

Preoperative Doppler Ultrasound Parameters as Predictors of Arteriovenous Fistula Maturation in End-Stage Renal Disease: A Prospective Cohort Study

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Background: Preoperative Doppler ultrasound (DUS) is routinely used to map upper-limb vessels before arteriovenous fistula (AVF) creation, yet the predictive value of individual morphologic and hemodynamic parameters remains inconsistent. This study evaluated whether preoperative vessel diameters and flow velocities predict functional AVF maturation in end-stage renal disease (ESRD).

Methods: In a prospective cohort (January 2023–June 2025), adults with ESRD undergoing first-time upper-limb AVF creation received standardized DUS within 2 weeks preoperatively. Arterial and venous internal diameters and peak systolic velocities were measured at planned access sites; measurements were obtained in triplicate and averaged. Functional maturation was defined as sustained two-needle cannulation for hemodialysis at ≥ 300 mL/min for ≥ 3 consecutive sessions within 6 months, without endovascular or surgical intervention.

Results: Ninety patients were enrolled; one patient was lost to follow-up before the primary outcome assessment, leaving 89 patients for analysis. Radiocephalic (Type 1) AVFs accounted for 32/90 (35.6%) and brachiocephalic (Type 2) AVFs for 58/90 (64.4%). Overall, 66/89 (74.2%) fistulas matured and 23/89 (25.8%) failed (12 early, 11 late). Maturation was not associated with fistula type, diabetes, or hypertension. Our study suggests that Larger distal radial artery diameter was paradoxically associated with failure (2.27 ± 0.54 mm vs 1.98 ± 0.52 mm; $p=0.037$) and remained significant after multivariable adjustment (coefficient = -1.892 ; $p=0.006$). No other assessed arterial or venous diameter or peak systolic velocity predicted outcome.

Conclusion: Most preoperative DUS measurements did not predict AVF maturation; however, larger distal radial artery diameter paradoxically correlated with failure. Larger multicenter studies incorporating arterial wall pathology, venous outflow resistance, and detailed hemodynamics are warranted to refine preoperative decision-making. Arterial quality may be as important as size alone.

Keywords: renal dialysis, arteriovenous fistula, vascular access devices, ultrasonography, doppler

Introduction

End-stage renal disease (ESRD) represents a significant global health challenge, with its prevalence continuing to rise due to factors such as aging populations, diabetes, and hypertension.^{1–4} For patients requiring renal replacement therapy (RRT), hemodialysis remains a cornerstone treatment modality, necessitating reliable vascular access.⁵ Among available options, autologous arteriovenous fistulas (AVFs) are widely recommended as the preferred vascular access for chronic hemodialysis, as endorsed by the National Kidney Foundation - Kidney Disease Outcomes Quality Initiative (NKF-KDOQI) guidelines and the Fistula First Breakthrough Initiative (FFBI).^{6–8} A recent nationwide cohort study further demonstrated that AVFs are associated with significantly lower risks of infection-related and all-cause mortality compared to central venous catheters.⁹

AVFs offer superior long-term patency, lower infection rates, and reduced morbidity compared to central venous catheters or arteriovenous grafts. Despite these advantages, AVF creation is fraught with challenges, particularly

regarding maturation and patency. Successful AVF maturation depends on adequate arterial inflow and venous outflow to sustain high-volume blood flow during dialysis, typically requiring a minimum flow of 400–600 mL/min. Preoperative assessment plays a critical role in optimizing outcomes, with Doppler ultrasound (DUS) commonly employed to evaluate vessel morphology and hemodynamics.⁸ Key parameters include arterial diameter (AD), venous diameter (VD), and blood flow velocity, which are hypothesized to influence fistula performance.^{10,11} However, the literature reveals inconsistencies regarding the optimal thresholds for these parameters. Studies have variably reported VD thresholds between 1.6 mm and 4 mm for predicting successful maturation, while AD thresholds range from 1.5 mm to 4.1 mm.^{12,13} For instance, Lauvao in 2009 identified VD as an independent predictor of functional maturation using multivariate analysis,¹² whereas Misskey emphasized the combined impact of AD (<2.1 mm) and minimum venous outflow diameter (<3.0 mm) on radiocephalic fistula patency.¹³ More recent investigations, such as those by Opera in 2018 and Wan in 2020, have linked larger vessel diameters to improved maturation rates, with VD ≥ 1.9 mm and AD ≥ 1.5 mm associated with success rates exceeding 60%.^{14,15}

A 2022 study further corroborated a significant association between diameters exceeding 2.0 mm and enhanced patency at 6 weeks postoperatively.¹⁶ Blood flow velocity has also been implicated, though its predictive value, alone or in combination with diameters, remains poorly defined and may be limited. These discrepancies arise from heterogeneous study populations, varying definitions of maturation, and limited focus on mid- to long-term outcomes. Moreover, while individual vessel parameters have been examined, the synergistic effects of AD, VD, and preoperative blood flow velocity on AVF success are not well elucidated. This knowledge gap hinders standardized preoperative decision-making and contributes to suboptimal fistula utilization rates. To address these limitations, the present study prospectively evaluated the relationship between preoperative radial and brachial artery diameters, cephalic, brachial, and basilic vein diameters, and corresponding blood flow velocities with the functional maturation of upper limb AVFs in ESRD patients. By analyzing these parameters in a cohort undergoing standardized DUS assessment and surgical procedures, we aimed to identify predictive thresholds and inform clinical strategies to enhance AVF outcomes.

Methods

Study Design and Setting

This prospective cohort study was conducted at Al-Zahra Hospital in Isfahan, a tertiary care center specializing in nephrology and vascular surgery, between January 2023 and June 2025. The study aimed to assess the predictive value of preoperative vascular parameters on the functional maturation of upper limb arteriovenous fistulas (AVFs) in patients with end-stage renal disease (ESRD). All procedures adhered to the principles outlined in the Declaration of Helsinki, and the study protocol was approved by the institutional review board. Written informed consent was obtained from all participants prior to enrollment.

Participants

Eligible participants were adults (aged ≥ 18 years) diagnosed with ESRD (defined as an estimated glomerular filtration rate < 15 mL/min/1.73 m² or requiring renal replacement therapy) who were scheduled for primary upper limb AVF creation as their initial permanent vascular access for hemodialysis. Patients were either pre-dialysis (CKD stage 5) or were currently receiving hemodialysis via a tunneled central venous catheter; no patient had a prior functioning AVF or graft in the target limb. Exclusion criteria included prior vascular access attempts in the target limb, active infection, severe comorbidities precluding surgery, pregnancy, or inability to provide informed consent. A total of 90 consecutive patients meeting these criteria were recruited. Sample size was determined a priori using power analysis based on prior studies, assuming a 40% maturation failure rate and aiming for 80% power to detect a significant association between vessel diameters and maturation outcomes ($\alpha=0.05$).

Preoperative Assessment

All participants underwent standardized preoperative Doppler ultrasound (DUS) evaluation within 2 weeks prior to surgery, performed by a certified vascular sonographer using a high-frequency linear probe (7–12 MHz) on the

ultrasound system. Patients were examined in a supine position with the arm extended and relaxed, under ambient room temperature (22–24°C) to minimize vasospasm. Key vascular parameters measured included:

- Arterial diameters (AD): Internal lumen diameter of the radial artery at the wrist and the brachial artery at the antecubital fossa, measured in millimeters (mm) at end-diastole.
- Venous diameters (VD): Internal lumen diameter of the cephalic vein at the wrist and antecubital fossa, brachial vein, and basilic vein in the upper arm, also in mm.
- Blood flow velocities: Peak systolic velocity (PSV) and end-diastolic velocity (EDV) in cm/s for the corresponding arteries and veins, with volume flow (mL/min) calculated using the formula: $\text{Flow} = \pi \times (\text{diameter}/2)^2 \times \text{time-averaged mean velocity} \times 60$.

Measurements were taken in triplicate at each site, and averages were used for analysis. Vessel mapping included assessment for stenoses, thrombi, or anatomical variants. Tourniquet application was used briefly (1–2 minutes) to enhance venous distensibility during VD measurements, as per NKF-KDOQI guidelines.

Surgical Procedure

AVF creation was performed under local anesthesia with sedation by experienced vascular surgeons (>5 years of practice and >100 AVFs annually). Preferred configurations were radiocephalic AVFs at the wrist, followed by brachiocephalic or brachio basilic AVFs if distal sites were unsuitable based on DUS findings. Anastomoses were constructed end-to-side using 6–0 polypropylene sutures, with intraoperative confirmation of thrill and bruit. No routine adjunctive procedures were employed unless intraoperative complications arose. Postoperative care included elevation of the limb, avoidance of compressive dressings, and initiation of hand exercises from day 1.

Outcome Measures and Follow-Up

The primary outcome was functional AVF maturation, defined as the ability to sustain two-needle cannulation for hemodialysis with a blood flow rate ≥ 300 mL/min for at least three consecutive sessions within 6 months postoperatively, without requiring interventions. The threshold of ≥ 300 mL/min was selected in accordance with international NKF-KDOQI guidelines, which recommend a minimum delivered blood flow rate to achieve adequate urea clearance ($Kt/V > 1.2$) in our center's standard dialysis prescription. Secondary outcomes included primary patency (time from creation to first intervention or thrombosis), assisted primary patency (patency with interventions), and complications. Follow-up assessments occurred at 2 weeks, 6 weeks, 3 months, and 6 months postoperatively, involving clinical examination (palpation for thrill/bruit) and DUS to monitor flow rates, diameters, and patency. Maturation failure was classified as early (within 6 weeks) or late (6 weeks to 6 months). Patient demographics, comorbidities, and dialysis vintage were recorded at baseline.

Statistical Analysis

Continuous variables were expressed as means $\pm$ standard deviations or medians (interquartile ranges) based on normality (assessed via Shapiro–Wilk test). Categorical variables were presented as frequencies and percentages. Univariate comparisons between matured and non-matured AVFs used Student's *t*-test or Mann–Whitney *U*-test for continuous data and chi-square or Fisher's exact test for categorical data. Multivariate logistic regression was employed to identify independent predictors of maturation, adjusting for confounders such as age, sex, diabetes, and smoking status. Receiver operating characteristic (ROC) curves determined optimal thresholds for AD, VD, and flow velocities, with area under the curve (AUC), sensitivity, specificity, and Youden's index reported. A *p*-value <0.05 was considered statistically significant. Missing data (<5% anticipated) were handled via multiple imputation.

Ethical Considerations

This study prioritized patient safety, with immediate referral for alternative access if DUS indicated high failure risk. Data were anonymized and stored securely in compliance with institutional data protection policies.

Results

Study Population and Baseline Characteristics

Between January 2023 and June 2025, a total of 90 adult patients with end-stage renal disease (ESRD) undergoing primary upper limb arteriovenous fistula (AVF) creation were prospectively enrolled in this cohort study. One patient was excluded from the final analysis due to incomplete follow-up data, resulting in 89 analyzable cases. The mean age of the cohort was 58.4 ± 12.7 years, with 54 (60.7%) males and 35 (39.3%) females. Comorbidities were prevalent, including diabetes mellitus in 30 patients (33.7%; 25 with type 2 and 5 with type 1) and hypertension in 74 patients (83.1%). Smoking history was reported in 28 patients (31.5%), and the median dialysis vintage prior to AVF creation was 4.5 months (interquartile range [IQR]: 2.0–8.0 months). No significant baseline differences were observed between patients with successful and failed AVF maturation in terms of age, sex, or dialysis vintage (all $p > 0.05$) (Tables 1–9 and Figures 1–6).

AVFs were preferentially created as radiocephalic (Type 1: wrist radial artery–cephalic vein) in 32 patients (35.6% of the total cohort) or brachiocephalic (Type 2: elbow brachial artery–cephalic vein) in 58 patients (64.4%), based on preoperative Doppler ultrasound (DUS) findings and surgical feasibility. Functional maturation, the primary outcome, was achieved in 66 AVFs (74.2%), defined as the ability to sustain two-needle cannulation with a blood flow rate of ≥ 300 mL/min for at least three consecutive hemodialysis sessions within 6 months postoperatively, without requiring endovascular or surgical interventions. Maturation failure occurred in 23 cases (25.8%), with 12 early failures (within 6 weeks) and 11 late failures (between 6 weeks and 6 months). Secondary outcomes, including primary patency (median:

Table 1 Distribution of Fistula Types in the Study Cohort

Fistula Type	Number of Patients (n)	Percentage (%)
Type 1 (Radial-Cephalic)	32	35.6
Type 2 (Brachial-Cephalic)	58	64.4
Total	90	100.0

Table 2 Maturation Outcomes by Fistula Type

Fistula Type	Failures (n)	Successes (n)	Success Rate (%)
Type 1	9	23	71.9
Type 2	14	44	75.9

Table 3 Distribution of Diabetes and Hypertension by Fistula Type

Risk Factor	Fistula Type	Absent (n, %)	Present (n, %)
Diabetes	Type 1	21 (65.6%)	11 (34.4%)
	Type 2	39 (67.2%)	19 (32.8%)
Hypertension	Type 1	4 (12.5%)	28 (87.5%)
	Type 2	12 (20.7%)	46 (79.3%)

Table 4 Maturation Outcomes by Diabetes and Hypertension Status

Risk Factor Status	Failures (n)	Successes (n)	Success Rate (%)
No Diabetes	16	44	73.3
Diabetes	7	23	76.7
No Hypertension	3	13	81.2
Hypertension	20	54	73.0

Table 5 Chi-Square Tests and Odds Ratios for Associations Between Fistula Type, Risk Factors, and Outcomes

Comparison	χ^2	df	p-value	OR (Success)	95% CI
Type (1 vs. 2) vs. Hypertension	0.469	1	0.493	-	-
Type (1 vs. 2) vs. Diabetes	0.000	1	1.000	-	-
Type (1 vs. 2) vs. Outcome	0.026	1	0.871	1.23	0.46–3.27
Diabetes (No vs. Yes) vs. Outcome	0.007	1	0.932	1.19	0.43–3.32
Hypertension (No vs. Yes) vs. Outcome	0.139	1	0.710	0.62	0.16–2.42

Table 6 Preoperative Ultrasound Parameters and Maturation Outcomes for Type 1 Fistulas

Variable	N	Failure Mean $\pm$ SD	Success Mean $\pm$ SD	t-Statistic	p-value (t-test)	r (Correlation)	p-value (Correlation)
Radial Artery Distal Diameter (mm)	31	2.22 $\pm$ 0.49	2.03 $\pm$ 0.55	0.972	0.345	-0.17	0.365
Cephalic Vein Distal Diameter (mm)	32	2.32 $\pm$ 0.83	2.46 $\pm$ 1.05	-0.386	0.704	0.06	0.730
Distance Between Radial Artery and Cephalic Vein (mm)	31	11.06 $\pm$ 7.50	11.74 $\pm$ 6.20	-0.242	0.812	0.05	0.794
PSV in Proximal Radial Artery (cm/s)	31	77.66 $\pm$ 25.56	63.44 $\pm$ 17.37	1.53	0.154	-0.32	0.082

Table 7 Preoperative Ultrasound Parameters and Maturation Outcomes for Type 2 Fistulas

Variable	N	Failure Mean $\pm$ SD	Success Mean $\pm$ SD	t-Statistic	p-value (t-test)	r (Correlation)	p-value (Correlation)
Cephalic Vein Proximal Diameter (mm)	58	3.44 $\pm$ 0.99	3.57 $\pm$ 0.74	-0.428	0.674	0.067	0.620
Brachial Artery Diameter Above Bifurcation (mm)	58	3.97 $\pm$ 0.98	4.09 $\pm$ 0.65	-0.412	0.686	0.068	0.615
Brachial PSV (cm/s)	58	82.41 $\pm$ 17.28	76.47 $\pm$ 22.45	1.038	0.308	-0.120	0.368

Table 8 Logistic Regression Analysis for Predictors of AVF Maturation Failure (n=89)

Variable	Unadjusted OR (95% CI)	P-value	Adjusted OR (95% CI)	P-value
Radial Artery Distal Diameter (per 1 mm increase)	0.36 (0.14–0.93)	0.034	0.15 (0.04–0.58)	0.006
Age (per 1 year increase)	1.01 (0.97–1.05)	0.612	1.02 (0.98–1.06)	0.342
Male Sex	0.85 (0.32–2.25)	0.743	0.78 (0.27–2.20)	0.635
Diabetes Mellitus	0.83 (0.30–2.30)	0.720	0.89 (0.30–2.65)	0.834
Hypertension	0.62 (0.16–2.42)	0.492	0.55 (0.13–2.35)	0.421

Note: Adjusted model includes all variables listed in the table.

Abbreviations: OR, odds ratio; CI, confidence interval.

Table 9 Primary Patency and Number at Risk Over 6-Month Follow-Up by Fistula Type

Time (Months)	Type 1 (Radiocephalic)		Type 2 (Brachiocephalic)	
	Survival Probability	No. at Risk	Survival Probability	No. at Risk
0	1.00	32	1.00	57
1	0.92	29	0.90	51
2	0.78	25	0.75	42
3	0.68	22	0.65	37

(Continued)

Table 9 (Continued).

Time (Months)	Type 1 (Radiocephalic)		Type 2 (Brachiocephalic)	
	Survival Probability	No. at Risk	Survival Probability	No. at Risk
4	0.58	19	0.55	31
5	0.52	17	0.50	28
6	0.48	15	0.48	27

Note: Number at risk represents the estimated count of patients with patent fistulas at each time point based on initial cohort size and observed survival probabilities.

5.2 months) and assisted primary patency (median: 5.8 months), were also tracked, with complications such as thrombosis (n=15, 16.9%) and infection (n=4, 4.5%) noted in a minority of cases.

Secondary Outcomes and Complications

Overall, 6-month primary patency was 74.2% (66/89). Thrombosis occurred in 15 patients (16.9%), including 8 early thromboses (within 6 weeks) and 7 late thromboses (6 weeks to 6 months). Localized wound infection was observed in 4 patients (4.5%), all of which resolved with oral antibiotics without requiring fistula ligation. There was no significant difference in complication rates between Type 1 and Type 2 fistula configurations (thrombosis: 6/32 [18.8%] vs. 9/58 [15.5%], $p = 0.77$; infection: 2/32 [6.3%] vs. 2/58 [3.4%], $p = 0.61$). Primary patency rates over the 6-month follow-up period are summarized in Table 9. The survival probabilities declined gradually in both groups, with comparable 6-month patency between Type 1 (48%) and Type 2 (48%) fistulas. The Log rank test for equality of survival distributions was not significant ($p = 0.42$).

Maturation Outcomes by Fistula Type and Risk Factors

Maturation success rates were comparable across fistula types, with 23 of 32 Type 1 AVFs (71.9%) and 44 of 58 Type 2 AVFs (75.9%) achieving functional maturation. Failures were distributed as 9 (28.1%) in Type 1 and 14 (24.1%) in Type 2, showing no substantial disparity.

The prevalence of risk factors was assessed in relation to fistula type and outcomes. Diabetes was evenly distributed, affecting 11 of 32 (34.4%) Type 1 patients and 19 of 58 (32.8%) Type 2 patients. Hypertension was more common overall, present in 28 of 32 (87.5%) Type 1 and 46 of 58 (79.3%) Type 2 patients. However, these distributions did not differ significantly between types.

When stratified by risk factors, maturation success rates showed minimal variation. Non-diabetic patients had a 73.3% success rate (44 of 60), compared to 76.7% (23 of 30) in diabetic patients. For hypertension, success was 81.2% (13 of 16) in non-hypertensive patients and 73.0% (54 of 74) in hypertensive patients. These differences were not indicative of a predictive relationship.

To evaluate potential associations, chi-square tests and odds ratios (OR) were calculated. No significant links were found between fistula type and diabetes ($\chi^2 = 0.000$, $df = 1$, $p = 1.000$), fistula type and hypertension ($\chi^2 = 0.469$, $df = 1$, $p = 0.493$), or fistula type and maturation outcome ($\chi^2 = 0.026$, $df = 1$, $p = 0.871$; OR for Type 2 vs. Type 1 success = 1.23, 95% CI: 0.46–3.27). Similarly, diabetes ($\chi^2 = 0.007$, $df = 1$, $p = 0.932$; OR = 1.19, 95% CI: 0.43–3.32) and hypertension ($\chi^2 = 0.139$, $df = 1$, $p = 0.710$; OR = 0.62, 95% CI: 0.16–2.42) were not associated with outcomes. All p-values exceeded 0.05, and 95% confidence intervals for ORs included 1, confirming the absence of statistical significance in this sample. This suggests that, within this cohort, fistula type, diabetes, and hypertension do not independently predict AVF maturation failure, potentially due to the high overall maturation rate or unmeasured confounding factors such as vessel quality or surgical technique.

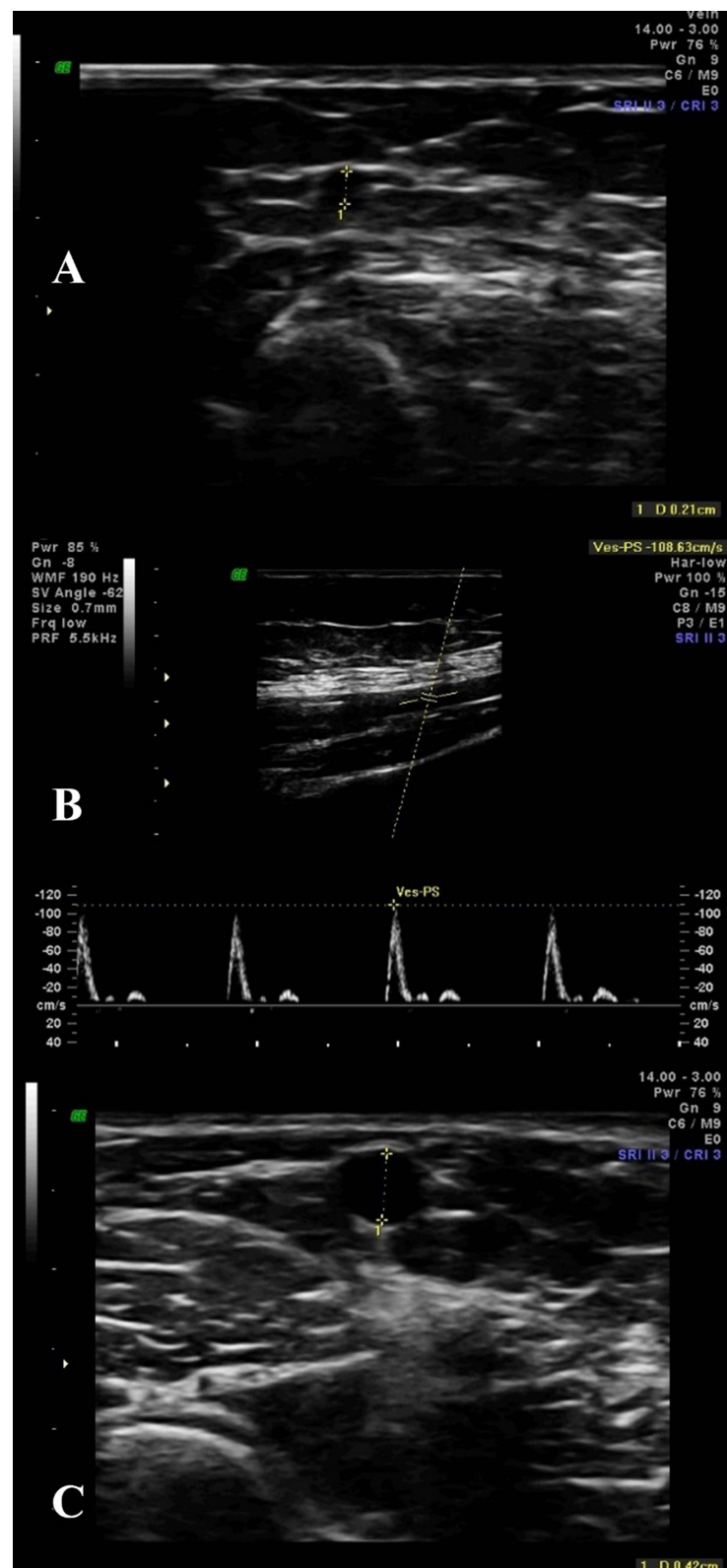


Figure 1 Mapping of brachiocephalic AVF; gray scale and spectral Doppler evaluation reveal: **(A)** Diameter of brachial artery 2 cm above cubital region has been measured (2.1mm); **(B)** Spectral Doppler shows triphasic waveform with PSV 108cm/s; **(C)** Diameter of cephalic vein at elbow has been measured (4.2mm). Dotted lines indicate the caliper placement for internal diameter measurement.

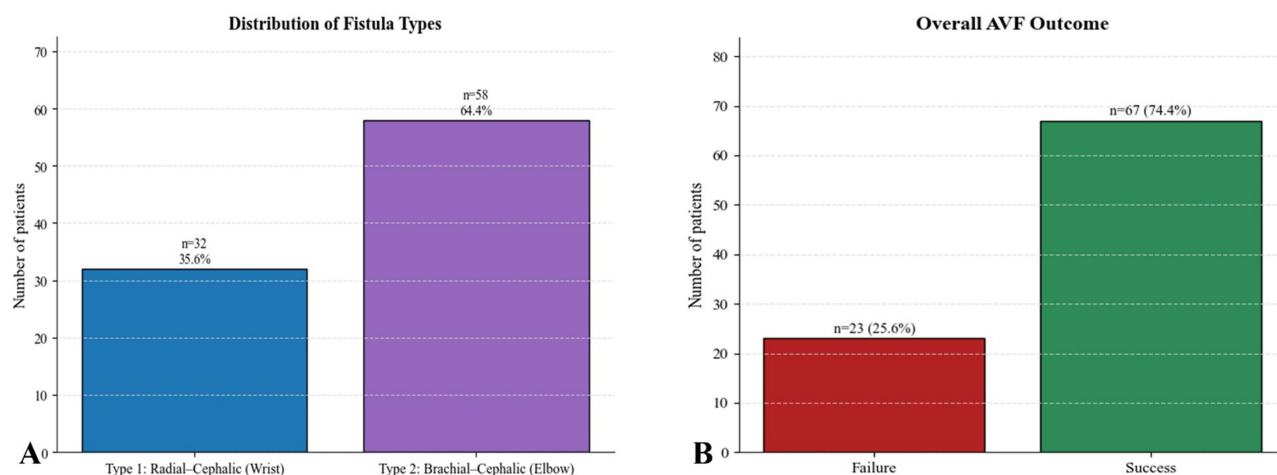


Figure 2 Distribution of fistula configuration and overall maturation outcome in the study cohort. **(A)** Bar chart showing the proportion of AVF types created (Type 1: radiocephalic/wrist; Type 2: brachiocephalic/elbow). **(B)** Bar chart summarizing overall functional maturation status (success vs failure), reported as counts and percentages.

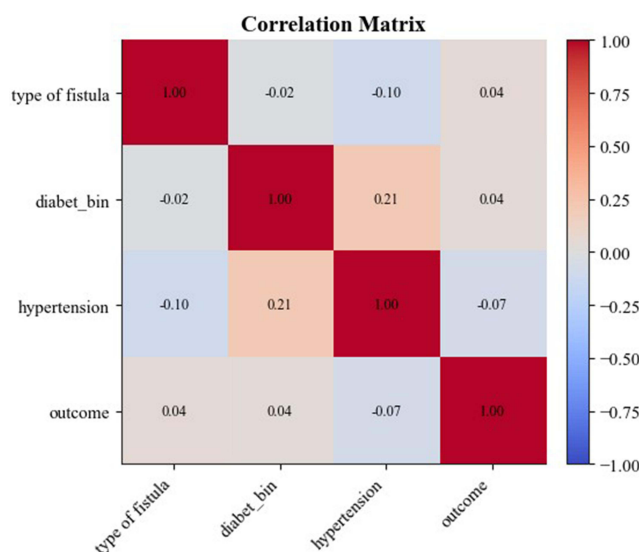


Figure 3 Correlation matrix of fistula type, comorbidities, and maturation outcome. Heatmap displaying pairwise correlation coefficients among fistula type, diabetes status, hypertension status, and functional maturation outcome.

Preoperative Ultrasound Parameters and Maturation Outcomes Within Fistula Types

Preoperative DUS parameters were analyzed separately for each fistula type to assess their predictive value for maturation, using Welch's t-tests for group comparisons and point-biserial correlations for associations with binary outcomes (success/failure). A p-value threshold of <0.05 was applied for significance, with trends noted for $p < 0.10$.

For Type 1 fistulas ($n=32$; one missing diameter measurement), failures exhibited slightly larger radial artery distal diameters (2.22 ± 0.49 mm) compared to successes (2.03 ± 0.55 mm), but this was not significant ($t=0.972$, $p=0.345$; $r=-0.17$, $p=0.365$). Cephalic vein distal diameters were similar (failure: 2.32 ± 0.83 mm vs. success: 2.46 ± 1.05 mm; $t=-0.386$, $p=0.704$; $r=0.06$, $p=0.730$), as were distances between the radial artery and cephalic vein (11.06 ± 7.50 mm vs. 11.74 ± 6.20 mm; $t=-0.242$, $p=0.812$; $r=0.05$, $p=0.794$). Peak systolic velocity (PSV) in the proximal radial artery showed a trend toward higher values in failures (77.66 ± 25.56 cm/s vs. 63.44 ± 17.37 cm/s; $t=1.53$, $p=0.154$; $r=-0.32$, $p=0.082$), suggesting a potential negative association warranting further investigation in larger samples, though it did not meet statistical significance.

Type 1 (Radial–Cephalic / Wrist): Continuous Variables by Outcome

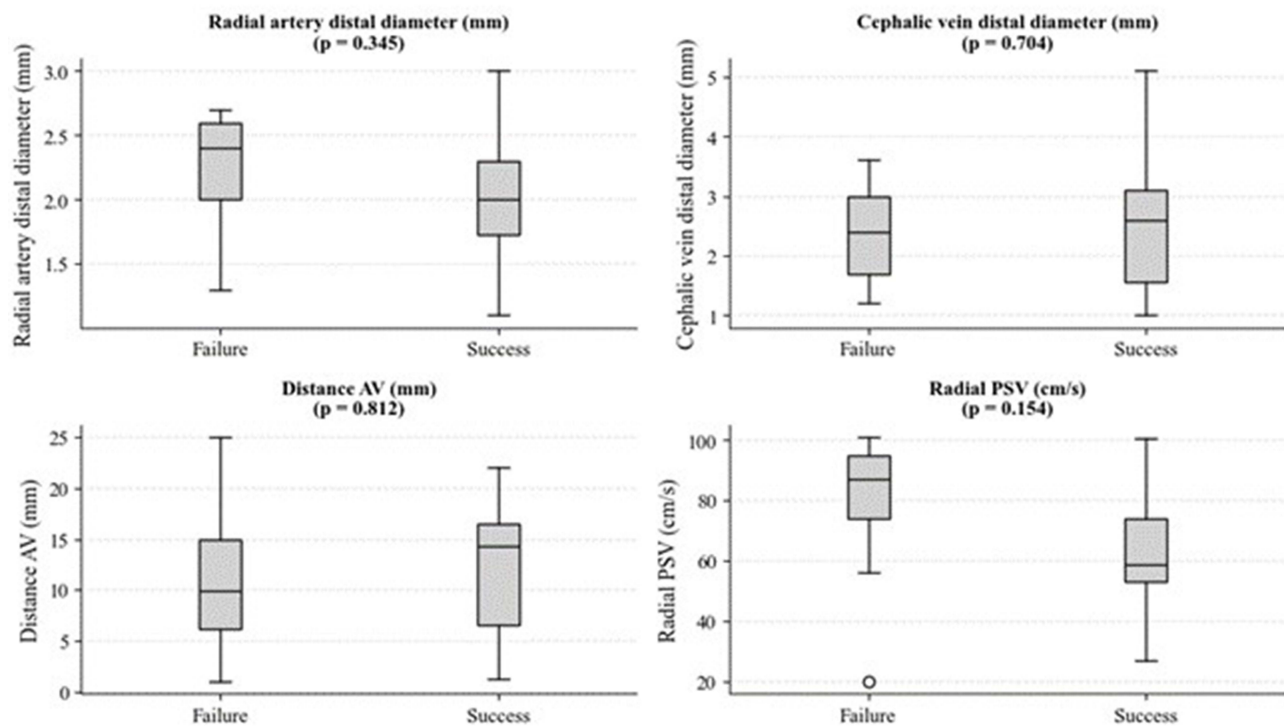


Figure 4 Type 1 (radiocephalic/wrist) AVFs: distribution of preoperative ultrasound variables by maturation outcome. Box-and-whisker plots comparing (i) radial artery distal diameter, (ii) cephalic vein distal diameter, (iii) distance between radial artery and cephalic vein, and (iv) proximal radial artery PSV between failed and successfully matured Type 1 AVFs; p-values shown on each panel.

For Type 2 fistulas ($n=58$), no significant differences emerged. Cephalic vein proximal diameters were comparable (failure: 3.44 ± 0.99 mm vs. success: 3.57 ± 0.74 mm; $t=-0.428$, $p=0.674$; $r=0.067$, $p=0.620$), as were brachial artery diameters above bifurcation (3.97 ± 0.98 mm vs. 4.09 ± 0.65 mm; $t=-0.412$, $p=0.686$; $r=0.068$, $p=0.615$) and brachial PSV (82.41 ± 17.28 cm/s vs. 76.47 ± 22.45 cm/s; $t=1.038$, $p=0.308$; $r=-0.120$, $p=0.368$). These findings indicate that the selected DUS parameters do not robustly predict maturation in brachiocephalic AVFs within this cohort, potentially reflecting the influence of other unmeasured variables such as arterial compliance or venous outflow resistance.

Multivariable Analysis of Predictors of Maturation Failure

In univariate logistic regression, larger distal radial artery diameter was associated with a reduced odds of maturation failure (unadjusted OR = 0.36, 95% CI: 0.14–0.93; $p = 0.034$). After adjusting for age, sex, diabetes mellitus, and hypertension, the association strengthened and remained independently significant (adjusted OR = 0.15, 95% CI: 0.04–0.58; $p = 0.006$). No other preoperative ultrasound parameter or demographic factor emerged as an independent predictor (Table 8).

Discussion

The present prospective cohort study evaluated preoperative Doppler ultrasound (DUS) parameters as predictors of functional arteriovenous fistula (AVF) maturation in 89 patients with end-stage renal disease (ESRD) undergoing primary upper limb AVF creation. Our key finding was a counterintuitive association between larger preoperative radial artery distal diameters and increased risk of maturation failure, with failures exhibiting significantly larger diameters (2.27 ± 0.54 mm vs. 1.98 ± 0.52 mm in successes; $p=0.037$). This association remained statistically significant after multivariable adjustment (see Table 8). In contrast, other parameters, including brachial artery diameters, peak systolic velocities

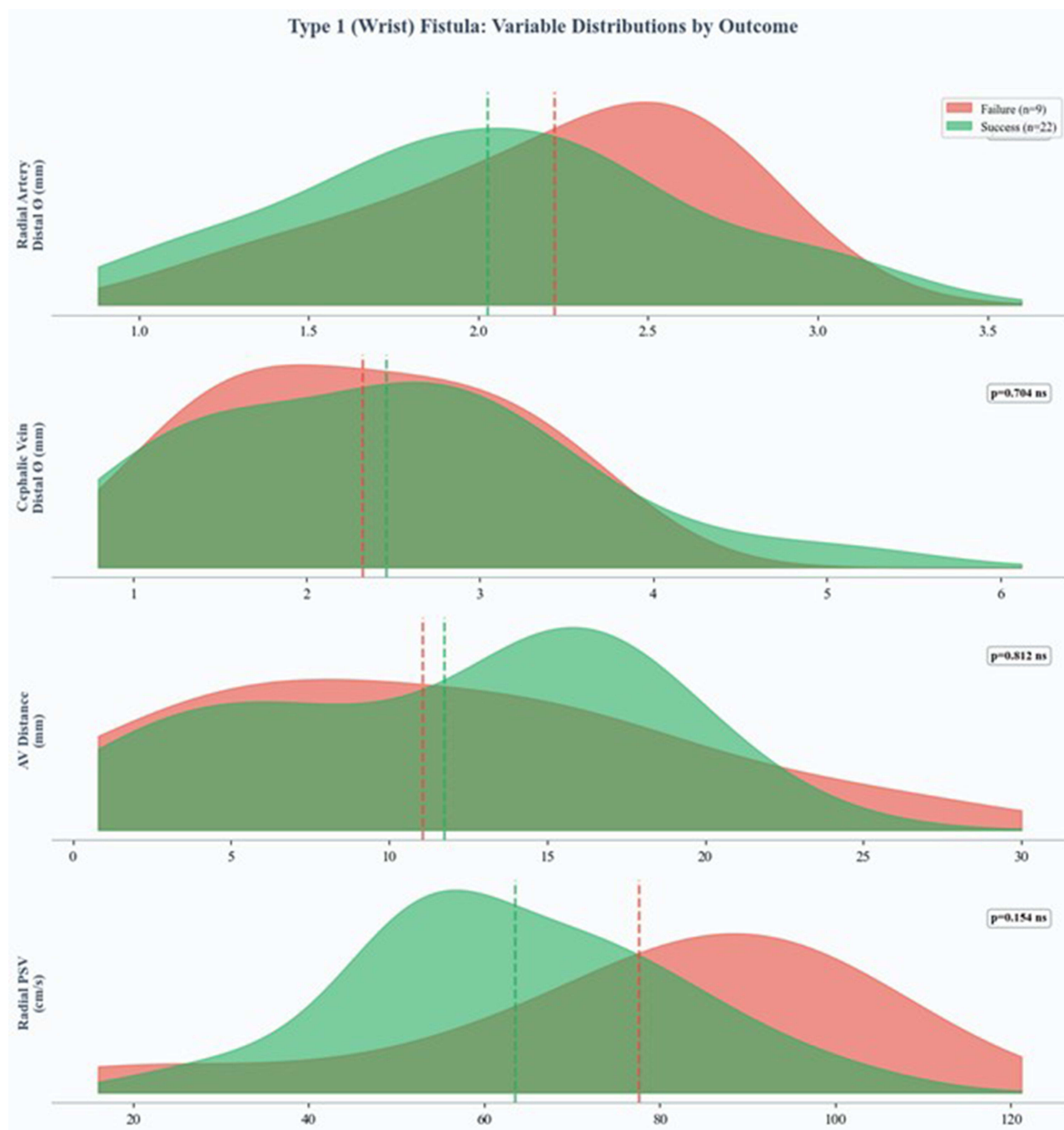


Figure 5 Type 1 (radiocephalic/wrist) AVFs: kernel density distributions of preoperative ultrasound variables by outcome. Overlaid density plots for failure vs success illustrating the distribution of radial artery distal diameter, cephalic vein distal diameter, artery–vein distance, and proximal radial artery PSV; vertical dashed lines indicate group central tendency, with corresponding p-values annotated.

(PSV), and vein diameters, showed no significant predictive value. Overall maturation rates were high at 74.2%, with no associations between fistula type (radiocephalic vs. brachiocephalic), diabetes, or hypertension and outcomes.

This paradoxical relationship challenges the prevailing literature, which generally supports larger arterial diameters as favorable for AVF success. Traditional thresholds, such as radial artery diameters ≥ 2.0 mm, have been associated with improved maturation and patency in prior studies. For instance, a 2020 study reported that reduced radial artery diameters were linked to higher immaturity risks in radiocephalic AVFs (RCAVFs), with smaller vessels (<2.0 mm) predicting failure. Similarly, a recent 2025 prediction model for RCAVF maturation failure in 196 ESRD patients identified smaller

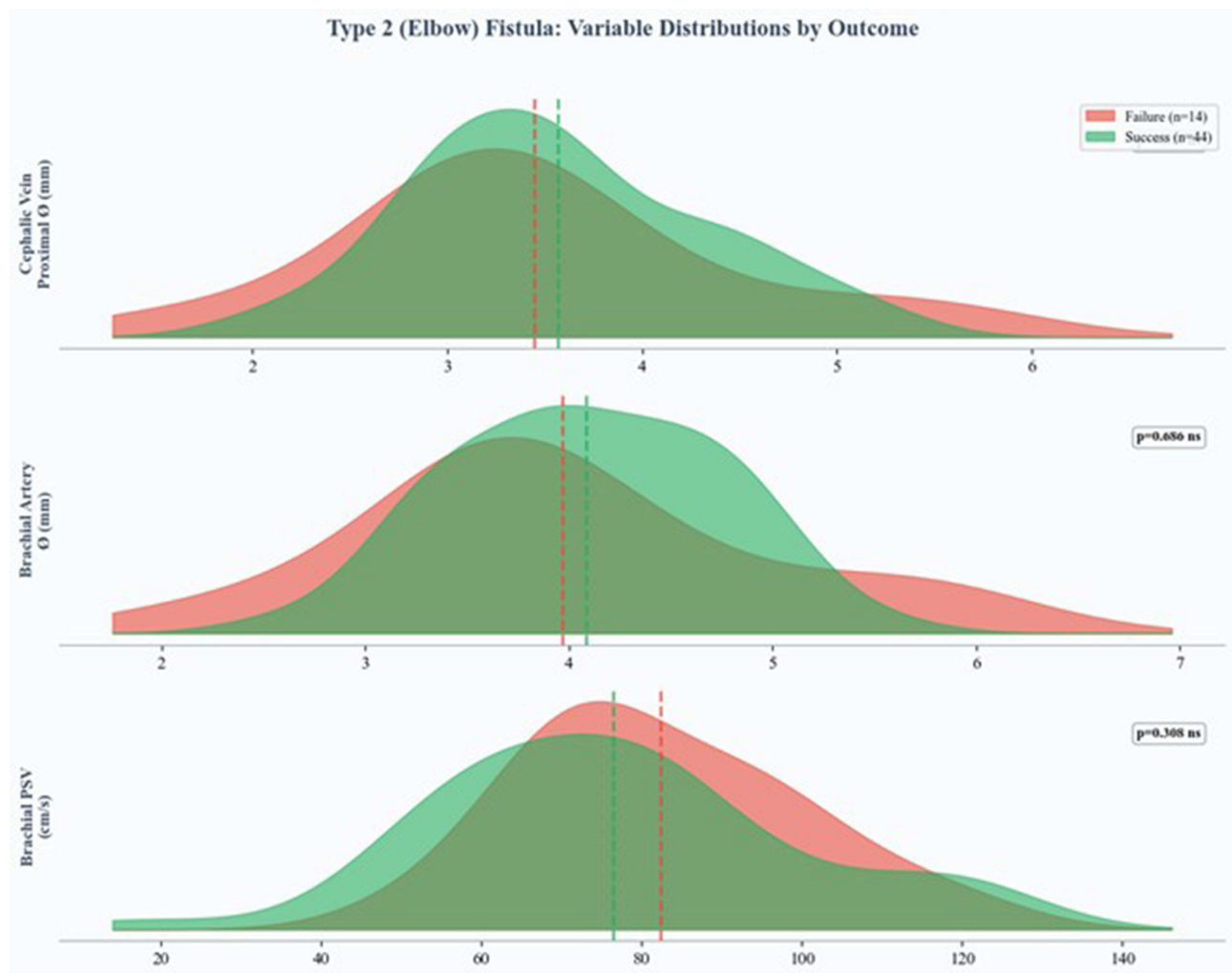


Figure 6 Type 2 (brachiocephalic/elbow) AVFs: kernel density distributions of preoperative ultrasound variables by outcome. Overlaid density plots comparing failure vs success for cephalic vein proximal diameter, brachial artery diameter above bifurcation, and brachial artery PSV; vertical dashed lines indicate group central tendency, with p-values annotated.

arterial diameters (median 1.9 mm in failures vs. 2.1 mm in successes; $p < 0.001$) as an independent predictor (multivariate OR=0.36, 95% CI: 0.459–0.934, $p=0.028$), alongside factors like age and lean tissue index. Restricted cubic spline analysis in that study further indicated elevated failure risk at diameters ≤ 2.0 mm, aligning with the conventional view that inadequate inflow from smaller arteries hinders remodeling and flow augmentation.¹⁷

However, our results echo emerging counterintuitive insights from recent analyses. A 2022 post-hoc analysis of multicenter randomized trials involving 914 RCAVF creations found that larger intraoperative radial artery diameters (per 1 mm increase) were associated with a 25% increased hazard of primary-assisted patency loss (HR=1.25, 95% CI: 1.05–1.49) and decreased rates of successful access use. The authors described this as “perplexing”, hypothesizing that larger arteries may be selected in patients with underlying vessel pathology, such as calcification or atherosclerosis, which impairs intimal adaptation. Alternatively, excessive shear stress from high-flow volumes in dilated arteries could promote turbulent flow and maladaptive venous remodeling, leading to stenosis or thrombosis. Although that study predates our enrollment period, it provides a mechanistic framework for our observations, particularly in radiocephalic configurations where distal radial anatomy amplifies such effects. Subgroup analysis in our cohort reinforced this trend in Type 1 (radiocephalic) fistulas, with failures showing non-significantly larger radial distal diameters (2.22 ± 0.49 mm vs. 2.03 ± 0.55 mm; $p=0.345$) and a trend toward higher proximal radial PSV, suggesting hemodynamic contributions.¹⁸

Comparisons with newly published research from 2024–2025 further contextualize our findings. A 2024 retrospective study developing a nomogram for AVF maturation risk emphasized postoperative vessel diameters (eg., anastomotic diameter and venous internal diameter at 1 month) as strong predictors (AUC=0.938), with preoperative criteria requiring arterial diameters >1.5 mm and venous >2.0 mm for inclusion. While that analysis focused on post-creation metrics, it underscores the limitations of preoperative DUS alone, as early postoperative changes may better reflect maturation potential. In contrast, a 2025 study on inflammatory biomarkers in 249 ESRD patients identified systemic inflammation response index (SIRI), triglyceride-glucose index with BMI (TyG-BMI), and high-sensitivity C-reactive protein to albumin ratio (HRR) as independent predictors of non-maturation (HRs ranging 1.44–2.68, all $p<0.001$), with no mention of vessel diameters. This highlights potential unmeasured confounders in our cohort, such as inflammation-driven endothelial dysfunction, which could interact with larger arterial diameters to exacerbate failure risks—particularly in diabetic or hypertensive subsets, though these were non-significant here.¹⁹

The absence of predictive value for vein diameters or PSV in our study aligns with mixed evidence. A 2025 analysis of postoperative trends in brachiocephalic AVFs noted significant increases in venous diameter and brachial flow within 6 weeks ($p<0.05$), but did not link preoperative values to outcomes.²⁰ Similarly, a 2025 meta-analysis on vessel diameters for RCAVF functional maturation aimed to define optimal radial artery and cephalic vein thresholds, but details suggest reinforcement of larger-is-better paradigms, contrasting our results. These discrepancies may stem from study heterogeneity, including AVF types (predominantly brachiocephalic in our cohort), definitions of maturation, and follow-up durations.²⁰

Several limitations warrant consideration. First and foremost, we did not routinely assess arterial wall pathology such as intima-media thickness or medial calcification via Doppler ultrasound. This is a critical omission, as the paradoxical finding of larger arteries failing is almost certainly driven by vessel quality (eg., stiff, non-compliant, or atherosclerotic vessels) rather than size alone. Second, Our single-center design and modest sample size may limit generalizability, potentially underpowering detection of associations for rarer predictors like PSV. Additionally, the sample size calculation assumed a 40% maturation failure rate based on historical institutional data; however, the observed failure rate was lower (25.8%). Consequently, the study may be underpowered to detect smaller effect sizes for venous parameters or flow velocities, and the negative findings regarding PSV and vein diameter should be interpreted with caution. We did not routinely assess arterial calcification or intima-media thickness via DUS, which could explain the counterintuitive diameter findings, as larger diameters might mask underlying atherosclerosis. Additionally, while we adjusted for key confounders, inflammatory markers or body composition indices—emerging predictors in 2025 studies—were not evaluated. Future research should integrate multimodal preoperative assessments, including advanced imaging and biomarkers, in larger multicenter cohorts to validate and refine thresholds.^{17,21}

Study Strengths

The primary strength of this investigation is its prospective design, which minimized recall bias and ensured standardized, protocol-driven preoperative ultrasound measurements performed within a narrow two-week window prior to surgery. Furthermore, the definition of functional maturation was stringent, requiring documented clinical usability for two-needle cannulation and sustained dialysis adequacy (≥ 300 mL/min) rather than relying solely on surrogate ultrasound flow metrics or physical examination findings.

Conclusion

In this prospective cohort of patients with end-stage renal disease undergoing first-time upper-limb arteriovenous fistula creation, approximately three-quarters of fistulas achieved functional maturation within 6 months. Most routinely collected preoperative Doppler ultrasound measurements—including venous diameters and peak systolic velocities—did not demonstrate clinically meaningful predictive value for maturation. Notably, a larger distal radial artery diameter was paradoxically associated with an increased likelihood of maturation failure and remained significant after multi-variable adjustment, suggesting that arterial caliber alone may not adequately capture access suitability and that arterial quality and downstream hemodynamic conditions may be equally (or more) important determinants of success. Overall, these findings support a more integrated preoperative evaluation strategy in which conventional ultrasound mapping is complemented by assessments of arterial wall pathology (eg., Doppler ultrasound measurement of intima-media

thickness or arterial calcification scoring), venous outflow resistance, and detailed intraoperative hemodynamics. Larger multicenter studies are warranted to validate this counterintuitive association and to develop more robust, clinically actionable prediction models for arteriovenous fistula maturation.

Abbreviations

AD, Arterial diameter; AUC, Area under the curve; AVF, Arteriovenous fistula; CI, Confidence interval; DUS, Doppler ultrasound; EDV, End-diastolic velocity; ESRD, End-stage renal disease; FFBI, Fistula First Breakthrough Initiative; HR, Hazard ratio; IQR, Interquartile range; NKF-KDOQI, National Kidney Foundation - Kidney Disease Outcomes Quality Initiative; OR, Odds ratio; PSV, Peak systolic velocity; ROC, Receiver operating characteristic; RRT, Renal replacement therapy; VD, Venous diameter.

Data Sharing Statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the principles of the Declaration of Helsinki. The study protocol was approved by the Ethics Committee of Isfahan University of Medical Sciences (approval number: IR.MUI.MED.REC.1403.373). Written informed consent was obtained from all participants prior to enrollment.

Consent for Publication

Not applicable, as no individual patient data or identifiable information is presented.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that they have no competing interests.

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