

ROLE OF DUPLEX ULTRASONOGRAPHY IN EVALUATION OF ARTERIOVENOUS FISTULA AND HAND COLLATERAL SYSTEM

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ABSTRACT

Arteriovenous fistula (AVF) is the preferred vascular access for long-term hemodialysis, but successful maturation depends on adequate arterial inflow, venous suitability, collateral circulation, and postoperative remodeling. Duplex ultrasonography provides simultaneous anatomical and hemodynamic assessment and may improve vascular access planning and surveillance. To evaluate the role of duplex ultrasonography in preoperative vascular mapping, validation of the Modified Allen test, and postoperative assessment of AVF patency, maturation, and complications in chronic kidney disease patients requiring hemodialysis. This cross-sectional study included 120 chronic kidney disease patients requiring hemodialysis. Preoperative duplex ultrasonography assessed arterial caliber, peak systolic velocity (PSV), venous diameter, venous distensibility, and collateral circulation. AVF site selection was based on duplex findings. Postoperative duplex evaluation at 24 hours, 2 weeks, and 6 weeks assessed patency, maturation, flow characteristics, and complications. The mean age of participants was 57.7 ± 12.5 years, and 69.2% were male. Adequate AVF maturation was achieved in 65.8% of patients. Higher radial and ulnar PSV, larger cephalic and basilic vein diameters after tourniquet application, greater venous distensibility, and normal Modified Allen test findings were significantly associated with successful maturation ($p < 0.001$). Matured AVFs demonstrated significantly greater caliber and flow volume than delayed AVFs. Low flow, stenosis, thrombosis, and poor maturation were predominantly observed in delayed maturation cases. Duplex ultrasonography is an effective modality for AVF planning and surveillance. Distal arterial inflow, venous recruitability, collateral circulation, AVF caliber, and access flow are important predictors of successful AVF maturation.

KEYWORDS: Duplex ultrasonography; Arteriovenous fistula; Chronic kidney disease; Hemodialysis; Fistula maturation.

1. INTRODUCTION

CKD is a widespread health issue across the globe that usually results in end-stage renal failure that demands renal replacement therapy. Hemodialysis is a highly common modality of therapy, and the efficacy of this technique hinges on an adequate supply of accessible vascular channels. There exist multiple access options; however, among these options, the autogenous arteriovenous fistula (AVF) stands out as the ideal choice for treatment due to its superior patency rate, low infection rates, decreased risk of thrombosis, and better outcomes as compared to other prosthetic devices and catheters (Abdelaziz et al., 2018). Nonetheless, the creation of an appropriate AVF is associated with significant difficulties since the majority of fistulas fail to mature satisfactorily or have some issues related to access (Bashar et al., 2023). There are multiple physiological and anatomical factors involved in AVF maturation, including proper arterial blood supply, venous drainage, arterial-venous distensibility, and adaptive remodeling of the vessel wall. Arterial and venous hemodynamics at the level of the distal arteries and veins are critical for the development of flow rates that would be adequate for hemodialysis (Chytilova et al., 2021). Identifying vascular anomalies early on can significantly enhance outcomes in vascular access procedures and reduce repeat intervention risks.

Duplex Doppler ultrasound has proved to be essential in assessing the vascular access for hemodialysis treatment. It allows for the simultaneous assessment of both anatomy and function of the vessels, allowing for an integrated evaluation of the arterial and venous vessels pre- and post-AVF formation (Conkbayir et al., 2018). This is because the use of ultrasonography in assessing the vasculature allows for the assessment of hemodynamics of the vessels, including the caliber and velocity of the flow of blood. Recent advances in the technology have enhanced its application in novel fistula configurations and maturation processes (Franco et al., 2020). The adoption of duplex ultrasonography within vascular access programs is a sign of an awareness of its clinical utility. Ultrasound imaging is increasingly being used to inform decisions in relation to planning access, maturation, and identification of complications (Fu et al., 2024). In addition, multimodal imaging research has identified the role of duplex ultrasonography as a primary method for assessing native fistulas and vascular grafts (Gonzalez et al., 2023). Vascular mapping prior to surgery and follow-up imaging after the procedure have been found effective in improving access selection due to objective evaluation of vessels and fistulas (Granata et al., 2021). More recently, ultrasound-based methods have been utilized in the classification and characterization of access dysfunction (Granata et al., 2025).

Even though duplex ultrasonography has been widely accepted in vascular access evaluation, many challenges arise when applying it in practice. Postoperative duplex examination can be helpful in assessing the function of the fistula; however, screening procedures have not yet become consistent practice at all facilities (Khalid Abdul-Hakim Abdul-Maqsoud et al., 2023). Another example of an application of duplex ultrasonography which has proven to be helpful is lesion detection; however, the criteria and cutoff points utilized are not consistent (Malik et al., 2022). Despite the available evidence suggesting that ultrasound can help assess a vascular access, there is no universally accepted protocol that uses both preoperative and postoperative examination (Mario et al., 2021). Additionally, various diagnostic imaging modalities may be applied selectively and therefore contribute to the variability of diagnostics and access management strategies (Marzouk et al., 2019). Diagnostic discrepancies result in inconsistent lesion identification and predictions of maturation outcomes (Mazhar et al., 2019).

Access-related issues, including thrombosis, stenosis, aneurysm, and infection, still play an important role in causing the dysfunction and failure of AVFs (Meola et al., 2021). While other techniques allow getting comprehensive vascular data, duplex ultrasonography is a convenient, non-invasive, and repeatable option that can be used for routine access evaluation and, thus, is especially appropriate for monitoring dialysis access (Meyer et al., 2017). In addition, ultrasound-guided procedures have been increasingly used for timely intervention and enhancing access preservation (Napoli et al., 2021). Arterial inflow, collateral circulation, and distal perfusion are some other important considerations that can affect the success rate of AVF. A lack of collateral circulation can expose individuals to risks of suffering from ischemia and affect their postoperative outcomes with regard to AVF function (Peters et al., 2020). As such, a comprehensive approach should be taken into account to determine which factors will determine the success of the procedure.

Research Objectives

Primary Objective

- To determine the optimal site for AVF construction using duplex ultrasonography and validate the Modified Allen test.

Secondary Objectives

1. To assess AVF patency at 24 hours after surgery.
2. To assess AVF maturation at 2 weeks and 6 weeks after surgery.

2. MATERIALS AND METHODS

2.1 Study Design and Setting

This cross-sectional study lasted for 18 months in a tertiary care hospital situated in Tamil Nadu, India, which had an overwhelmingly rural clientele base. This study was carried out to examine the importance of duplex ultrasonography in pre-operative vascular mapping, evaluation of collateral circulation, and follow-up assessment after AVF surgery among patients suffering from CKD undergoing hemodialysis treatment.

2.2 Study Population

Patients who had been diagnosed with chronic kidney disease and who needed a vascular access point for hemodialysis were selected as part of the study population. Consecutive patients who met eligibility criteria and who were referred for AVF construction as well as those who's dysfunctional AVFs needed to be replaced by another one were included in this study. The study was approved by the institutional ethics committee before the study commenced.

2.3 Inclusion and Exclusion Criteria

Study participants were those who needed hemodialysis due to their chronic kidney disease and those with faulty AVFs requiring creation of a new fistula. Patients who required vascular prosthetics and those with thrombosed veins not suitable for fistula formation were not included in the study.

2.4 Sample Size

This sample size estimation was carried out based on the results of a previous study where the average PSV of the radial artery was stated to be 33 ± 8.78 cm/s. The consideration of a maximum permissible error that is equal to 5% of the average PSV plus the non-response rate resulted in the estimate of a sample size equal to 120 people. Hence, 120 patients participated in the study.

2.5 Duplex Ultrasonography Protocol

All tests were done with the use of the Mindray DC80 Ultrasound Scanner with a high frequency linear probe (3-5 MHz). Patients were positioned in a relaxed sitting posture with the upper limbs supported by a pillow in their non-dominant side while keeping their elbows extended. Ultrasound Duplex was done based on a set procedure for preoperative evaluation and post-operative monitoring of AVFs.

2.5.1 Preoperative Arterial Assessment

The arterial study was conducted prior to the operation to assess whether the upper extremity arteries could be used for AVF creation. Both the brachial and radial arteries were analyzed using diameter, PSV, and wave forms. In addition, distal arterial patency and elasticity were evaluated. A clenched fist test was used to measure the elasticity of the radial artery.

2.5.2 Preoperative Venous Assessment

Superficial venous system was analyzed with regard to the measurement of diameters of cephalic vein, basilic vein, and median cubital vein. Venous distensibility was determined based on the diameter of veins before and after tourniquet application. The extent of change in venous diameter following venous augmentation was measured as an indication of recruitability of veins. The information obtained was helpful for selection of veins suitable for formation of a fistula.

2.5.3 Assessment of Collateral Circulation

Hand collaterals circulation was tested through the Modified Allen test. Compression of the radial and ulnar arteries above the transducer was done in order to examine the patency of the palmar arch and the adequacy of the blood flow through the collaterals.

2.5.4 AVF Site Selection

The location at which the AVF would be created was determined through the assessment of arterial flow dynamics, vein diameter, vein compliance, and collateral flow. Information obtained from the duplex ultrasound examination was used to determine the optimal arterial and venous locations for formation of the vascular access.

2.5.5 Postoperative Duplex Surveillance

After a successful establishment of an AVF, patients had their progress monitored with ultrasound examination 24 hours, 2 weeks, and 6 weeks after surgery. In every follow-up assessment, arterial parameters such as artery caliber, PSV, and waveforms in the brachial, radial, and ulnar arteries were recorded. On the other hand, parameters assessed for AVF included its caliber, PSV, flow volume, and depth from the skin surface.

2.5.6 Assessment of AVF Maturation and Complications

Postoperative monitoring was done to evaluate the status of fistula maturation as well as complications associated with fistula access. The most focus has been given on assessment of the AVF diameter, blood flow volume through the fistula access, and hemodynamics changes in the postoperative period.

2.6 Outcome Measures

The first main outcome measure was whether the AVF matured properly or not, classified into two groups – maturation proper and delayed maturation according to the results from the duplex ultrasonography performed. The second outcome measures were AVF patency 24 hours postoperatively and postoperative complications such as low flow state, stenosis, thrombosis, wall thickening, and maturation failure.

2.7 Statistical Analysis

Data entry was done using Microsoft Excel while statistical analysis was carried out using Statistical Package for Social Sciences (SPSS) version 17. For quantitative data, means and standard deviations were used, but categorical data was summarized as frequencies and proportions. Difference tests were carried out to assess whether there were differences in maturation among groups while Chi-square test was used to determine the relationships between categorical variables. Independent predictors for delayed AVF maturation were identified using multivariate logistic regression. A level of significance of $p < 0.05$ was adopted throughout the study.

3. RESULTS

3.1 Baseline Demographic and Clinical Characteristics

The total number of patients with chronic kidney disease that underwent creation of AVF was 120. The patient population mainly consisted of middle-aged and elderly subjects, as the average age was 57.7 ± 12.5 years and the median age was 59 years. More than two-thirds of the patients belonged to the male gender, which is a characteristic of hemodialysis patient population. The procedures performed on either left or right arm of the subjects were nearly equal, suggesting that the decision regarding the access site was based on vascular suitability only (Table 1).

Table 1. Baseline Demographic and Clinical Characteristics of Study Participants (N = 120)

| Category | Variable | n (%) / Mean \pm SD |
|----------|----------|-----------------------|
|----------|----------|-----------------------|

| | | |
|--------------------|--------------------|--------------|
| Age | Mean age (years) | 57.7 ± 12.5 |
| | Median age (years) | 59.0 (35–78) |
| Age Group | 30–40 years | 14 (11.7) |
| | 41–50 years | 28 (23.3) |
| | 51–60 years | 24 (20.0) |
| | 61–70 years | 30 (25.0) |
| | 71–80 years | 24 (20.0) |
| Gender | Male | 83 (69.2) |
| | Female | 37 (30.8) |
| Side of AVF | Left | 64 (53.3) |
| | Right | 56 (46.7) |

Demographic variables for the patients included in the study are provided in Figure 1 below, showing the distribution among age groups, genders, and sides where AVF was formed.

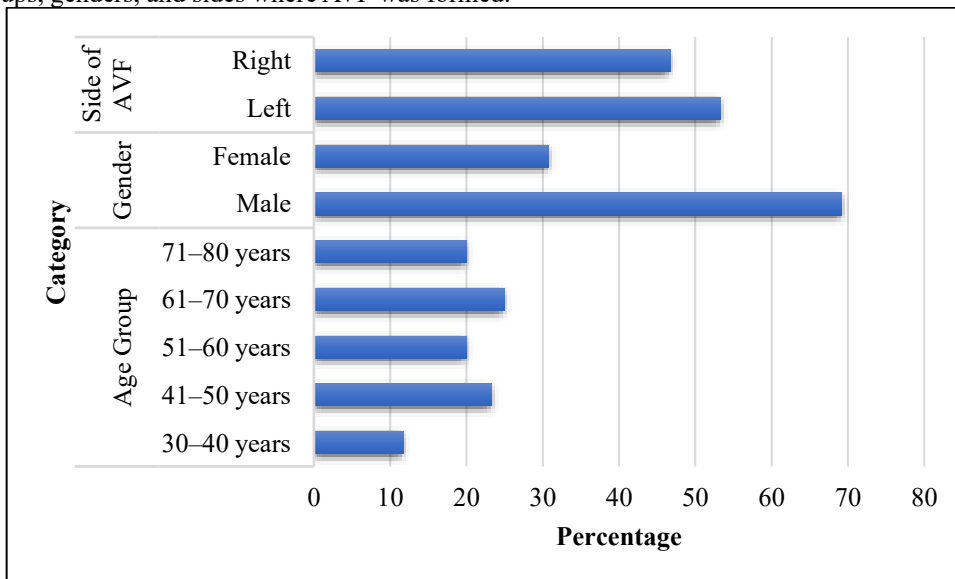


Figure 1. Demographic Profile of Study Participants

The results depicted in Figure 1 revealed that the study participants were mostly males, with the largest percentage of subjects falling under the age group of 61–70 years. The AVF formation procedure was undertaken on the left side more often compared to the right side.

3.2 Preoperative Duplex Vascular Assessment

Most patients had normal upper limb artery and vein anatomy on the preoperative duplex ultrasonography for planning of AVF. This was seen as a physiological decrease in the caliber of the arteries and the PSV in the arteries from proximal to distal vessels, being highest in the subclavian artery and gradually decreasing till the radial and ulnar artery. Venous mapping showed good cephalic vein and basilic vein augmentation after the application of a tourniquet, which meant good venous compliance and distensibility. These findings indicate that, in general, the characteristics of the arterial inflow and venous outflow are suitable for creation of AVF among the study population (Table 2).

Table 2. Preoperative Duplex Vascular Assessment (N = 120)

| Category | Parameter | Mean ± SD |
|----------------------------|-------------------------------------------|----------------|
| Arterial Parameters | Subclavian caliber (mm) | 7.45 ± 0.95 |
| | Subclavian PSV (cm/s) | 114.21 ± 20.22 |
| | Axillary caliber (mm) | 6.48 ± 0.87 |
| | Axillary PSV (cm/s) | 103.15 ± 19.31 |
| | Brachial caliber (mm) | 5.57 ± 0.88 |
| | Brachial PSV (cm/s) | 92.42 ± 21.32 |
| | Radial caliber (mm) | 2.75 ± 0.47 |
| | Radial PSV (cm/s) | 45.91 ± 16.55 |
| | Ulnar caliber (mm) | 2.64 ± 0.34 |
| | Ulnar PSV (cm/s) | 42.80 ± 14.27 |
| Venous Parameters | Cephalic diameter without tourniquet (mm) | 2.49 ± 0.66 |
| | Cephalic diameter with tourniquet (mm) | 3.65 ± 1.03 |
| | Cephalic distensibility (%) | 46.15 ± 15.64 |
| | Basilic diameter without tourniquet (mm) | 3.14 ± 0.76 |

| | | |
|--|---------------------------------------|---------------|
| | Basilic diameter with tourniquet (mm) | 4.50 ± 1.21 |
| | Basilic distensibility (%) | 42.45 ± 12.94 |
| | Median cubital vein diameter (mm) | 4.17 ± 0.69 |

Evaluation of hand collateral circulation (Modified Allen test) is shown separately in Figure 2.

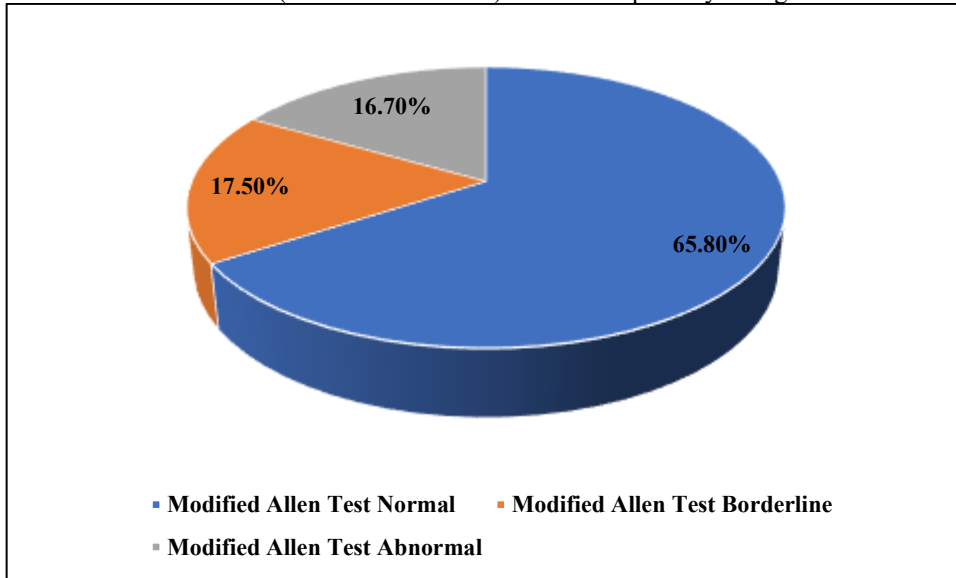


Figure 2. Modified Allen Test Results

Most of the patients had a normal collateral circulation by Modified Allen test, and a smaller number had borderline or abnormal collateral circulation. Collateral circulation was impaired in about a third of patients overall, highlighting the need for preoperative evaluation of their vascular status, including collateral assessment, especially if distal AVF creation is to be considered.

3.3 AVF Site Selection and Early Postoperative Findings

Preoperatively vascular mapping was used and brachio basilic AVF was the most commonly chosen access configuration followed by brachiocephalic and radiocephalic fistulas. From the overall group, early postoperative duplex showed satisfactory fistular caliber and flow characteristics, confirming the success of access creation in the early postoperative period and functional patency of most fistulas (Table 3).

Table 3. Early Postoperative Duplex Findings (N = 120)

| Postoperative Duplex | Value |
|----------------------|-----------------|
| AVF caliber (mm) | 4.36 ± 1.39 |
| AVF PSV (cm/s) | 245.98 ± 55.68 |
| Flow volume (mL/min) | 804.38 ± 339.55 |
| Depth from skin (mm) | 6.72 ± 2.02 |

The distribution of AVF configurations selected for vascular access creation is presented in Figure 3.

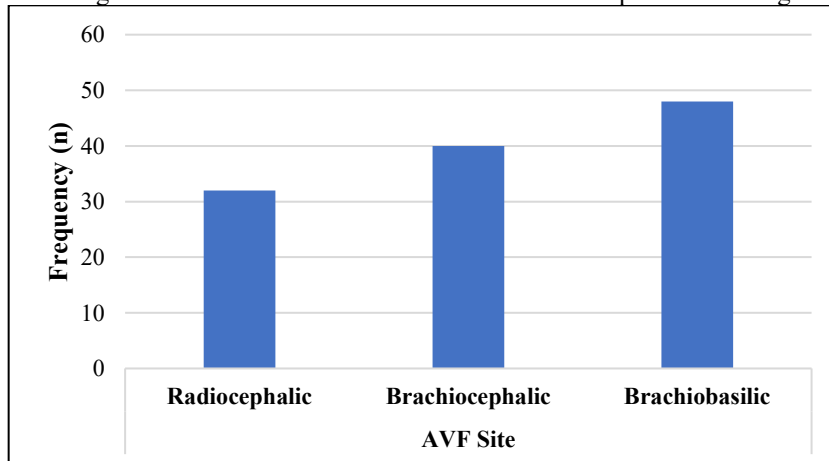


Figure 3. AVF Site Distribution

The most frequent access site chosen was brachio basilic AVF, followed by brachiocephalic and radiocephalic access sites. This distribution reflects the fact that the best possible vascular anatomy for AVF formation was selected based on the pre-operative duplex results and in this manner the chances of maturation and long term function of the AVF were optimised.

3.4 AVF Maturation Outcomes and Postoperative Complications

A total of 65.8% had adequate AVF maturation at six weeks, while 34.2% had delayed AVF maturation. While most patients did not have complications, low-flow states, stenosis and early thrombosis were the most common abnormalities found at surveillance. There was a highly significant association between maturation outcome and postoperative complications ($\chi^2 = 120.0$, $p < 0.001$). Structured postoperative surveillance was seen to be important as all fistulas were complication free if they had reached adequate maturity, while all those who had delayed maturity showed one or more abnormal findings by duplex (Table 4).

Table 4. AVF Maturation Status, Complications and Their Association with Maturation Outcome (N = 120)

| Category | Adequate n (%) | Delayed n (%) | Total n (%) |
|------------------|-------------------|-------------------|--------------------|
| No complication | 79 (100.0) | 0 (0.0) | 79 (65.8) |
| Low flow | 0 (0.0) | 13 (31.7) | 13 (10.8) |
| Stenosis | 0 (0.0) | 11 (26.8) | 11 (9.2) |
| Early thrombosis | 0 (0.0) | 8 (19.5) | 8 (6.7) |
| Poor maturation | 0 (0.0) | 5 (12.2) | 5 (4.2) |
| Wall thickening | 0 (0.0) | 4 (9.8) | 4 (3.3) |
| Total | 79 (100.0) | 41 (100.0) | 120 (100.0) |

Chi-square = 120.0; p < 0.001

3.5 Preoperative Predictors of AVF Maturation

Preoperative duplex parameters were compared and it was found that higher arterial inflow distal to the AVF and better venous suitability were good predictors of successful maturation of the AVF. Patients with well-matured fistulae had significantly higher radial and ulnar PSV, larger cephalic and basilic vein diameter and higher venous distensibility. Also, there was a highly significant correlation between Modified Allen test and maturation status, all well matured fistulas occurring in patients who had good collateral circulation, thus confirming its role as clinically relevant assessment tool (Table 5).

Table 5. Preoperative Duplex Predictors of AVF Maturation (N = 120)

| Category | Adequate (n = 79) Mean ± SD | Delayed (n = 41) Mean ± SD | p-value |
|----------------------------------------|-----------------------------|----------------------------|---------|
| Distal Arterial PSV | | | |
| Radial PSV (cm/s) | 55.19 ± 12.02 | 28.02 ± 5.92 | <0.001 |
| Ulnar PSV (cm/s) | 50.97 ± 10.07 | 27.05 ± 4.69 | <0.001 |
| Venous Parameters | | | |
| Cephalic diameter with tourniquet (mm) | 4.32 ± 0.45 | 2.35 ± 0.33 | <0.001 |
| Cephalic distensibility (%) | 51.85 ± 13.41 | 35.18 ± 13.76 | <0.001 |
| Basilic diameter with tourniquet (mm) | 5.27 ± 0.62 | 3.01 ± 0.32 | <0.001 |
| Basilic distensibility (%) | 48.35 ± 10.31 | 31.07 ± 9.47 | <0.001 |

3.6 Postoperative Duplex Characteristics According to Maturation Status

Postop duplex showed significant difference between well matured and delayed AVFs. In matured fistulas there was a significantly larger fistular diameter and a significantly higher access flow volume, meaning better vascular remodeling and functional performance. In contrast, AVF peak systolic velocity and depth from skin surface were not different between groups and therefore are less reliable measures of successful maturation than caliber expansion and flow augmentation (Table 6).

Table 6. Postoperative Duplex Characteristics According to AVF Maturation Status (N = 120)

| Parameters | Adequate (n=79) Mean ± SD | Delayed (n=41) Mean ± SD | p-value |
|----------------------|---------------------------|--------------------------|---------|
| AVF caliber (mm) | 5.20 ± 0.88 | 2.73 ± 0.37 | <0.001 |
| AVF PSV (cm/s) | 242.38 ± 56.23 | 252.93 ± 54.61 | 0.327 |
| Flow volume (mL/min) | 1005.20 ± 232.30 | 417.41 ± 68.15 | <0.001 |
| Depth from skin (mm) | 6.56 ± 2.02 | 7.03 ± 1.99 | 0.226 |

The parameters of postoperative duplex analysis for well-matured and delayed AVFs is illustrated in figure 4.

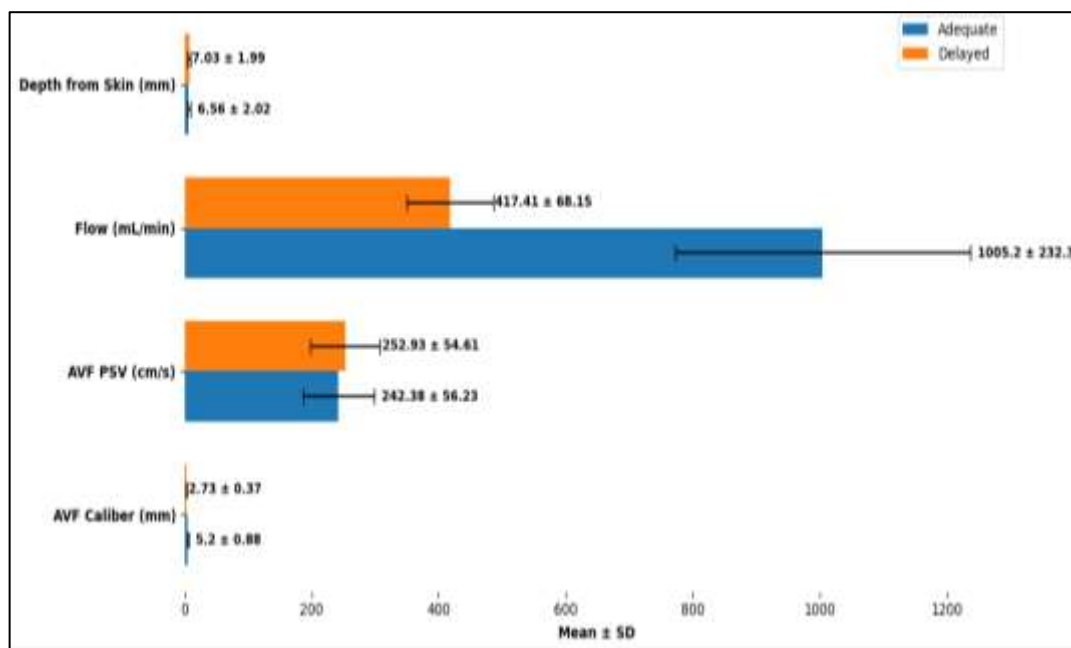


Figure 4. Postoperative Duplex Characteristics by AVF Maturation Status

Figure 4 has shown that the AVF caliber was bigger in the adequately matured AVFs and the flow volume was significantly higher than that of delayed AVFs, while the AVF PSV and the distance from the skin were relatively smaller than that of delayed AVFs.

3.7 Multivariable Logistic Regression Analysis

Multiple logistic regression analysis revealed that distal arterial PSV, recruitability of superficial veins, venous distensibility, post-operative diameter of AVF, and flow rate of access had independent roles in predicting delayed maturation. Higher radial and ulnar PSV, increased tourniquet-induced cephalic and basilic vein diameters, and venous distensibility were found to have statistically significant negative effects on delayed maturation. In contrast, neither AVF site configuration nor AVF site depth from the skin surface independently influenced outcomes, which suggests that vascular function is more important than anatomy (Table 9).

Table 9. Multivariable Logistic Regression Predicting Delayed AVF Maturation (N = 120)

| Category | Predictor | Adjusted OR | 95% CI | p-value |
|--------------------------|---------------------------------------|-------------------|-----------|---------|
| Arterial Parameters | Radial PSV (per +10 cm/s) | 0.12 | 0.06–0.22 | <0.001 |
| | Ulnar PSV (per +10 cm/s) | 0.14 | 0.07–0.25 | <0.001 |
| Venous Diameter | Cephalic diameter with TQ (per +1 mm) | 0.10 | 0.05–0.19 | <0.001 |
| | Basilic diameter with TQ (per +1 mm) | 0.18 | 0.09–0.35 | <0.001 |
| Venous Distensibility | Cephalic distensibility (per +10%) | 0.62 | 0.45–0.86 | 0.004 |
| | Basilic distensibility (per +10%) | 0.58 | 0.40–0.84 | 0.003 |
| Collateral Assessment | Modified Allen test | Very large effect | — | <0.001 |
| Postoperative Parameters | Flow (per +100 mL/min) | 0.35 | 0.26–0.48 | <0.001 |
| | AVF caliber (per +1 mm) | 0.08 | 0.03–0.17 | <0.001 |
| AVF Configuration | Brachiocephalic vs Brachiobasilic | 1.18 | 0.52–2.66 | 0.688 |
| | Radiocephalic vs Brachiobasilic | 1.62 | 0.69–3.84 | 0.268 |
| Other Factors | Depth from skin (per +1 mm) | 1.06 | 0.91–1.23 | 0.451 |

Taken together, the findings indicate that distal arterial flow, vein recruitment, vein compliance, collaterals, and flow dynamics after surgery are the key factors in determining success in AVF maturation in hemodialysis access patients.

4. DISCUSSION

The current study investigated the importance of duplex ultrasonography for preoperative vascular assessment, evaluation of collaterals, and postoperative follow-up of AVFs in chronic kidney disease patients necessitating hemodialysis. Results from the current study revealed that the success in achieving AVF maturation was highly correlated with proper preoperative arterial and venous anatomy, good collateral supply, and excellent postoperative hemodynamics. The individuals who showed proper maturation had significantly higher PSV measurements, better recruitment of superficial veins, increased venous distensibility, and improved flow dynamics when compared to delayed-maturing AVF patients. Therefore, it is concluded that both arterial inflow and venous quality play critical roles in vascular access creation. One key result from the research is the close link between the results of Modified Allen's test and AVF maturation. All sufficiently matured fistulas existed among individuals who had normal collateral circulation, while delayed maturation

cases only occurred in individuals who had either borderline or abnormal collateral flow. This shows that collateral flow testing is an essential part of the process of planning access especially for distal AVF. In addition, the results from the post-surgical follow-up showed that there was a closer relationship between AVF size and volume flow rather than just PSV alone. While continuous evaluation of PSV after surgery at 24 hours, 2 weeks, and 6 weeks showed gradual adaptation to the fistula circuit, flow parameters were found to be better predictors of fistula maturation.

The results of this current study compare well with those of other studies that have highlighted the importance of duplex ultrasonography in vascular access planning and surveillance. Pham et al. (2024) indicated that the objective duplex assessment has its value as access dysfunction often is related to hemodynamic abnormalities, which cannot be detected by clinical examination alone. Likewise, Pichot et al. (2023) called for standardized duplex ultrasound (US) protocols for thorough assessment of hemodialysis vascular access, highlighting the need for consistent hemodialysis-related measurements throughout the lifetime of all accesses. The present study's strong predictive value of the preoperative arterial and venous parameters aligns with the findings of Sharma et al. (2019), who showed that duplex vein mapping was reliable to assess the suitability of vein for AVF creation. Shrivastava et al. (2023) also reported similar findings, emphasizing the role of preoperative colour Doppler evaluation in enhancing vascular access success in chronic kidney disease patients. Moreover, the correlation between the post-operative surveillance results and maturation results is consistent with the recommendation as mentioned by Pirozzi et al. (2021) and Saati et al. (2022) that routine duplex monitoring is a key element in the follow-up of AVF. Previously, Zonnebeld et al. (2017) have shown the reproducibility and reliability of the preoperative duplex measurements, which further supports the validity of the predictors that were identified in the present investigation with the duplex.

The significance of the results found in the clinic is large. The objective assessment of the arterial inflow, venous recruitability, collateral circulation and postoperative access performance can be made using comprehensive duplex ultrasonography and this will enable objective decision making in AVF planning. If patients at risk of delayed maturation are identified early, it is possible that this will allow individual patients to be monitored, intervention to be implemented in a timely fashion and optimization of vascular access outcomes. The addition of the Modified Allen test and the duplex evaluation may further improve the risk stratification preoperatively and help in choosing the best access configuration.

There are a number of caveats to be noted. The study was performed in only one tertiary care hospital, and the results might not apply to other groups of people or other health care facilities. Also, follow up was restricted to early maturation period and long-term patency and survival were not assessed. The observational nature of the study also makes it difficult to draw clear conclusions about the causes and effects of duplex parameters on maturation outcomes.

Longer follow up periods and multicenter cohorts are needed for future studies to assess the long-term predictive value of duplex-derived parameters. Additional studies on standardized surveillance algorithms and incorporating duplex with clinical and biochemical markers could aid in the development of better risk prediction models and help guide personalized vascular access management in hemodialysis patients.

5. CONCLUSION

The duplex ultrasonography was a valuable, non-invasive clinically useful method for the comprehensive evaluation of AVF creation and maturation in hemodialysis patients with chronic kidney disease. The study was able to demonstrate that distal arterial inflow, superficial venous suitability, venous distensibility and collateral circulation were all important factors in successful AVF maturation. The cephalic and basilic vein diameters with the tourniquet and the venous distensibility values were found to be significantly associated with adequate maturation as well as the radial and ulnar PSVs. The Modified Allen test was highly predictive of maturation outcome, highlighting the need to evaluate the hand collateral circulation prior to AVF creation, especially for distal access planning. In the postoperative period, the fistulas with adequate maturation had larger AVF caliber and higher flow volume, which means that the maturation process is better reflected by the AVF caliber (structure) and flow volume (function) than by PSV value alone or fistula depth. Duplex surveillance also allowed identification of complications like low flow, stenosis, thrombosis, poor maturation, wall thickening, etc., early on, which were associated with delayed maturation. Vascular quality and hemodynamic competence were higher factors than AVF site alone when analyzed by multivariable analysis. In general, the use of structured mapping and postoperative follow-up based on duplex imaging can help in access-site selection, determine maturation potential, identify early access dysfunction, and enhance better outcomes of hemodialysis vascular access.

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