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RESEARCH

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Do fistula flow rate and fistula location have any effects on heart failure developing in patients with arteriovenous fistula?

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Abstract

Background This study aims to explore the effects of arteriovenous fistula locations in the arm and fistula flow rates on the potential development of heart failure in patients with arteriovenous fistula (AVF).

Material and methods A total of 116 patients with AVF due to chronic kidney disease were retrospectively reviewed between January 2022 and August 2022. Fifty-six patients with distal AVFs and 60 with proximal AVFs were compared in terms of demographic, clinical, and echocardiographic characteristics. Fistula flow rates were assessed using Doppler ultrasonography, while cardiac parameters were evaluated with echocardiography. The correlation between fistula location and cardiac parameters was analyzed using ROC analysis.

Results The mean AVF blood flow rate was 1.47 (0.57–2.9) L/min for proximal fistulas and 0.85 (0.52–2.3) L/min for distal fistulas. There were statistically significant differences between the proximal and distal AVF groups regarding cardiac index, cardiac output, and cardiopulmonary recirculation values ($p< 0.001$). According to the New York Heart Association classification, Class III can be categorized as high cardiac output failure (HCOF), as cardiac index was calculated at 6.87 ± 1.65 L/min/m^2 (4.7–9.4), fistula flow rate at 2.60 L/min (2.1–2.9), and cardiac output at 8.08 ± 0.69 L/min.

Conclusions When heart failure develops in patients with AVF, underlying heart disease should not be the sole factor considered. Proximal high-flow AVFs, in particular, may contribute to heart failure development and warrant careful monitoring.

Keywords Hemodialysis, Fistula location, Fistula flow rate, Heart failure

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Introduction

End-stage renal disease (ESRD) is a clinical condition that affects nearly all organ systems and can be life-threatening if untreated. Due to the insufficient number of kidney transplants, hemodialysis remains the most commonly used treatment method. Among vascular access options, arteriovenous fistula (AVF) is considered the safest and most durable, with the lowest rates of mortality and morbidity [1, 2]. Effective hemodialysis requires sufficient blood flow, durability, and easy, repeatable cannulation. AVFs are categorized by their location as proximal (e.g., brachiocephalic, brachiobasilic) or distal (e.g., snuffbox, radiocephalic). However, complications such as bleeding, infection, hematoma, thrombosis, stenosis, ischemic neuropathy, skin necrosis, steal syndrome, aneurysm/pseudoaneurysm, and high cardiac output failure (HCOF) are associated with AVFs. Fistula flow rate (Qa) plays a critical role in ensuring effective hemodialysis. While low Qa may indicate vascular access issues, high Qa is hypothesized to increase cardiac output (CO), potentially leading to HCOF [3]. Studies on long-term hemodialysis patients have introduced the concept of the Qa-to-CO ratio, known as cardiopulmonary recirculation (CPR) [4].

The Vascular Access Society guidelines define high-flow AVF as one with a Qa of 1.0–1.5 L/min and a CPR > 0.20 [5]. Not all patients with high-flow AVFs develop heart failure. Some researchers suggest that HCOF, defined as symptomatic heart failure with an elevated cardiac index, is a rare complication of high-flow AVFs and usually occurs only in the presence of underlying heart disease [6, 7]. This study aims to investigate the relationship between fistula flow rates and heart failure symptoms, the correlation of Qa with CO, and the effects of fistula location on flow and cardiac output, and echocardiographic changes in patients with AVFs.

Materials and methods

This study included 116 chronic hemodialysis patients treated and monitored at the Cardiovascular Surgery Clinic of Tekirdağ Namık Kemal University. Patients participated in a dialysis program for at least six months between January 2022 and August 2022. Among them, 56 had distal and 60 had proximal arteriovenous fistulas (AVFs). The study was conducted in compliance with the Declaration of Helsinki principles and approved by Tekirdağ Namık Kemal University Faculty of Medicine Non-Interventional Clinical Research Ethics Committee with the approval number E-46048792-050.01.04-25488. Informed consent to participate was obtained from all the study participants. The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

AVF flow rate was calculated using Doppler ultrasonography (DUS). Flow volume was determined based on AVF vessel diameter and mean flow rate using an algorithm embedded in the ultrasonography system [8]. Patients were examined in the supine position with the access limb supported. B-mode and color Doppler images were obtained in longitudinal and transverse planes, covering ≥ 10 cm of the arterial inflow and anastomosis. Flow velocities were measured at multiple sites proximal to the anastomosis, and the highest volume flow was recorded. The access flow rate (Qa, in ml/min) was calculated using the formula: time-averaged mean velocity × cross-sectional area × 60. This technique is consistent with Guidelines for Vascular Access [5, 8]. A linear color Doppler ultrasound scan (L12-4 for ClearVue Transducer, Philips) was performed with a probe and an incidence angle of 60 degrees to optimize the signal. Flow rate (Qa) (ml/min) = time-averaged mean velocity x section area x 60. Cardiopulmonary recirculation (CPR) is defined as the degree of purified blood that bypasses tissue circulation and returns to the heart before it is passed through pulmonary circulation for oxygenation. CPR was calculated as mean vascular access flow volume/cardiac output. Cardiac output (mL/min) was measured as left ventricular output area (cm^2) x velocity time integral (cm) x heart rate (bpm). Cardiac index ($l/min/m^2$) was calculated by dividing cardiac output by body surface area.

A distal AV fistula was defined as a radiocephalic fistula (an anastomosis of the radial artery and the cephalic vein at the wrist level), which is surgically created at the wrist by connecting the radial artery to the cephalic vein. This was often considered the "first-choice" site due to its distal placement. A proximal AV fistula was defined as a brachiocephalic fistula (an anastomosis between the brachial artery and the cephalic vein in the proximal forearm or a brachial-basilic fistula, an anastomosis between the brachial artery and the basilic vein in the upper arm). These definitions were carefully adopted after a thorough review of existing literature and guidelines to maintain alignment with widely accepted terminology in vascular access research. AV fistulas had been created before inclusion, and only those with adequate blood flow (More than 500 ml/min) were assessed and included in the dialysis program. Dialysis initiation criteria were determined based on the guideline recommendations.

The study cohort comprised patients with preserved left ventricular systolic function, defined as a left ventricular ejection fraction (LVEF) > 50%, and asymptomatic or minimally symptomatic cardiac status (New York Heart Association [NYHA] Functional Class I). Individuals with a history of active heart failure requiring hospitalization were excluded from participation to minimize confounding by advanced cardiac dysfunction. Our study did not include detailed data on patients' fistulas or related complications such as aneurysms or infections.

Exclusion criteria included patients with Class IV heart failure (HF) per the New York Heart Association (NYHA) classification, a history of cardiac surgery, structural heart disease (e.g., valvular or congenital abnormalities) identified by echocardiography (ECHO), prior kidney transplantation, or arterivenous grafts other than native ones. Demographic data and hemodialysis (HD) duration were recorded (Table 1). Before transthoracic ECHO, HF symptoms were evaluated using the NYHA classification:

- Class I: No limitation of physical activity.
- Class II: Slight limitation of physical activity (HF symptoms with ordinary activity but not at rest).
- Class III: Marked limitation of physical activity (HF symptoms with mild activity but not at rest).
- Class IV: Symptoms of HF at rest.

Patients were classified and recorded per the NYHA stages of HF at baseline and during follow-up. Class III was considered high cardiac output failure (HCOF) only if the cardiac index (CI) exceeded normal values (> 3.0 L/min/m²) [9]. Heart failure symptoms included dyspnea, paroxysmal nocturnal dyspnea, orthopnea, and pulmonary and/or peripheral edema, assessed in conjunction with an elevated CI (> 3.0 L/min/m²) [9]. Cardiac parameters, including left ventricular and left atrial functions, pulmonary arterial pressure, cardiac output (CO), ejection fraction (EF), and heart rate, were calculated via ECHO. Patients were grouped based on fistula location. Assessments were performed within 24 h post-dialysis.

Statistical analysis

SPSS 25.0 software was used for data analysis. Categorical variables were summarized as numbers and percentages, while continuous variables were expressed as means and standard deviations (or medians with minimum and maximum values, as necessary). Categorical variables were compared using the Chi-square or Fisher's exact test. Continuous variables were analyzed with one-way ANOVA or Student's t-test for parametric distributions and the Kruskal-Wallis or Mann-Whitney U test for non-parametric distributions. Receiver operating characteristic (ROC) curve analysis was used to calculate sensitivity and specificity for AVF location cut-off values. Statistical significance was set at $p < 0.05$ for all tests.

Results

The study included 116 patients, of whom 78 (67.25%) were male, and 38 (32.75%) were female. The mean age was 56.3 ± 10.03 years. Table 1 provides demographic and clinical characteristics of the patients. The mean body mass index (BMI) was 23.5 ± 3.58, with 68 patients classified as normal weight (BMI 18–25), 42 as overweight (BMI 25–30), 4 as underweight (BMI < 18), and 2 as obese (BMI > 30). The mean hemoglobin (Hb) level was 11.25 ± 1.82 g/dL. Among the patients, 30 (25.86%) had diabetes mellitus (DM), 50 (43.1%) had hypertension (HT), 2 (1.7%) had a history of myocardial infarction, and 2 (1.7%) had cerebrovascular disease. The mean systolic blood pressure was 127.1 ± 21.7 mmHg, and the diastolic blood pressure was 74.5 ± 15.6 mmHg. Most patients (86%, 100 patients) underwent 4-hour dialysis sessions, with 14% (16 patients) undergoing sessions shorter than 4 h. No patients had sessions longer than 4 h. Additionally, 95% of patients (110) had dialysis three times a week, while 5% (6) had it twice weekly.

The mean AVF duration was 46.1 ± 18.12 months, and no patients exhibited cardiac arrhythmias. In our study, hydration status was appropriately managed in all patients. However, since this was a cross-sectional study, we did not have data on whether patients experienced hypervolemia during the study period.

Clinical and cardiac characteristics

Table 1 summarizes patient characteristics by AVF location: According to this, 60 patients had proximal and 56 patients had distal AVF. Statistically significant differences were observed between groups for age, BMI, AVF duration, and Hb values but not for blood pressure. Table 1 shows echocardiographic differences, including significant variations in left ventricular dimensions, volumes, and mass index, as well as left atrial parameters and pulmonary arterial pressure. Complications were observed in a total of 4 patients. In 2 patients with brachiocephalic AVF; hematoma occurred in the 1 st week controls and subsequently the hematoma was evacuated. In 2 patients with radiocephalic AVF; there was discharge in the skin suture line and it was debrided and re-sutured. In the controls, the fistulas were thrilled and no infection or hematoma was observed.

AVF flow rate and NYHA classification

The mean Qa was 1.47 (0.57–2.9) L/min in proximal fistulas and 0.85 (0.52–2.3) L/min in distal fistulas ($p < 0.001$, Table 2). Significant differences were also observed in CI (5,4 and 3,3 L/min/m2; $p < 0{,}001$), CO (6,6 ± 1,2 and 5,7 ± 1,1 L/min; $p < 0{,}001$), and CPR (%24,6 ± 6,7 and %16,4 ± 5,4; $p < 0{,}001$). NYHA classification revealed.

- Proximal AVF Patients: 17% in Class I, 57% in Class II, and 26% in Class III ($p < 0{,}001$).
- Distal AVF Patients: 50% in Class I, 46% in Class II, and 4% in Class III ($p < 0{,}001$).

A statistically significant higher proportion of proximal AVF patients were in NYHA Classes II and III. Among the Class III patients ($n = 18$), all were classified as HCOF,

Table 1 Clinical characteristics and echocardiographic parameters according to the location of AVFs

Variables	Proximal AVF	Distal AVF	*p* values
Age, years	58.3 ± 9.9	53.9 ± 9.6	*0.011*
BMI, (kg/m2)	24.5 ± 3.5	22.5 ± 3.3	*0.002*
Diabetes mellitus, n%	17 (%28.3)	13 (%23.2)	*0.161*
Hypertension, n%	26 (%43.3)	24 (%42.8)	*0.402*
Myocardial infarction, n%	1 (%1.6)	1 (%1.7)	*0.537*
Cerebrovascular disease, n%	1 (%1.6)	1 (%1.7)	*0.641*
Systolic blood pressure, mm/Hg	129.1 ± 11.3	125.4 ± 13.5	*0.263*
Diastolic blood pressure, mm/Hg	75.5 ± 16.6	73.5 ± 11.0	*0.145*
Hemodialysis time, < 4 h	8 (%13.3)	8 (%14.2)	*0.166*
3 times a week of hemodialysis	59 (%98.2)	51 (%91)	*0.943*
AV fistula duration, months	54(28–82)	34(16–80)	*0.001*
Hemoglobin, gr/dl	10.7 ± 1.4	11.8 ± 2.0	*0.001*
Systolic blood pressure, mm/hg	127.2 ± 22.3	121.1 ± 22.8	*0.148*
Diastolic blood pressure, mm/hg	74.5 ± 15.7	74.3 ± 17.8	*0.945*
Baseline medical treatment, n(%)			
ACEinh/ARB	23 (%38.3)	18 (%32.1)	*0.121*
beta blocker	54 (%90)	49 (%87.5)	*0.332*
Diuretics	24 (%40)	21 (%37.5)	*0.093*
Calcium channel blocker	42 (%70)	39 (%69.6)	*0.284*
LV diastolic diameter, mm	55.36 ± 7.85	50.63 ± 4.74	*0.001*
LV systolic diameter, mm	40.24 ± 8.14	35.84 ± 5.46	*0.001*
Diastolic IVS, mm	11.85 ± 1.55	10.96 ± 0.75	*0.668*
Diastolic posterior Wall, mm	10.46 ± 1.63	11.65 ± 1.67	*0.842*
LV diastolic volüme, ml	110 ± 18	70 ± 16	*0.001*
LV systolic volüme, ml	46 ± 10	33 ± 8	*0.001*
LA diameter, mm	43.6 ± 5.6	39.2 ± 4.5	*0.001*
LA volume, ml/m^2	50 ± 21	37 ± 7	*0.001*
Systolic PAP, mmHg	33.56 ± 9.84	28.75 ± 9.66	*0.001*
LV mass index, g/m^2	158.93 ± 80.76	108.56 ± 43.24	*0.001*
Qa, l/min	1.47 (0.57–2.9)	0.85(0.52–2.3)	*0.001*
Kt/V	1.31 ± 0.63	1.27 ± 0.52	*0.129*
LV ejection Fraction, %	51.5 ± 8.7	57.0 ± 78	*0.001*
Global longitudinal strain, %	−17.4	−19.2	*0.032*
Cardiac output, L/min	6.6 ± 1.2	5.7 ± 1.1	*0.001*
Cardiac index, L/min/m^2	5.4(3.1–9.4)	3.3(2.6–8.9)	*0.001*
A, mitral late diastolic velocity, cm/sn	0.9 ± 0.3	0.8 ± 0.1	*0.289*
E, mitral early diastolic velocity, cm/sn	1.8 ± 0.7	1.6 ± 0.9	*0.164*
E/A ratio	2.1 ± 0.3	1.5 ± 0.4	*0.041*
E wave deceleration time (DT), ms	124.7 ± 21.7	166.6 ± 33.1	*0.022*
Isovolumetric relaxation time (IVRT), ms	65.3 ± 9.6	84.2 ± 15.9	*0.036*
Right Ventricular Ejection Fraction, %	40.1	45.4	*0.022*
Right Ventricular Fractional Area Change, %	31.4	36.2	*0.015*
RV s'Velocity, cm/s	10.3	10.6	*0.091*
Tricuspid Regurtation Systolic Jet Velocity, m/sn	3.2	2.1	*0.027*
Tricuspid Annular Plane Systolic Excursion, mm	13.1 ± 2.6	16.4 ± 3.5	*0.018*
Cardiopulmonary recirculation, %	24.6 ± 6.7	16.4 ± 5.4	*0.001*
Heart rate, beat/min	72.4 ± 15.8	72 ± 13.8	*0.866*
NYHA classification			
Class I	10(%16.6)	28(%50)	*< 0.001*
Class II	34(%56.7)	26(%46.4)	
Class III	16(%26.7)	2(%3.6)	

LV left ventricle, *IVS* interventricular septum, *LA* left atrium, *Kt/V* dialyzer clearance of ureaxdialysis time/volume of distribution of urea, *Qa* AVF flow rate, *PAP* pulmonary artery pressure

Table 2 Comparison of cardiac parameter and AVF characteristics according to NYHA classification

	Class I (*n* = 38)	Class II (*n* = 60)	Class III (*n* = 18)	*P* value
Qa, (l/min)	0.76(0.52–1.2)	1.30(0.57–2.3)	2.60(2.1–2.9)	***< 0.001***
EF, (%)	58.10 ± 7.90	54.4 ± 7.40	45.5 ± 7.11	***< 0.001***
Cardiac output, (l/min)	5.30 ± 1.01	6.13 ± 0.81	8.08 ± 0.69	***< 0.001***
Cardiac index, (l/min/m2)	3.29 ± 0.72	4.8 ± 1.36	6.87 ± 1.65	***< 0.001***
AVF duration, (months)	24(18–36)	48(16–80)	54(28–82)	***< 0.001***
CPR, (%)	15.2 ± 4.9	19.2 ± 6.5	25.7 ± 6.7	***< 0.001***

AVF Arteriovenous Fistula, *EF* Ejection fraction, *CPR* Cardiopulmonary recirculation, *Qa* AVF flow rate

Table 3 Bivariate correlations between NYHA class and continuous patient variales

		Correlation Coefficient	*P* value
Patient characteristics	AGE(year)	−0.246	0.008
	BMI(kg/m2)	−0.341	< 0.001
AVF and hemodialysis characteristics	HF Duration time (h)	0.179	0.054
	HF freequency (Per/week)	−0.177	0.058
	Qa	0.779	< 0.001
	CPR %	−0.541	< 0.001
Echocardiographic findings	EF%	0.442	0.001
	Cardiac output	0.661	< 0.001
	Cardiac index	0.754	< 0.001

AVF Arteriovenous Fistula, *EF* Ejection fraction, *HF* Hemofiltration, *CPR* Cardiopulmonary recirculation, *BMI*: Body mass index, Qa AVF flow rate

with a CI of 6.87 ± 1.65 L/min/m², Qa of 2.60 L/min, and CO of 8.08 ± 0.69 L/min (Table 2).

Bivariate correlation analysis demonstrated significant associations between NYHA class and several continuous patient variables. Among personal characteristics, age ($r = -0.246$, $p = 0.008$) and BMI ($r = -0.341$, $p < 0.001$) were negatively correlated with NYHA class, indicating that lower age and BMI were associated with higher NYHA class (Table 3).

Regarding AVF and hemodialysis parameters, access flow (Qa) showed a strong positive correlation with NYHA class ($r = 0.779$, $p < 0.001$), while cardiopulmonary reserve percentage (CPR%) had a significant negative correlation ($r = -0.541$, $p < 0.001$). Hemodialysis frequency and duration showed weak correlations with NYHA class but were not statistically significant.

In echocardiographic findings, significant positive correlations were observed between NYHA class and EF% ($r = 0.442$, $p = 0.001$), cardiac output ($r = 0.661$, $p < 0.001$), and cardiac index ($r = 0.754$, $p < 0.001$), reflecting a hyperdynamic circulatory profile in patients with higher NYHA class.

Multiple linear regression analysis was performed to identify predictors of NYHA functional class. The model revealed that AVF location (B = 0.522, $p < 0.001$), QA (blood flow rate) (B = 0.001, $p < 0.001$), and AVF duration (B = −0.004, $p = 0.032$) were statistically significant predictors.

AVF location and QA were positively associated with higher NYHA class, indicating worse functional status. Other variables, including EF, CO, CI, CPR, hemogloin, blood pressure, and dialysis parameters, did not show statistically significant associations ($p > 0.05$).

The correlation between fistula locations and cardiac parameters was analyzed using ROC curve analysis. According to the ROC analysis, if the Qa value is > 1.15, the patient's AVF location is likely to be distal, with 64.3% sensitivity, 63.3% specificity, and 73.2% probability. Conversely, if the CPR % value is > 18.5, the AVF location is expected to be proximal, with 80% sensitivity, 75% specificity, and 82.7% probability. If the patient's CO value is > 6.0, the AVF location is likely distal, with 67.9% sensitivity, 60% specificity, and 71.5% probability. Additionally, if the CI value is > 4.2, the AVF location is expected to be distal, with 75% sensitivity, 70% specificity, and 82.8% probability (Table 4 and Fig. 1).

Discussion

Our findings demonstrate a strong association between high-flow AVFs, particularly those located proximally, and markers of high-output cardiac failure. While the cross-sectional nature of this study precludes causal

Table 4 Cutoff, sensitivity, specificity, AUC, and 95% confidence interval values of Qa, CO, CI, and CPR

	Cut off	AUC	95% CI AUC		Sencivity %	Spesivity %	*P* value
			Lower ound	Upper ound			
Qa	1.15	0.732	0.64	0.82	64.3	63.3	0.001
CO	6.0	0.715	0.62	0.81	67.9	60.0	0.001
CI	4.2	0.828	0.75	0.90	75.0	70.0	<0.001
CPR	18.5	0.827	0.75	0.90	80.0	70.0	<0.001

Qa AVF flow rate, *CO* Cardiac Output, *CI* Cardiac Index, *CPR* Cardiopulmonary recirculation

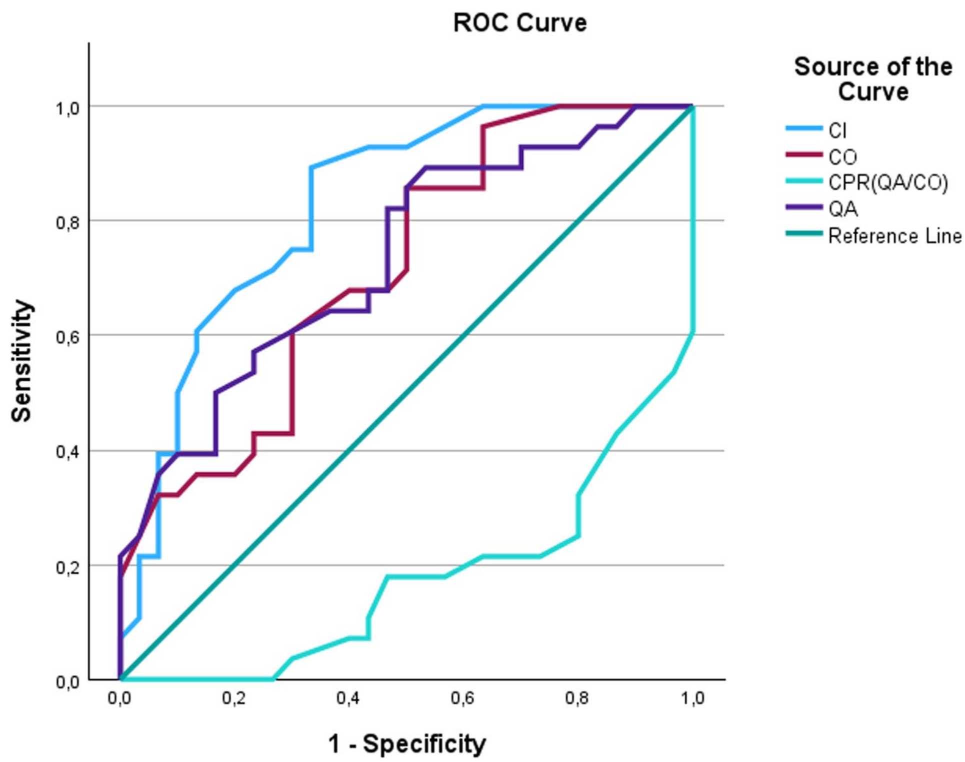

Fig. 1 According to ROC analysis, the values of Qa, CO, and CI vary depending on fistula localization, with CI exhibiting the highest sensitivity and specificity

inference, the data suggest that high AVF blood flow may contribute to or exacerbate cardiac dysfunction, warranting close cardiovascular monitoring in patients with proximal or high-flow fistulas. According to the findings of our study, it seems reasonable to try to operate distal AVF and avoid high-flow proximal AVFs in patients requiring fistula for dialysis. Furthermore, the management of these patients is a team effort including nephrology, cardiology, and cardiovascular surgeons. The presence of an arteriovenous fistula reduces systemic vascular resistance, leading to increased stroke volume and cardiac output (CO) to maintain blood pressure [10]. This adaptation has been demonstrated by studies showing a significant increase in mean blood flow on the AVF side compared to the contralateral side [11]. For instance, brachial arterial flow rates measured via Doppler ultrasound (DUS) increased markedly from baseline values after AVF creation, underscoring the substantial hemodynamic impact of AVFs. However, the correlation between AVF flow rate (Qa) and CO remains poorly understood, with limited data on their interdependence, and it is also estimated that high fistula flow rates increase CO and lead to HCOF.

Some studies suggest that high fistula flow rates (> 2.0 L/min) significantly increase CO, potentially resulting in high cardiac output failure (HCOF). Interestingly, while CO remains stable with AVF flow rates up to 2.0 L/min, further increases can overwhelm myocardial adaptation mechanisms, leading to cardiac dysfunction [3, 12]. This phenomenon is supported by findings indicating a higher prevalence of HCOF in patients with proximal AVFs compared to distal AVFs, as proximal AVFs tend to have higher Qa and CO values [3, 13, 14]. Our analysis showed a parallel increase in cardiac index (CI) values and a higher number of NYHA Class III patients in the proximal AVF group, suggesting a greater risk of HCOF development in this population. When Class II was analyzed, there was no significant difference between the number of patients with proximal AVFs and those with distal AVFs; however, there was a significant difference between the groups for Classes I and III.

The findings of this study emphasize the importance of monitoring AVF flow and cardiac parameters to identify patients at risk for HCOF. According to the correlation analisys a Qa value > 1.15 L/min is associated with a distal AVF, while a CPR > 18.5% and CO > 6.0 L/min suggest a proximal AVF. Additionally, a CI value > 4.2 indicates a distal AVF. Furthermore, echocardiographic data from our study revealed significant cardiac changes after AVF creation, such as increased left ventricular end-diastolic diameter (LVEDD), fractional shortening, and cardiac output (CO). Additionally, when comparing the data obtained right before and 14 days after AVF creation, significant increases were observed in left ventricular end-diastolic diameter (+4%), fractional shortening (+8%), and CO (+15%) [12, 14]. In the long term, cardiac adaptation, characterized by left ventricular hypertrophy (LVH), occurs in hemodialysis patients due to volume overload [15]. While these changes are initially adaptive, they may lead to long-term complications such as LVH, diastolic dysfunction, and ultimately heart failure in patients with high-flow AVFs.

The pathophysiological mechanisms linking high-flow AVFs to heart failure include chronic volume overload and increased left ventricular diastolic volume (LVDV) [16–18]. Evidence from both short- and long-term studies suggests that LVH and elevated left atrial volume (LAV) contribute to diastolic pressure elevation, further exacerbating cardiac dysfunction. This progression underscores the importance of identifying patients predisposed to AVF-induced cardiac decompensation. Although some authors propose that AVF-related heart failure occurs only in those with pre-existing cardiac conditions, our findings indicate that high-flow AVFs alone can trigger HCOF in patients without prior heart disease. Risk factors for high-flow AVFs include male sex, upper-arm AVF placement, and prior fistula surgeries. Additionally, our study corroborates trends from the literature showing increased LVEDV and worsening cardiac parameters in patients with Qa > 2.0 L/min.

Given these findings, regular monitoring of AVF flow using DUS and cardiac function using echocardiography (ECHO) is critical. Such surveillance can help mitigate the risk of HCOF, particularly in patients with proximal AVFs. Our study's data align with previous research emphasizing the need for threshold values, such as Qa and CPR, to guide interventions. For instance, high CPR values (≥20%) and high flow rates (Qa ≥ 2.0 L/min) may serve as predictive markers for cardiac risk. However, further prospective studies are required to validate these thresholds and develop comprehensive guidelines for managing high-flow AVFs.

Limitations of our study include its retrospective, single-center design and the relatively small sample size (116 patients). There are many risk factors for heart failure and cardiac decompensation in the dialysis population. Our patient numbers were low because of the creation of two similar groups with respect to numerous confounding factors. Due to the retrospective design of our study, echocardiography was performed only once and cardiac output monitoring could not be performed. In addition, cardiac catheterization for cardiac output measurement, validation and monitoring could have enriched the results. Furthermore, as a retrospective study, we were unable to monitor complications related to fistulas, hydration imbalances during the study period, or unidentified factors affecting heart failure, which may have influenced patient outcomes. Although hydration status was carefully managed for all patients included in our study, we recognize that some cases of hypervolemia may have occurred, with appropriate interventions presumably being administered at dialysis centers. However, the lack of systematic documentation regarding these cases represents an additional limitation of our study.We agree that a prospective follow-up study would be ideal. However, due to the nature of this patient group—often receiving care at different centers—long-term follow-up is challenging. Despite these limitations, our findings provide valuable insights into the hemodynamic and cardiac consequences of AVFs, particularly their potential to induce HCOF.

Conclusion

The main message of your study is to try to operate a distal AVF on most of the patients and avoid proximal AVFs with high flow. High-flow arteriovenous fistulas, especially proximal ones, are strongly associated with a hyperdynamic circulatory state and worse cardiac functional status, as reflected by higher NYHA class and elevated cardiac output parameters. Our study indicates that proximal AVFs are associated with higher AVF Qa, CI, CO, and CPR values, which collectively suggest an increased risk for HCOF, even in patients without prior heart disease. Therefore, regular monitoring of AVF flow via Doppler ultrasound and cardiac function via echocardiography is essential. While causality cannot be confirmed in this cross-sectional design, the findings suggest that patients with high-flow AVFs are at increased risk of HCOF. Regular cardiovascular evaluation and careful monitoring of AVF flow may help mitigate cardiac complications in chronic hemodialysis patients. Future prospective studies are warranted to validate thresholds like Qa ≥ 2.0 L/min and CPR ≥ 20% as predictive markers for HCOF.

Abbreviations

AVF	Arteriovenous Fistula
BMI	Body mass index
CO	Cardiac Output
CPR	Cardiopulmonary recirculation
ESRD	End-stage renal disease
EF	Ejection fraction
IVS	Interventricular septum
HCOF	High cardiac output failure
HF	Hemofiltration
LA	Left atrium
LV	Left ventricle
Kt/V	Dialyzer clearance of ureaxdialysis time/volume of distribution of urea
PAP	Pulmonary artery pressure
Qa	AVF flow rate

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Authors' contributions

G.Y., A.D.,S.G., Ö.G. and M.O.D. wrote the main manuscript text and prepared figures. G.Y., S.G., M.O.D. and Ö.G. performed fistula openings for the patients and recorded the patient characteristics.A.D. monitored the patients' heart insufficiency and systematically filed their records.All authors reviewed the manuscript.

Data availability

The data of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The study was conducted in compliance with the Declaration of Helsinki principles, and approved by Tekirdağ Namık Kemal University Faculty of Medicine Non-Interventional Clinical Research Ethics Committee with the approval number E-46048792-050.01.04-25488. Informed consent to participate was obtained from all the study participants. The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

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