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Research Article
Comparative Study of Hemodialysis in Arteriovenous Fistulas in Low Versus High Blood Flow Rate

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Abstract
Background and Objective: Arteriovenous Fistula (AVF) is an essential requirement in Hemodialysis (HD) to remove toxins and excess fluid from the blood of patients with Chronic Renal Failure (CRF). The Blood Flow Rate (BFR) in AVF is an important factor in the success of HD. Due to a lack of studies of low BFR during HD, this study was conducted. The objective of this study was to compare the success rate of HD in patients with a BFR = 400-500 mL min^{-1} (group-2), in comparison to those of higher BFR (group-1). **Materials and Methods:** This prospective cohort study was conducted at the ultrasound Doppler (USD) unit in King Fahad Hospital in Almadinah from July to December, 2019. In this study, 44 patients underwent AVF for HD and were assessed by USD for 2 consecutive visits at 3 months intervals. The success rate of HD was measured in patients with a BFR = 400-500 mL min^{-1} and in those with BFR>500 mL min^{-1}. A comparison of the success rate in the 2 groups was done. **Results:** Among the 44 patients, 59% were males and 41% were females. The age of participants ranged from 20-80 years (mean: 46.75±13.67 years). The patients underwent HD 3 or 2 session's week^{-1} for 3 or 4 hrs (mean 3.84±0.36 h) per session. In the first assessment, the success rate was 100% in both groups but it was 88.24% in group-1 and 70% in group-2 in the second assessment. **Conclusion:** The success rate of hemodialysis in patients with BFR 400-500 mL min^{-1} in AVF was acceptable in comparison to that in patients with BFR>500 mL min^{-1}.

Key words: Arteriovenous fistula, hemodialysis success, high blood flow rate, low blood flow rate, chronic renal failure, arteriovenous graft, renal replacement therapy

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Hemodialysis (HD) or peritoneal dialysis is an essential therapy in patients of Chronic Renal Failure (CRF) concerned with the removal of toxins and excess fluid from the blood[1]. Vascular access for Arteriovenous Fistula (AVF) is an essential requirement to do HD[2]. The establishment and maintenance of AVF for HD acts as a lifeline for patients with CRF who need renal replacement therapy[1,3]. The upper limbs are the most commonly used for creating Arteriovenous Access (AVA) for dialysis and can be created by an artery to vein Arteriovenous Fistula (AVF) or by interposing a synthetic conduit between the artery and vein as an Arteriovenous Graft (AVG). On examination, AVA will have a thrill or vibration due to turbulent blood flow within it. Change in the thrill may indicate a problem with the graft. A weak thrill can denote poor arterial inflow or arterial stenosis. Feeling a pulse rather than a thrill denotes high-grade stenosis at the outflow of the AVA. An increase in venous pressure during dialysis can indicate significant stenosis at the venous outflow[4]. Mature AVF should be of high patency and free of infection because mortality among hemodialysis patients remains high due to sepsis and ischemic heart disease[4,5]. The AVF must be able to sustain blood flow demands for the HD machine. The BFR in the AVF should be slightly greater than the demands of the blood pump. Duplex Ultrasound (DUS) is a widely available, non-invasive and effective imaging modality used to evaluate the AVF for dialysis[4,6]. A Peak Systolic Velocity (PSV) of $\geq$500 cm sec^{-1} is reliable in predicting $\geq$50% stenosis in AVF with 89% sensitivity and 99% Positive Predictive Value (PPV)[7]. Creatinine is a metabolic product of muscles that are normally excreted by the kidneys and it is a reliable indicator of renal function. Serum phosphate is another marker that increased in CRF with different kinetics from the kinetics of the creatinine[8]. The efficacy of HD is influenced by 1) Blood Flow Rate (BFR), 2) Dialysis Fluid Flow Rate (DFR) and 3) the mass transfer area coefficient. The flow ratio (BFR: DFR) is said to be 1:2 to obtain balanced HD efficacy[9]. Decrease BFR is postulated to cause inadequate HD, however, the optimal BFR is still unclear[10]. "The rule of 6" identifies the characteristics of mature AVF by ultrasound imaging, includes BFR>600 mL min^{-1}, the diameter of the out-flow vein $\geq$6 mm and the depth of the out-flow vein $\leq$6 mm from the surface of the skin[11]. A flow rate of $\geq$400 mL min^{-1} in the radio-cephalic arteriovenous fistula (RC-AVF) in the first month, post-operation, predict a more successful HD than blood flow rate $\leq$400 mL min^{-1} (81 vs. 62%)[12].

This study objective was to compares the success rate of HD in patients with a BFR = 400-500 mL min^{-1}, in comparison to those of a BFR>500 mL min^{-1} (Fig. 1). We suspected that AVF with a BFR 400-500 mL min^{-1} has a similar success rate of HD in comparison with a BFR>500 mL min^{-1}.

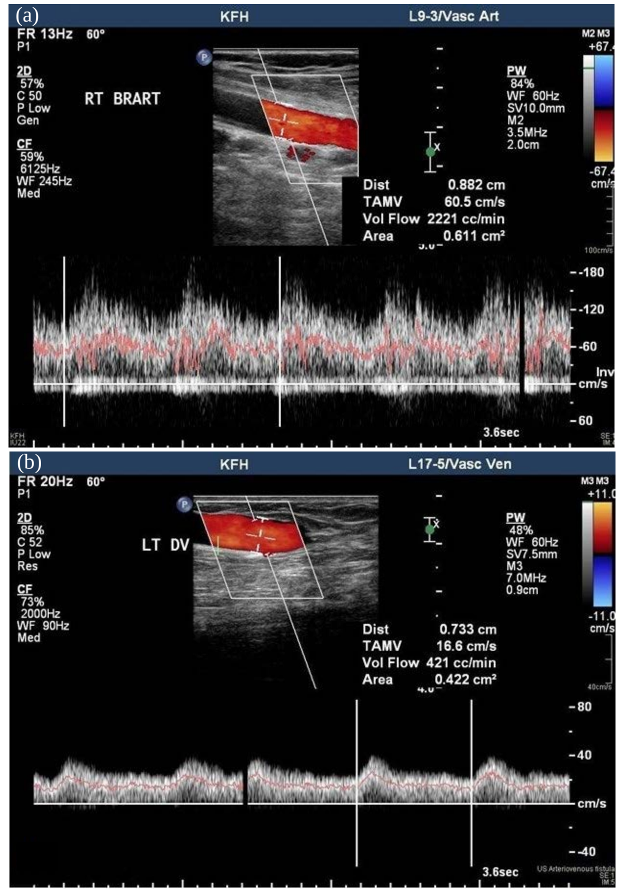

Fig. 1(a-b): Duplex ultrasound images of different two patients with arteriovenous fistula for hemodialysis shows (a) high blood flow volume (2221 mL min^{-1}) in the right brachial artery and (b) low blood flow volume (421 mL min^{-1})

MATERIALS AND METHODS

Patient selection: This prospective cohort study was conducted at King Fahad Hospital in Almadinah, from 1st July to December 31st, 2019. In this study, 44 patients of CRF underwent AVF for HD and were assessed for two consecutive visits at three-month intervals at the Doppler unit. The cohort study consisted of 34 patients in group 1 (BFR>500 mL min^{-1}) and 10 patients in group 2 (BFR = 400-500 mL min^{-1}). This study included patients of CRF who recently underwent AVF for HD in the last month. Exclusion criteria include the following: (1) Patients with AVF older than 1 month,

(2) Patients who had non-functioning AVF in the second assessment and (3) Patients who lost in the second assessment.

Study design: First, consent was obtained and individual structural interviews were performed with the participants. Second, the DUS assessment of the AVF and measurement of the BFR was performed for each patient in the first month of doing AVF (first assessment). Finally, appointments for the next DUS were arranged after three months to follow up on the study parameters (second assessment).

Procedure: DUS assessment was done by a highly qualified radiologic technologist with 13 year's experience working with DUS. Linear vascular transducers of L9-3 MHz and L17-5 MHz of Philips IU22 ultrasound machine were used to assess the diameter, PSV and BFR in AVF of all patients who participated in this study. Diameter, PSV and BFRs were assessed in the brachial artery proximal to the site of arteriovenous anastomosis in all participants.

BFR was measured using the following Eq.[11]:

$$\text{BFR (mL min}^{-1}) = \text{Mean velocity (cm sec}^{-1}) \text{ x area } (r^2\pi) \text{ x 60 sec}$$

The success rate (Number of patients with the success of HD) was measured in the first and second assessments using the simple equation of measuring ratio[13].

Study variables: During each assessment, the date of AVF, site of AVF (Radio-cephalic or brachio-cephalic) and diameter (mm), the frequency of HD (session week^{-1}), duration of the session of HD (h session^{-1}), PSV (cm sec^{-1}) and BFR (mL min^{-1}) were assessed.

Data analysis: Data analysis was performed using the "Statistical Package for Social Sciences" (SPSS) program. The data were presented as frequency and percentage for continuous variables and the mean±standard deviation (SD) for descriptive variables. An Independent-samples t-test was done to show the difference in means between the 2 groups in the first and second assessments. A chi square test was used to evaluate the significance of the results. This was assumed to be significant when the p-value reached $p<0.05$.

RESULTS

Among the 44 patients enrolled in this study, 26 (59%) were males and 18 (41%) were females. Their ages ranged from 20-80 years (mean: 46.75±13.67 years). The patients underwent HD 3 or 2 sessions (mean: 2.86±0.41 session) per week for 3 or 4 h (mean 3.84±0.36 h) per session. Table 1 summarizes the information of the native AVF of the patients involved in the study.

In comparison between the 2 groups in the second assessment, the Independent-samples t-test showed that BFR 2 was higher in group-1 in both the first and second assessments (p = 0.035) and the success rate was higher in group-1 (p<0.001 and = 0.018, respectively) (Table 2).

Table 1: Information on the Arteriovenous Fistula (AVF) of the enrolled patients

Variables	Categories	Numbers	Percentage
Side of AVF	Right	12	27.3
	Left	32	72.7
	Total	44	100.0
Site of AVF	Brachiocephalic/basilic	21	47.7
	Radio cephalic	23	52.3
	Total	44	100.0
Frequency of dialysis (session week^{-1})	Three times	40	91.0
	Two times	4	9.0
	Total	44	100.0
Duration of dialysis (H session^{-1})	Four hours	37	84.0
	Three hours	7	16.0
	Total	44	100.0
Blood flow rate in the first assessment (BFR-1)	>500	34	77.3
	400-500	10	22.7
	Total	44	100.0
Blood flow rate in the second assessment (BFR-2)	>500	32	72.7
	400-500	5	11.4
	Non-functioning	7	15.9
	Total	44	100.0

AVF: Arteriovenous fistula, BFR-1: Blood flow rate in the first assessment within the first month after doing AVF, BFR-2: Blood flow rate in the second assessment three months later to the first assessment

Table 2: Independent-samples t-test to compare between the 2 groups (Group-1 with BFR>500 mL min^{-1} and group-2 with BFR<500 and $\geq$400 mL min^{-1})

Variables	BFR	N	Mean	Std. deviation	Std. error mean	p-value
Diameter 1	Group-1	34	5.8441 mm	1.37162	0.23523	0.055
	Group-2	10	3.9100 mm	0.80340	0.25406	
Diameter 2	Group-1	34	5.9118 mm	2.90368	0.49798	0.775
	Group-2	10	3.1200 mm	2.23348	0.70629	
PSV 1	Group-1	34	176.4706 cm sec^{-1}	48.04558	8.23975	0.061
	Group-2	10	108.5000 cm sec^{-1}	30.37269	9.60469	
PSV 2	Group-1	34	171.1765 cm sec^{-1}	92.71215	15.90000	0.288
	Group-2	10	81.5000 cm sec^{-1}	62.93957	19.90324	
BFR 1	Group-1	34	1143.2353 mL min^{-1}	646.92616	110.94692	<0.001
	Group-2	10	413.0000 mL min^{-1}	39.45462	12.47664	
BFR 2	Group-1	34	1119.7059 mL min^{-1}	860.14264	147.51325	**0.035**
	Group-2	10	360.0000 mL min^{-1}	270.76025	85.62191	
Success 2	Group-1	34	88.24%	0.32703	0.05609	**0.018**
	Group-2	10	70%	0.48305	0.15275	

The table revealed significant differences in the BFR between the two groups (p<0.001), (95% confidence interval 503.298-957.172) in the 1st assessment and significant differences in the 2nd assessment (p = 0.035). It showed a significant difference in the success rate of dialysis between the two groups (p = 0.018), which was 88.23% in group 1 and 70% in group 2. Group-1: Patients with BFR>500 mL min^{-1}, Group-2: Patients with BFR<500 and $\geq$400 mL min^{-1}, Diameter-1: Diameter of the brachial artery in the first assessment, Diameter-2: Diameter of the brachial artery in the second assessment, PSV-1: Peak systolic velocity in the measured in the first assessment, PSV-2: Peak systolic velocity measured in the second assessment, BFR-1: Blood flow rate measured in the first assessment, BFR-2: Blood flow rate measured in the second assessment, Success-2: The number of patients with the success of HD in the second assessment

Table 3: Independent-samples t-test compared the biological data in brachiocephalic/basilic and radio-cephalic AVF

Variables	Site of AVF	N	Mean	Std. deviation	Std. error mean	p-value
Diameter 1	Brachiocephalic	21	6.2524 mm	1.47838	0.32261	0.153
	Radio-cephalic	23	4.6304 mm	1.04900	0.21873	
Diameter 2	Brachiocephalic	21	6.2714 mm	3.38499	0.73866	0.136
	Radio-cephalic	23	4.3696 mm	2.28123	0.47567	
PSV 1	Brachiocephalic	21	181.4286 cm sec^{-1}	52.27674	11.40772	0.842
	Radio-cephalic	23	142.3913 cm sec^{-1}	47.09443	9.81987	
PSV 2	Brachiocephalic	21	182.1429 cm sec^{-1}	108.27709	23.62800	0.096
	Radio-cephalic	23	122.1739 cm sec^{-1}	69.89970	14.57510	
BFR 1	Brachiocephalic	21	1266.6667 mL min^{-1}	739.63054	161.40062	<0.001
	Radio-cephalic	23	713.0435 mL min^{-1}	406.75473	84.81422	
BFR 2	Brachiocephalic	21	1221.4286 mL min^{-1}	992.58897	216.60067	**0.008**
	Radio-cephalic	23	696.5217 mL min^{-1}	556.17696	115.97091	
Success 2	Brachiocephalic	21	85.71%	0.35857	0.07825	**0.583**
	Radio-cephalic	23	82.61%	0.38755	0.08081	

The table revealed a significant difference in BFR between brachiocephalic/basilic and radio-cephalic AVF (p<0.001), (95% confidence interval 194.734-912.512) in the 1st assessment, and significant differences in the 2nd assessment (p = 0.008). However, there were no significant differences in the success rate between the two sites of AVF (p = 0.583). Diameter-1: Diameter of the brachial artery in the first assessment, Diameter-2: Diameter of the brachial artery in the second assessment, PSV-1: Peak systolic velocity measured in the first assessment, PSV-2: Peak systolic velocity measured in the second assessment, BFR-1: Blood flow rate measured in the first assessment, BFR-2: Blood flow rate measured in the second assessment, Success-2: The number of patients with the success of HD in the second assessment

Table 4: Success rate in group 1 and 2 and in brachiocephalic/basilic and radio-cephalic AVF

Variables	Categories	Total no. of patients	No. of success patients	Success (%)	p-value
BFR 1	Group-1	34	34	100.00	-
	Group-2	10	10	100.00	
BFR 2	Group-1	34	30	88.24	**0.018**
	Group-2	10	7	70.00	
Site of AVF	Brachiocephalic	21	18	85.71	0.583
	Radio-cephalic	23	19	82.61	

The table showed no difference in the success rate (Number of patients with the success of HD) between the two groups in the first assessment but showed a significant difference in the second assessment (p = 0.018). The table showed no significant difference in the success rate between brachiocephalic/basilic and radio-cephalic AVF (p = 0.583). BFR-1: Blood flow rate measured in the first assessment, BFR-2: Blood flow rate measured in the second assessment, BFR: Blood flow rate

In comparison between the brachiocephalic/basilic and radio-cephalic AVF in the second assessment, the Independent-samples t-test showed that BFR 2 in brachiocephalic/basilic AVF was higher than in the radio cephalic AVF (p = 0.008) but the success rate was not significantly higher (p = 0.583) (Table 3).

The success rate was 100% in both groups in the first assessment and the success rate was 88.24% in group 1 and 70% in group 2 in the second assessment. However, it was 85.71 and 82.61% in the brachiocephalic/basilic and radiocephalic AVF, respectively (Table 4).

DISCUSSION

This study investigated the success rate of HD in AVFs with a BFR = 400-500 mL min^{-1}, in comparison to those with a BFR> 500 mL min^{-1}. Herein, 44 patients with CRF underwent AVF for HD was assessed for two consecutive visits at 3 month intervals using DUS. The results showed that patients with BFR = 400-500 mL min^{-1} achieved a success rate not very far from those with BFR>500 mL min^{-1}.

Berland *et al.*[14] reported that the physiological suitability of AVF was defined by target BFR>500 mL min^{-1} and the diameter of the cannulated blood vessel $\geq$4 mm. Our results showed larger diameters in brachiocephalic AVF and smaller diameters in radio-cephalic AVF with acceptable success rates apart from the significant difference in BFR between the two sites of AVF.

In our results, AVF with BFR = 400-500 mL min^{-1} achieved success rates of dialysis not far from those of AVF with BFR>500 mL min^{-1}. These BFRs are entailed the minimum flow rate recommended by a previous study which reported that BFR should be $\geq$312 mL min^{-1}[15].

Zamboli *et al.*[16] reported that 65% of AVF with a high BFR had symptoms of heart failure and were diagnosed with High Cardiac Output Failure (HCOF). Basile *et al.*[17] reported that AVF with a high BFR may harm heart functions and may cause HCOF. Our study and the last two studies suggested that radio-cephalic AVF that achieved success rates close to those in brachiocephalic/basilic may be better regarding their low BFR and low HCOF rate[16,17].

This study was limited by its small sample size and laboratory investigations were measured only in the first assessment. The BFR was not measured in patients who failed to undergo hemodialysis in the second assessment.

CONCLUSION

The success rate of hemodialysis in patients with BFR<500 mL min^{-1} (exactly 400-500 mL min^{-1}) in arteriovenous fistula was acceptable in comparison to that in patients with BFR>500 mL min^{-1}. Radio-cephalic AVF achieved a success rate close to brachiocephalic AVF with similar outcomes with the preference of the lower risk complications.

SIGNIFICANCE STATEMENT

This study discovers that the success rate of hemodialysis in arteriovenous fistulas with a blood flow rate from 400-500 mL sec^{-1} near that those with blood flow rates of more than 500 mL sec^{-1}. This study will help the physicians of nephrology in working with patients of chronic renal failure. We are the first researchers to explore this point. Thus, we recommend more studies like this in arteriovenous fistulas with a blood flow rate of less than 400 mL sec^{-1}.

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