months postoperative			
No	1	2	
Yes	3	30	0.071a
Yes	3	31	
Preoperative parameters			
Artery at the site of anastomosis			
Depth (mm)	5.01±1.37	3.25±0.17	0.002b
Diameter (mm)	3.55±1.06	1.78±0.13	<0.0001b
Flow (ml/min)	93.02±7.28	75.86±6.72	<0.0001b
Average vein measurements			
Depth (mm)	2.99±1.55	2.64±0.38	0.566b
Diameter (mm)	2.64±0.24	2.23±0.08	<0.0001b
Flow (ml/min)	3.48±0.93	3.27±0.48	0.561b
Immediately postoperative measurements			
Artery at site of anastomosis			
Diameter (mm)	4.05±1.06	2.28±0.13	<0.0001b
Flow (ml/min)	78.02±7.28	60.86±6.72	<0.0001b
Average vein measurements			
Depth (mm)	3.56±0.52	3.61±0.28	0.801b
Diameter (mm)	4.12±0.41	3.14±0.45	<0.0001b
Flow (ml/min)	375.07±64.79	233.85±12.94	0.004b
6 weeks postoperative parameters			
Artery at the site of anastomosis			
Diameter (mm)	4.35±1.06	2.7±0.07	0.035b
Flow (ml/min)	73.02±7.28	59.5±0.71	0.013b
Average vein measurements			
Depth (mm)	4.01±0.55	4.35±0.07	0.384b
Diameter (mm)	6.05±0.45	5±0.23	0.006b
Flow (ml/min)	694.25±97.53	461.13±82.4	<0.0001b
Change in average vein diameter with hydrostatic dilatation immediately postoperatively			
Difference in vein diameter in mm	1.5±0.19	0.93±0.39	<0.0001b
% increase in diameter	56.38±3.58	41.51±16.92	<0.0001b
Change in average vein blood flow with hydrostatic dilatation immediately postoperatively			
Difference in vein flow in ml/min	371.59±64.95	230.58±54.29	<0.0001b
% increase in flow	11222.58±2890.42	6951.38±2641.81	<0.0001b
Change in average vein diameter 6 weeks postoperatively			
Difference in vein diameter in mm	3.30±0.28	2.77±1.39	<0.0001b
% increase in diameter	129.16±11.2	124.01±10.59	0.004b
Change in average vein blood flow 6 weeks postoperatively			
Difference in vein flow in ml/min	690.76±97.67	457.29±20.48	<0.0001b
% increase in flow	20828.17±4863.83	14.001±3822.63	<0.0001b

[a]*P* value calculated using χ^2test. [b]*P* value calculated using independent *t*-test.

95% CI 3.45-278.4), duration of hemodialysis of more than 24 months (*P* value <.0001, OR 12.5, 95% CI 3.108–50.278), a positive history of previous vascular access (*P* value .001, OR 11, 95% CI 2.587–46.779), initial heart rate below 84 (*P* value 0.005, OR 21.857, 95% CI 2.586–184.717and performing a brachiocephalic AVF (*P* value 0.025, OR 3.911, 95% CI 1.191–12.849) were significantly associated predictors of successful AVF maturation.

Vascular parameter regression showed that arterial depth greater than 3.92 mm, arterial flow velocity greater than 88 ml/min, preoperative average vein diameter of greater than 2.5 mm, arterial flow velocity of greater than 73 ml/min immediately postoperatively, and average vein diameter of greater than 3.94 mm immediately postoperatively were significant predictors of successful maturation at 6 weeks postoperatively (*P* values 0.001, <0.0001,

Figure 2



Area under the curve	p-value	Cut off value	Sensitivity	1-Specificity
0.780	.067	322.8ml/min	.756	.250

Receiver-operated curve curve showing average vein flow velocity values above which the arteriovenous fistu is likely to mature.

<0.0001, <0.0001, and <0.0001, respectively). Multivariate logistic regression analysis showed that the most important factor associated with the response for predictors of successful AVF maturation is the blood flow in the artery at the site of anastomosis preoperatively of more than 88 ml/min with an odds ratio OR of 255 (Table 5).

Discussion

Although AVFs are regarded as the preferred dialysis access, there is still a high rate of failure [13]. Consequently, the quest to attain a reliable parameter that can predict the successful maturation of an AVF has been relentlessly sought by vascular surgeons, owing to the delicacy of the procedure, fragility of the patient population, and the dire need for a reliable access to dialysis to accommodate the increasing average life expectancy of patients on renal replacement therapy.

Numerous factors have been postulated to predict successful maturation, the least controversial of which are preoperative absolute vein and artery diameters. The relevance of absolute preoperative vein diameter as a predictor for the outcome has been studied by several research projects, and the controversy regarding the cutoff value was addressed by the KDOQI guidelines initially in 2016, recommending a minimum vein diameter of 2.5 mm, to provide primary patency ranging from 63% to 76% [14].

However in other studies—in addition to the most recent update of the KDOQI guidelines—it is considered reasonable that while there is no minimum diameter threshold to create an AVF, arteries and veins of less than 2 mm in diameter should undergo careful evaluation for feasibility and quality to create a functioning AVF, as the previously stated recommendation had not been validated [4,15].

For instance, a study by El Khoury and her colleagues emphasized that neither the maximum target vein diameter nor a target vein size greater than 3 mm was significantly predictive of AVF maturation on multivariate analysis [16]. In our study, preoperative vein diameters greater than 2.51 mm were associated with statistically significant higher maturation rates.

Other predicting factors for failure to mature stated in KDOQI guidelines were female gender, old age, obesity, and the presence of comorbidities such as coronary heart disease and peripheral vascular disease [4]. In our study, none of the aforementioned predictors was statistically significantly different

Table 5 Logistic regression analysis for predictors of successful arteriovenous fistu maturation

	Univariate analysis				Multivariate analysis			
			95% CI for OR				95% CI for OR	
	P	Odds ratio (OR)	Lower	Upper	*P*	Odds ratio (OR)	Lower	Upper
Age>46 years	0.002	31.000	3.451	278.444				
DM	0.001	0.115	0.031	0.433				
Duration of HD>24 months	<0.0001	12.500	3.108	50.278				
History of previous access	0.001	11.000	2.587	46.779				
Pulse≤84 bpm	0.005	21.857	2.586	184.717				
DBP≤80 mmHg	0.085	6.652	0.768	57.624				
PLT >312 $\times 10^3$	0.026	4.016	1.184	13.622				
Creat >5 mg/dl	<0.0001	39.000	6.681	227.650				
ALT >26 U/L	<0.0001	33.833	6.648	172.194				
AST>25 U/L	<0.0001	18.200	4.184	79.168				
Site of the fistula	0.025	3.911	1.191	12.849				
Artery at the site of anastmosis preoperative								
Depth >3.92 mm	0.001	11.000	2.587	46.779				
Flow velocity >88 ml/min	<0.0001	255.000	21.502	3024.073	<0.0001	255.000	21.502	3024.073
Vein at the site of anastmosis pre operative								
Diameter >2.51 mm	<0.0001	164.333	15.814	1707.725				
Vein 3 cm proximal preoperative								
Diameter >2.5 mm	<0.0001	119.000	12.261	1154.917				
Vein 6 cm proximal preoperative								
Diameter >2.49 mm	<0.0001	248.000	20.870	2947.004				
Average vein measurements preoperative								
Diameter>2.5 mm	<0.0001	164.333	15.814	1707.725				
Artery at the site of anastomosis immediately postoperative								
Flow velocity>73 ml/min	<0.0001	255.000	21.502	3024.073				
Vein at the site of anastomosis immediately postoperative								
Diameter>4 mm	<0.0001	164.333	15.814	1707.725				
Vein 3 cm proximal immediately postoperative								
Diameter>3.95 mm	<0.0001	119.000	12.261	1154.917				
Vein 6 CM proximal immediately postoperative								
Diameter>3.88 mm	<0.0001	164.333	15.814	1707.725				
Average vein measurements immediately postoperative								
Diameter>3.94 mm	<0.0001	77.333	11.678	512.124				
Difference and % increase immediately postoperative								
Difference diameter >1.38 mm	<0.0001	48.333	8.677	269.224				
% increase diameter >55.62	0.001	12.778	2.969	54.999				
Difference and % increase 6 weeks postoperative								
Difference in vein diameter >2.99	<0.0001	48.333	8.677	269.224				
% increase in diameter>119.89	0.035	3.750	1.100	12.786				

between the successfully matured and failed to mature groups with the exception of age greater than 46 years and diabetes.

When it comes to flow velocity, some studies have tackled absolute perioperative values of flow velocity in both the artery and the vein as predictors for success. Flow is an important determinant of AVF maturation, and therefore providing flow predictions for surgical planning might improve functional maturation rates [17]. For example, a study by Berman and his colleagues found a significant difference between the maximal intraoperative flow rates in the vein 5 mm from the arteriovenous anastomosis between functional (defined as AVFs that were successfully cannulated by two needles for three complete dialysis sessions) and nonfunctional AVFs (573.6±103 ml/min vs. 216.8 ±35.8 ml/min; $P<0.05$) [18].

Similar results for blood flow rate as a predictor of AVF maturation were reported by Robbin and his colleagues. They analyzed 602 participants during a study period of 3 years, assessing the anatomic development of AVFs during the first 6 weeks after AVF creation using ultrasonography measurements in a multicenter hemodialysis fistula maturation study. In their study, the percentages of fistulas that met the 1-day, 2-week, and 6-week KDOQI maturation criteria were 67% (308/459), 79% (346/459), and 76% (347/459), respectively. Blood flow rate at day 1 was usually more than 50% of that determined at 6 weeks. According to Robbin *et al.*, more than 60% of participants had AVF flows of at least 250 ml/ min at the 1-day assessments [19].

In reference to our data, 78% (39/50) of participants with AVF had AVF flows of greater than 250 ml/min at the 1-day assessments. Our data of AVF flow on the 1-day assessment are comparable to those of Robbin *et al.*

Moreover, Benaragamaand colleagues, Johnsonand colleagues., Berman and colleagues, and Gjorgjievskiand colleagues found that 300 ml/min blood flow, 320 ml/min blood flow (in native AVFs), 308 ml/min (in brachiocephalic AVFs), and 395 ml/min blood flow, respectively, within the first postoperative 24 h are threshold values associated with AVF maturation [18,20–22].

In our study, we observed that an immediately postoperative average venous flow velocity of 326.15 ml/min was the cutoff value for predicting successful AVF maturation, which is comparable with the findings of the aforementioned studies. Moreover, we found that an immediate increase in flow velocity of 322.8 ml/min intraoperatively is the cutoff value that predicts AVF maturation.

Our study limitations include our findings that the absolute preoperative vein flow velocity cannot be exclusively used as a reliable predictor for AVF maturation. However, ROC curves revealed an increase in flow velocity to be a *fair* test when it comes to sensitivity or specificity in predicting the successful maturation of AVF, in addition to including a small number of patients. However, because the objective of our study was to predict access maturation, our findings may be useful to predict maturation and plan early interventions for fistulas that will result in maturation failure.

Conclusion

Our study is one among the few that analyzed the impact of baseline blood vessel hemodynamics and morphological characteristics on AVF maturation. It has been shown previously that DUS enables the best assessment of AVF functionality and follow-up of morphological and hemodynamic parameters. This study found that measuring flow velocity immediately postoperatively using Doppler ultrasonography after arteriovenous fistula creation with a cutoff value of 322 ml/min had a good predictor for successful AVF maturation.

Conflicts of interest

The authors of this article have no conflicts of interest to disclose.

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