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Beyond the vascular access: unveiling the cardiovascular impact of dialysis access flow rates

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Abstract

Objective To investigate the impact of arteriovenous fistula (AVF) and arteriovenous graft (AVG) flow rates on cardiac function and blood pressure in hemodialysis patients, comparing changes before and after vascular access creation and assessing differences between high and non-high flow access groups.

Methods This prospective, observational study included 80 hemodialysis patients (43 males), all of Iranian ethnicity, at a university-affiliated referral hospital in Tehran, Iran. Flow rates (Qa) of vascular accesses were measured using Color Doppler ultrasonography (Acuson Sequoia system). Echocardiographic parameters, including systolic blood pressure, ejection fraction (EF), and left ventricular end-diastolic dimension (LVEDD), were assessed at baseline and six months post-intervention. Data were analyzed using paired t-tests and Pearson correlation coefficients.

Results Following vascular access creation, a significant decrease in systolic blood pressure was observed (156.48 ± 18.04 mmHg to 141.42 ± 15.82 mmHg, $p < 0.001$), along with a notable decline in EF (57.18% ± 6.51 to 50.31% ± 4.99, $p < 0.001$), and an increase in LVEDD (4.43 ± 0.27 cm to 5.51 ± 0.26 cm, $p < 0.001$), suggesting potential cardiovascular burden in high-flow access patients. Patients with high-flow access exhibited greater cardiovascular burden, likely due to increased cardiac output demands and risk of high-output heart failure. No significant differences in cardiac outcomes were observed between proximal and distal AVFs or upper and lower limb AVGs.

Conclusions These findings underscore the need for proactive cardiovascular monitoring, particularly in patients with high-flow vascular access, to prevent potential complications such as high-output cardiac failure. Routine Doppler ultrasonography and echocardiographic assessments should be integrated into clinical practice to identify high-risk patients and guide timely interventions.

Keywords Arteriovenous fistula flow rate, Cardiovascular effects of Dialysis access, High-Flow arteriovenous access, Hemodialysis and cardiac function, Arteriovenous grafts and cardiac burden

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Background

End-stage renal disease (ESRD) is a growing global health concern, with arteriovenous fistulas (AVFs) and grafts (AVGs) being the primary vascular access choices for hemodialysis due to their durability and lower infection rates [1, 2]. However, AVF creation introduces significant hemodynamic alterations, leading to increased cardiac output, reduced systemic vascular resistance (SVR), and potential cardiovascular complications [3]. While AVFs reduce the risk of thrombosis and infections compared to AVGs [4], they have been implicated in conditions such as high-output cardiac failure (HOHF), pulmonary hypertension, and left ventricular dysfunction [5, 6].

High-flow AVFs, generally defined as those with a blood flow rate ≥ 2000 mL/min, have been strongly associated with HOHF due to excessive venous return and increased cardiac workload [3]. Some studies suggest a lower threshold (1200–1500 mL/min) in post-kidney transplant patients due to their higher cardiovascular risk [7, 8]. These elevated flow rates can increase pulmonary artery pressures and contribute to left ventricular dilation, right ventricular dysfunction, and progressive cardiac remodeling [9–11]. While this threshold is widely recognized, patient-specific factors necessitate individualized assessment to balance dialysis efficiency and cardiovascular risk [12–14].

The hemodynamic burden of AVFs is primarily driven by reduced SVR, increased venous return, and sustained left ventricular volume overload. This chronic volume overload contributes to left ventricular hypertrophy and can eventually impair myocardial function [15, 16]. Prolonged high cardiac output, coupled with increased preload and reduced afterload, imposes additional stress on the heart, increasing the risk of HOHF and worsening cardiovascular outcomes [17].

Given the frequent presence of cardiovascular comorbidities in patients undergoing hemodialysis, understanding the isolated impact of AVF and AVG creation on cardiac function is essential. Careful assessment of AVF-related hemodynamic changes is necessary to optimize vascular access management while minimizing cardiovascular risk.

This study aims to evaluate the impact of AVF and AVG flow rates on cardiac function and blood pressure in ESRD patients undergoing hemodialysis. The findings will help refine risk assessment strategies and guide clinical decisions regarding vascular access management to optimize cardiovascular outcomes in this high-risk population.

Methods

Study design

This prospective observational study was conducted at Taleghani Hospital in Tehran over a period of 15 months, from December 2020 to April 2021. A consecutive sampling method was used to include all eligible patients, minimizing selection bias. It involved all consecutive patients undergoing arteriovenous fistula (AVF) or arteriovenous graft (AVG) creation as part of their treatment for End-Stage Renal Disease (ESRD). After informed consent, patients were enrolled unless they had pre-existing cardiac conditions that could significantly confound the assessment of heart function and bias the study outcomes.

These exclusions included structural heart disease, high-output cardiac states unrelated to ESRD, significant valvular heart disease, or a history of heart transplantation, as these conditions could independently influence cardiac function and obscure the effects of AV access creation.

Baseline demographic information such as age, sex, smoking status, along with medical history, was meticulously gathered through structured questionnaires. Diabetes was specifically identified by the patient's use of anti-diabetic medications, while hypertension was determined based on blood pressure readings exceeding 140/90 mmHg or the current use of antihypertensive medications. To ensure data accuracy and minimize variability, blood pressure readings were taken on three separate occasions and averaged. Essential laboratory tests, including hemoglobin, hematocrit, serum creatinine, and albumin levels, were conducted on the day of the baseline echocardiographic examination to provide a comprehensive patient profile.

Echocardiographic assessment

Two independent cardiologists blinded to patient grouping, following American Society of Echocardiography (ASE) guidelines evaluated echocardiographic parameters such as left ventricular ejection fraction (EF) and left ventricular end-diastolic diameter (LVEDD). To enhance precision, inter-observer reliability was assessed, yielding an intraclass correlation coefficient (ICC) of ≥ 0.90.

Baseline echocardiography was performed prior to the dialysis access procedure, and a follow-up assessment was conducted six months post-surgery to evaluate potential changes in cardiac function and structure.

The arteriovenous fistula (AVF) and arteriovenous graft (AVG) flow rates (Qa) were meticulously assessed using Color Doppler ultrasonography with the Acuson Sequoia system. Ultrasound measurements were taken in a standardized manner by a single experienced operator to minimize inter-observer variability. Patients were systematically stratified into two distinct groups:

- Non-High Flow Access (non-HFA): Qa < 2000 ml/min.
- High Flow Access (HFA): Qa ≥ 2000 ml/min.

The threshold of 2000 ml/min was chosen based on prior studies indicating that AV access flow rates exceeding this level are strongly associated with high-output heart failure due to increased venous return and subsequent volume overload. This classification allows for better differentiation of patients at risk for adverse cardiovascular outcomes.

Echocardiography assessment

Echocardiographic parameters, including EF and LVEDD, were assessed at two time points: baseline (pre-procedure) and six months post-procedure. Echocardiography was performed on each patient by two independent cardiologists blinded to patient grouping, following the American Society of Echocardiography (ASE) guidelines.

The biplane method of disks, also known as the modified Simpson's rule, was utilized for volume measurements. This involved obtaining images of the heart in the apical four-chamber and two-chamber views at end-diastole and end-systole. The left ventricular volumes were calculated by tracing the endocardial borders to provide a quantitative evaluation of the heart's pumping ability.

To reduce measurement bias, all echocardiographic assessments were performed by two independent cardiologists, and inter-observer reliability was evaluated using intraclass correlation coefficient (ICC ≥ 0.90).

Left ventricular systolic function was further assessed by the velocity of longitudinal shortening during systole at the septal mitral annulus (s'). Left ventricular end-diastolic diameter (LVEDD) was measured using M-mode or two-dimensional echocardiography in the parasternal long-axis view, capturing the largest internal dimension of the left ventricle just before the mitral valve closure.

LV diastolic function was evaluated by measuring the velocity of early diastolic blood flow (E), septal diastolic annular tissue velocities (e'), and calculating the ratio of E/e'. The left atrial volume index was determined by the biplane method of disks to assess atrial size and function.

To account for missing data (< 5% of echocardiographic measurements), multiple imputation techniques were employed to ensure the robustness of statistical analyses.

A comparative analysis of each patient's baseline data with the six-month follow-up data was performed to detect changes in cardiac function and structure.

Experienced cardiologists reviewed and interpreted the echocardiograms, ensuring consistency in interpretation through regular meetings and calibration sessions among the interpreting staff. Any discrepancies were discussed and resolved to maintain the integrity of the data.

Blinded follow-up echocardiography was performed six months post-procedure, with the primary outcomes measured being absolute changes in EF and LVEDD, reflecting the impact of AVF or AVG placement on cardiac function.

Sample size determination

to ensure the study was sufficiently powered; sample size was calculated using the Cochran formula for an infinite population, followed by a finite population correction (FPC) to adjust for the limited number of ESRD patients at our center. A 95% confidence level, 0.5 variance assumption, and 10% margin of error were used, following standard statistical recommendations. Based on hospital records, approximately 400 ESRD patients undergo treatment at our center annually, providing the estimated population size required for FPC adjustment.

After applying FPC, the adjusted required sample size was 78 patients. To account for potential dropout, the final sample size was increased to 80 patients, ensuring adequate statistical power despite possible loss to follow-up. This adjustment was made to accommodate expected variations in patient retention commonly observed in long-term clinical studies.

To maintain clarity and conciseness in the Methods section, the detailed formulae and systematic calculations have been provided in the Appendix 1.

Statistical analysis

Statistical analyses were conducted using SPSS 26. Descriptive statistics were used to summarize patient characteristics and clinical outcomes. Categorical variables (e.g., gender, diabetes) were reported as frequencies (%), while continuous variables (e.g., age, fistula flow, blood pressure, cardiac function) were summarized as mean ± standard deviation (SD).

The effect of fistula insertion on cardiac function and blood pressure was assessed using paired t-tests, with 95% confidence intervals (CIs) calculated for key cardiovascular parameters, including ejection fraction (EF) and left ventricular end-diastolic dimension (LVEDD). Differences between the High Flow Access (HFA) and Non-High Flow Access (non-HFA) groups were analyzed using independent t-tests. Pearson correlation analysis was conducted to explore relationships between fistula flow and cardiovascular outcomes, with correlation coefficients (r) reported to indicate the strength and direction of associations.

Missing data accounted for < 5% of echocardiographic measurements and were handled using multiple imputation techniques. Sensitivity analysis confirmed that imputed and non-imputed datasets yielded consistent results, ensuring the robustness of findings.

A p-value < 0.05 was considered statistically significant, and all tests were two-tailed.

Results

A total of 80 patients were evaluated in this study. The mean age of participants was 56.48 years (SD = 5.41), with 43 patients (53.8%) being male. Smoking was reported in

Table 1 Demographic and primary characteristics of patients in HFA and Non-HFA groups (Now includes 95% confidence intervals (CI))

Variable	HFA (Mean ± SD or %)	Non-HFA (Mean ± SD or %)	*p*-value	95% Confidence Interval (CI)
Age (years)	57.59 ± 5.19	55.92 ± 5.48	0.194	(56.02–59.16)
Gender (% Male)	16 (59.3%)	27 (50.9%)	0.636	(42.1 – 67.5%)
Smoking (% Yes)	16 (59.3%)	35 (66%)	0.626	(47.8 – 70.8%)
Diabetes (% Yes)	19 (70.4%)	21 (39.6%)	0.017	(57.9 – 82.9%)
Type of Access	AVF: 19 (70.4%) AVG: 8 (29.4%)	AVF: 38 (71.7%) AVG: 15 (28.3%)	> 0.99	(65.3 – 77.9%) (20.1 – 38.7%)
Location of Access	Proximal: 23 (85.2%) Distal: 4 (14.8%)	Proximal: 42 (79.2%) Distal: 11 (20.8%)	0.763	(68.9 – 91.5%) (6.5 – 23.1%)
Access Site	Upper Limb: 25 (92.6%) Lower Limb: 2 (7.4%)	Upper Limb: 45 (84.9%) Lower Limb: 8 (15.1%)	0.481	(79.8 – 97.4%) (2.6 – 20.2%)
Access Flow (mL/min)	3,123.55 ± 687.93	1,017.73 ± 313.84	< 0.001	(2,910.3–3,336.8

Table 2 This table presents detailed information on these comparisons, including the 95% confidence intervals for each parameter

Variable	HFA Mean ± SD	Non-HFA Mean ± SD	*p*-value	95% Confidence Interval (CI) (Reviewer Request: Added 95% CI)
Systolic Blood Pressure	132.18 ± 13.73	146.13 ± 14.80	< 0.001	(127.00–137.36) / (142.15–150.11)
Ejection Fraction (EF)	46.25 ± 2.94	52.37 ± 4.54	< 0.001	(45.14–47.36) / (51.15–53.59)
LVEDD	5.45 ± 0.25	5.54 ± 0.26	0.175	(5.36–5.54) / (5.47–5.61)

63.7% of patients, and diabetes was present in 50% of the cohort (Table 1).

Regarding vascular access, 57 patients (71.2%) had an arteriovenous fistula (AVF), while 23 patients (28.8%) had an arteriovenous graft (AVG). Among AVF placements, all were in the upper limb, with 42 (73.7%) in the proximal location and 15 (26.3%) in the distal location. AVG placements were distributed as follows: 13 (56.5%) in the upper limb and 10 (43.5%) in the lower limb, all of which were in the proximal location.

The mean vascular access flow rate (Qa) was 1,728.45 mL/min (SD = 1,064.11 mL/min). Based on vascular access flow rates, patients were divided into two groups:

- Non-High Flow Access (non-HFA): 53 patients (Qa < 2,000 mL/min).
- High Flow Access (HFA): 27 patients (Qa ≥ 2,000 mL/min).

Statistical analysis revealed no significant differences between the two groups in terms of age ($p = 0.194$), gender ($p = 0.636$), smoking status ($p = 0.626$), vascular access type ($p > 0.99$), access location ($p = 0.763$), or access site ($p = 0.481$).

However, diabetes prevalence was significantly higher in the HFA group (70.4% vs. 39.6%, $p = 0.017$), and vascular access flow rates were significantly greater in the HFA group (3,123.55 ± 687.93 mL/min vs. 1,017.73 ± 313.84 mL/min, $p < 0.001$).

Changes in cardiac function and blood pressure following fistula creation

In this study, changes in cardiac function and blood pressure were evaluated before and after fistula implantation. The parameters assessed included systolic blood pressure (SBP), ejection fraction (EF), and left ventricular end-diastolic dimension (LVEDD).

- The mean systolic blood pressure before fistula insertion was 156.48 (SD = 18.04) and decreased to 141.42 (SD = 15.82) after insertion, reflecting a reduction of 9.6% ($p < 0.001$).
- The mean ejection fraction (EF) before insertion was 57.18 (SD = 6.51) and declined to 50.31 (SD = 4.99) post-insertion, representing a 12.0% decrease ($p < 0.001$).
- The mean LVEDD increased from 4.43 (SD = 0.27) to 5.51 (SD = 0.26), corresponding to a 24.4% increase ($p < 0.001$).

All changes were statistically significant ($p < 0.001$), indicating a notable alteration in each parameter following fistula placement.

Comparison of cardiac function and blood pressure in HFA vs. Non-HFA Groups (Table 2)

Cardiac function and blood pressure parameters were compared between the High Flow Arteriovenous (HFA) and Non-High Flow Arteriovenous (non-HFA) groups.

- The mean systolic blood pressure in the HFA group was 132.18 (SD = 13.73), significantly lower than in the non-HFA group (146.13 (SD = 14.80), $p < 0.001$).
- The mean EF was 46.25 (SD = 2.94) in the HFA group compared to 52.37 (SD = 4.54) in the non-HFA group, showing a statistically significant difference ($p < 0.001$).

- The mean LVEDD was 5.45 (SD = 0.25) in the HFA group and 5.54 (SD = 0.26) in the non-HFA group, with no statistically significant difference (*p = 0.175).*

The Pearson correlation analysis was conducted to assess the relationship between fistula flow and various cardiovascular parameters, including systolic blood pressure, ejection fraction (EF), and left ventricular end-diastolic dimension (LVEDD).

- The analysis yielded a correlation coefficient of -0.419 with a *p*-value of less than 0.001 for the relationship between fistula flow and systolic blood pressure, indicating a significant negative correlation.
- Similarly, the correlation between fistula flow and EF was found to be significant, with a correlation coefficient of -0.537 and a *p*-value of less than 0.001, suggesting a substantial negative correlation between these variables.
- However, no significant correlation was observed between fistula flow and LVEDD (*p = 0.182*), implying the absence of a linear relationship between these parameters.

These statistical findings reflect the strength and significance of the associations without drawing clinical or interpretative conclusions.

Refer to Fig. 1 for a graphical representation of the correlation between fistula flow and systolic blood pressure.

Additionally, Fig. 2 illustrates the significant inverse correlation between fistula flow and ejection fraction, providing a visual representation of the statistical correlations discussed.

Comparison of cardiac function and blood pressure between AVF and AVG

Comparative analyses were conducted to assess the distinctions in cardiac function and blood pressure between patients with arteriovenous fistula (AVF) and arteriovenous graft (AVG). This analysis included High Flow Arteriovenous (HFA) and Non-High Flow Arteriovenous (Non-HFA) groups, examining their influence within each access type. Systolic blood pressure, ejection fraction (EF), and left ventricular end-diastolic dimension (LVEDD) were the primary parameters compared across these subgroups.

For the AVF group, the mean systolic blood pressure was 142.05 (SD = 15.68) in the Non-HFA subgroup

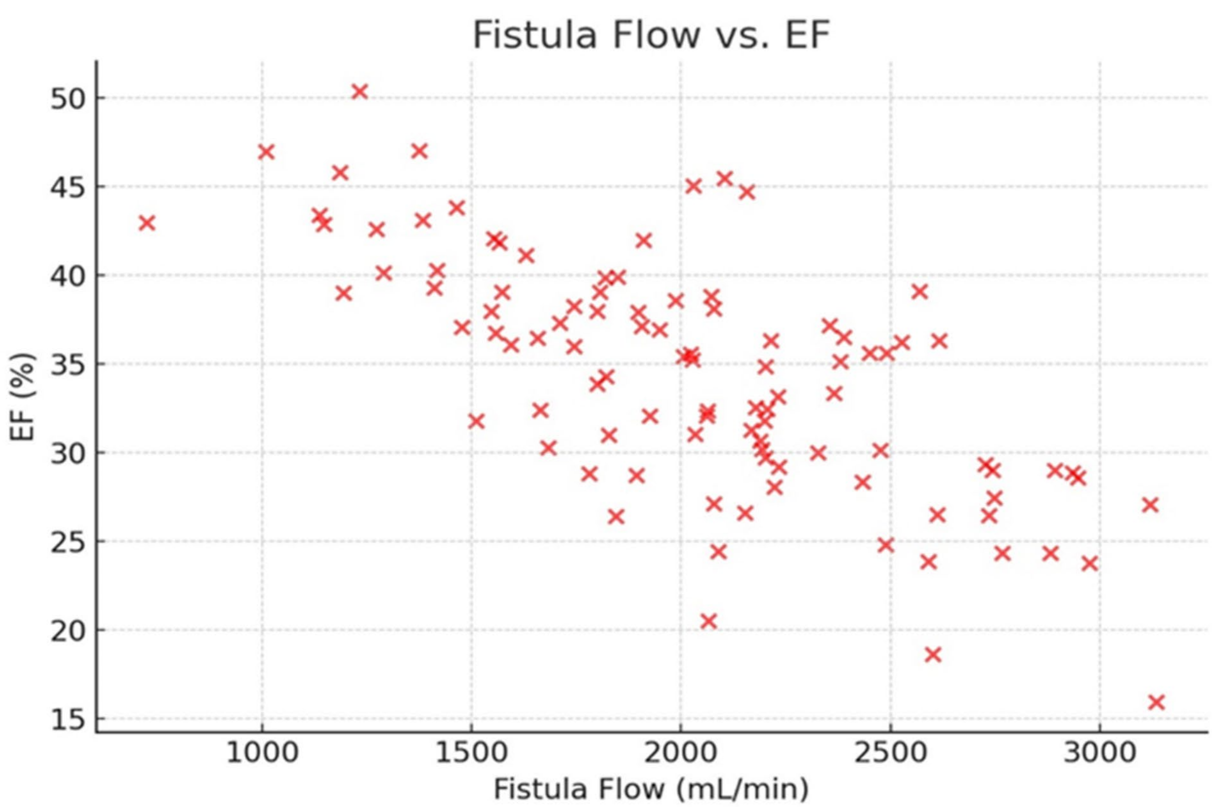

Fig. 1 Scatter plot showing the negative correlation between fistula flow and systolic blood pressure ($r = -0.419$, $p < 0.001$r = -0.419, $p < 0.001$r = −0.419, $p < 0.001$). Higher fistula flow is associated with lower systolic blood pressure

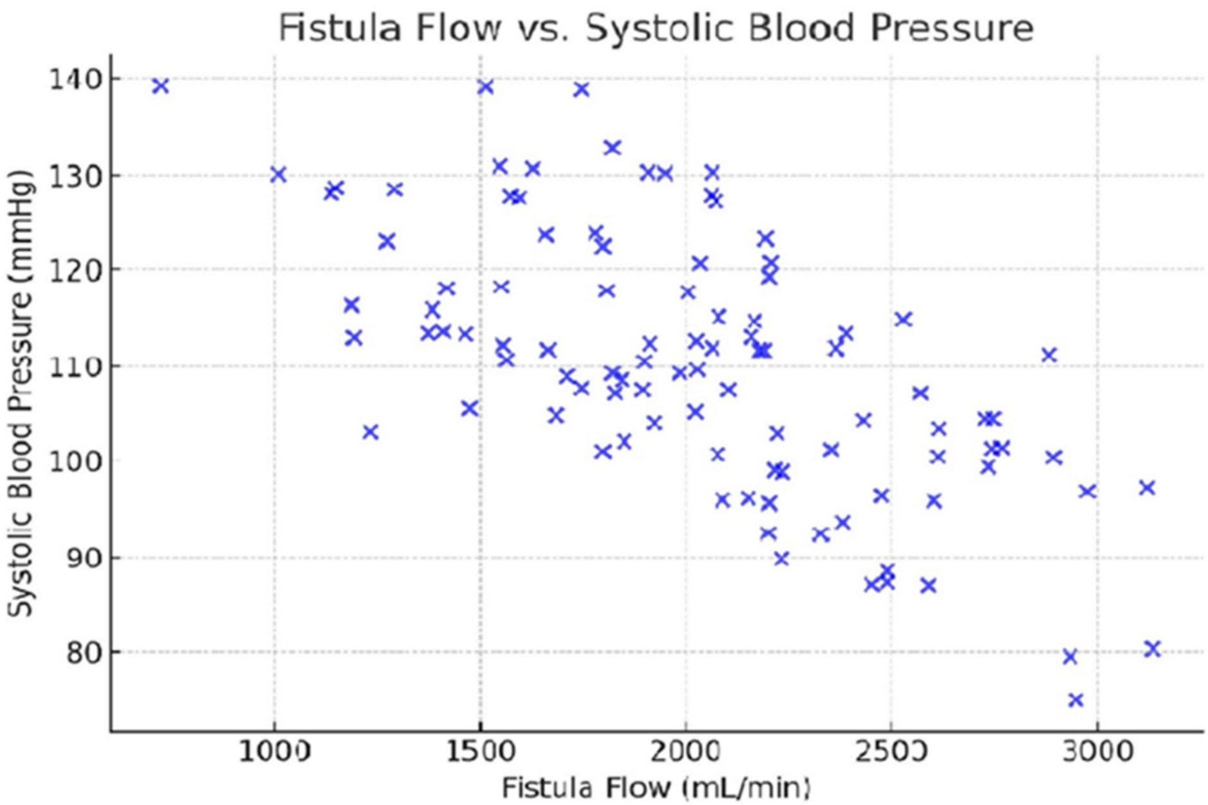

Fig. 2 Scatter plot illustrating the significant negative correlation between fistula flow and ejection fraction ($r = -0.537$, $p < 0.001$r = -0.537, $p < 0.001$r = −0.537, $p < 0.001$). Increased fistula flow is associated with a decrease in ejection fraction

and 139.86 (SD = 16.41) in the HFA subgroup. The corresponding values for EF were 50.45 (SD = 4.97) in the Non-HFA group and 49.95 (SD = 5.12) in the HFA group. Similarly, the mean LVEDD was 5.47 (SD = 0.27) in the Non-HFA subgroup and 5.60 (SD = 0.22) in the HFA subgroup.

For the AVG group, the mean systolic blood pressure was 140.09 (SD = 15.65) in the Non-HFA subgroup and 147.20 (SD = 15.77) in the HFA subgroup. The mean EF was 50.36 (SD = 5.01) in Non-HFA vs. 50.06 (SD = 5.04) in HFA, and the LVEDD was 5.52 (SD = 0.27) in Non-HFA vs. 5.46 (SD = 0.24) in HFA.

The statistical analysis yielded p-values of 0.580, 0.688, and 0.57 for the comparisons of systolic blood pressure, EF, and LVEDD, respectively, indicating no statistically significant differences between these groups.

Figure 3 provides a general comparison of cardiac function and blood pressure parameters between HFA and Non-HFA groups, regardless of access type (AVF or AVG), representing an overall perspective on the impact of fistula flow.

Cardiac function and blood pressure comparison between proximal and distal fistulas

A comparative analysis was conducted to evaluate differences in cardiac function and blood pressure between patients with proximal and distal arteriovenous fistulas. The parameters assessed included systolic blood pressure (SBP), ejection fraction (EF), and left ventricular end-diastolic dimension (LVEDD).

For proximal fistulas, the mean systolic blood pressure was 140.09 (SD = 15.65, 95% CI: 135.36–144.82), the EF was 50.36 (SD = 5.01, 95% CI: 48.84–51.88), and LVEDD was 5.52 (SD = 0.27, 95% CI: 5.44–5.60).

For distal fistulas, the mean systolic blood pressure was 147.20 (SD = 15.77, 95% CI: 139.22–155.18), the EF was 50.06 (SD = 5.04, 95% CI: 47.51–52.61), and LVEDD was 5.46 (SD = 0.24, 95% CI: 5.34–5.58).

The p-values for the comparisons of SBP (0.117), EF (0.834), and LVEDD (0.450) indicate no statistically significant differences between proximal and distal fistulas.

Discussion

The long-term cardiovascular implications of AVF placement in ESRD patients remain a subject of extensive investigation. While AVFs provide superior vascular

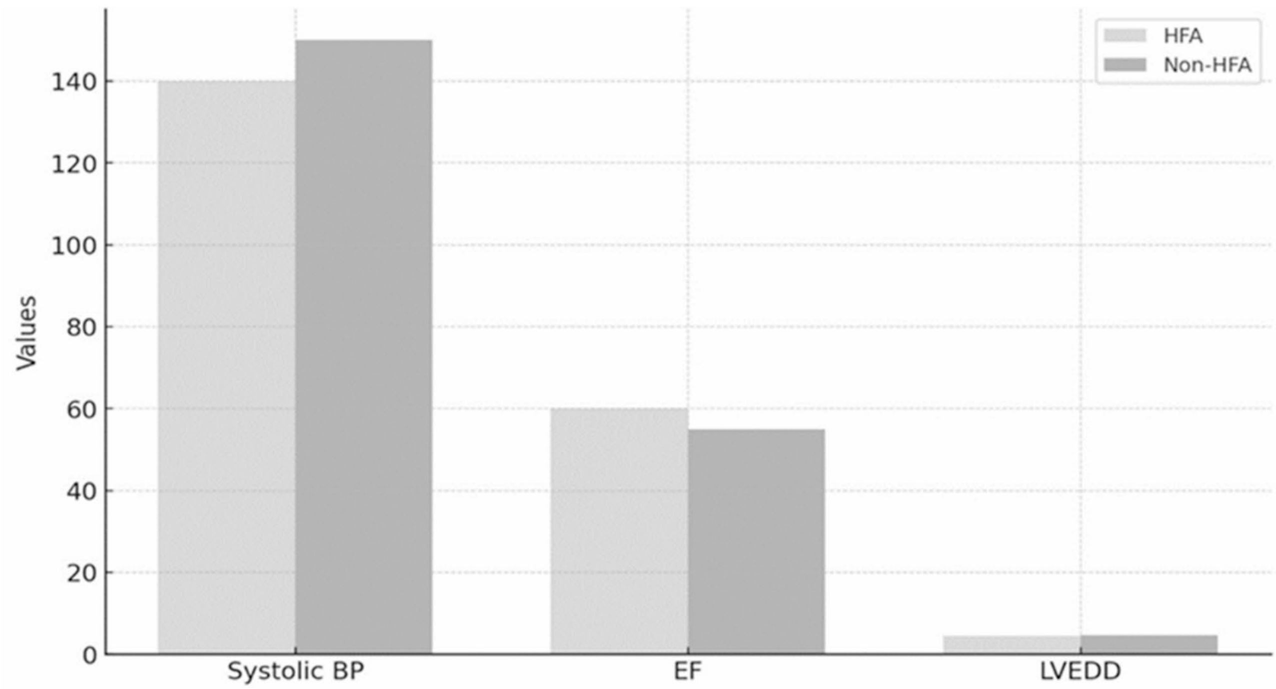

Fig. 3 Comparison of mean systolic blood pressure, ejection fraction (EF), and left ventricular end-diastolic dimension (LVEDD) between High Flow Arteriovenous (HFA) and Non-High Flow Arteriovenous (Non-HFA) groups within both arteriovenous fistula (AVF) and arteriovenous graft (AVG) categories

access patency compared to tunneled central venous catheters, their substantial impact on cardiac morphology and function necessitates a more nuanced approach in patient selection and management [18]. The present findings corroborate the notion that AVF-induced hemodynamic alterations, particularly in high-flow states, contribute to maladaptive cardiac remodeling, increasing the risk of high-output cardiac failure (HOCF) [19].

The impact of AVF and AVG flow rates on cardiac function in ESRD patients has been well documented, with evidence indicating a significant reduction in systolic function and progressive ventricular remodeling following AVF/AVG creation [20]. A major concern raised in previous literature is whether high-output cardiac failure (HOCF) is an inevitable consequence of AVF creation or a modifiable risk factor. This study contributes to this debate by demonstrating that AVF-induced cardiac changes are dependent on patient-specific hemodynamic adaptation rather than a uniform response across all individuals.Similar results were reported by Tayebi et al. (2019) [21], who documented significant reductions in ejection fraction and enlargement of both the left ventricle and left atrium in hemodialysis patients with high-flow AVFs. Wohlfahrt et al. (2020) [22] demonstrated that targeted surgical flow reduction in patients with high cardiac output resulted in substantial improvement in left ventricular structure and function, highlighting the reversibility of AVF-induced cardiac remodeling in selected cases. Additionally, Malik et al. (2021) [23] emphasized the importance of individualized access strategies based on baseline cardiac function, suggesting that distal AVF placement or alternative modalities may better serve patients with compromised cardiovascular status.

The interplay between AVF flow dynamics and cardiac adaptation has been further elucidated in prior studies demonstrating increased left ventricular mass and reduced ejection fraction post-AVF creation [24]. These structural changes, largely driven by augmented venous return and chronic volume overload, align with the Frank-Starling mechanism, wherein sustained preload elevation leads to ventricular dilation and impaired contractility [20]. Importantly, our findings confirm that left ventricular hypertrophy (LVH) and ventricular dilation can develop as early as six months post-AVF creation, supporting the hypothesis that these changes are rapid and require early monitoring. Such maladaptation has been linked to an elevated risk of atrial fibrillation (AF) and heart failure, highlighting the necessity of individualized flow regulation strategies [25].

Despite these concerns, some studies have challenged the uniformity of AVF-related cardiac burden. A study by Martinez-Gallardo et al. 2012 [26] found that preemptive vascular access placement was not invariably associated with adverse cardiac events, suggesting that preexisting cardiovascular status plays a critical role in modulating AVF-induced changes. Similarly, Rao et al. 2019 [27] demonstrated that AVF ligation following kidney transplantation resulted in significant regression of left ventricular hypertrophy, reinforcing the hypothesis that AVF flow itself is a modifiable risk factor rather than an inevitable contributor to heart failure.

Given the heterogeneity in reported outcomes, it is evident that AVF-related cardiac stress is not solely contingent upon access site or flow volume but also on patient-specific cardiovascular resilience. The observed discrepancies across studies may be attributed to variations in baseline cardiac function, dialysis duration, and comorbid conditions. To address this variability, we propose that standardized pre-AVF echocardiographic screening be implemented to identify patients at elevated risk of HOCF and guide individualized access planning.

Furthermore, emerging evidence suggests that non-invasive hemodynamic monitoring techniques, such as ultrasound dilution and echocardiographic indices, may provide valuable insights into AVF-related cardiac load [28]. Current guidelines advocate for routine surveillance of cardiac output and pulmonary artery pressures in patients with high-flow AVFs to mitigate the risk of volume overload and subsequent heart failure [29]. However, standardized protocols for AVF flow regulation remain an area of ongoing research, with further studies needed to delineate optimal flow thresholds that balance dialysis adequacy with cardiovascular protection.

This study has several limitations that warrant consideration. First, its observational design precludes the establishment of direct causality between AVF characteristics and cardiac dysfunction. Second, the follow-up duration may not have been sufficient to capture the long-term cardiovascular adaptations to AVF flow alterations. Third, confounding variables such as preexisting cardiovascular disease, volume status, and patient-specific hemodynamic compensatory mechanisms could have influenced the observed outcomes. Additionally, the lack of serial echocardiographic assessments limited the ability to track progressive cardiac remodeling over time. Future studies employing prospective, randomized designs with extended follow-up periods are necessary to refine risk stratification and optimize vascular access selection strategies.

Conclusion

The findings of this study underscore the critical role of AVF flow characteristics in modulating cardiac function in ESRD patients, independent of vascular access location. While AVFs remain the preferred mode of vascular access due to their superior patency and lower infection rates, the potential for high-output cardiac failure necessitates a patient-specific approach to access planning and surveillance. Given the variability in individual hemodynamic responses, standardized pre-AVF cardiac screening and post-AVF monitoring protocols should be integrated into routine clinical practice. Emerging non-invasive monitoring tools, including echocardiographic flow assessments and biomarkers of cardiac stress, may facilitate early identification of patients at risk for adverse cardiac remodeling.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13019-025-03424-8.

Supplementary Material 1

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Author contributions
All authors analyzed data and writing, participated in collection of data, participated in design testing and supervision testing. All authors read and approve the manuscript version final.

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Data availability
All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate
This study was approved by the local ethics committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.MSP.REC.1398.567). All procedures were performed in accordance with relevant guidelines and regulations, including the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Clinical trial registration
Not applicable.

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