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Research Article

Role of pre-operative ultrasonography derived parameters as predictors of post-operative outcome in arterio-venous fistula formation surgeries

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Abstract: *Introduction:* The conventional clinical evaluations are qualitative and usually lack consistency in forecasting arteriovenous fistula (AVF). Recently introduced method doppler ultrasonography which is usually done before the operation provides a better assessment of vascular parameters which is crucial for enhancing the surgical plan and the outcomes of vascular access.***Objective:*** The current study shows the importance of preoperative Doppler vein diameter, arterial diameter and flow velocity on predicting outcomes of AVF with the help of ultrasonography. ***Methods:*** This prospective, hospital-based study was conducted at the Department of Radiodiagnosis, Government medical Srinagar, over a duration of 18 months. Ethical approval was received from the Institutional Ethics Committee. Preoperative doppler ultrasound assessment of vessel diameter and flow was performed to categorized patients according to their pre tourniquet vein diameter. The postoperative assessment of AVF outcomes were considered, and data were analyzed using SPSS v20 and statistical inferences were done by ANOVA and chi- square tests with $p<0.05$ as significance.***Results:*** The sample size of 270 patients requiring AVF for hemodialysis, were included, excluding those having venous disease, thrombosis, or other contraindications. Preoperative Doppler ultrasound demonstrated a strong association between larger vein diameters and successful AVF maturation, with success rates of 80.6% in Group C (≥3.0 mm), 59.8% in Group B (2.5–2.9 mm), and 34.9% in Group A (<2.5 mm). Whereas, no significant impact showed by Age and gender, insisting vessel parameters as key predictors.***Conclusion:*** Doppler ultrasound before surgery could be very useful in predetermining the success of AVF, and the diameter of the vein as a main predictor. Use of Doppler results in the surgical planning process can improve the vascular access performance among hemodialysis patients.

Keywords: Arteriovenous fistula, Duplex ultrasonography, arterial flow, hemodialysis, vascular access, CKD, fistula maturation .

INTRODUCTION

Chronic kidney disease (CKD), being a major global health concern, affects approximately 11-15% of the adult population worldwide, ultimately necessitating the renal replacement therapy (RRT) such as hemodialysis (HD)[1-2]. The success of HD is heavily dependent on the establishment of durable, functional, and well-matured vascular access, which serves as a conduit for efficient blood flow and filtration. Among the available vascular access options, arteriovenous fistula (AVF) is the preferred choice, given its superior long-term patency rates, lower infection risk, and reduced need for interventions compared to arteriovenous grafts (AVG)[3]. Traditionally, clinical examinations and subjective vessel palpation have been used to assess vascular suitability for AVF creation. But success rate was low as up to 40% of AVFs failed to mature adequately, leading to primary failure, prolonged catheter dependence, and increased morbidity[4]. An adequate knowledge of vascular anatomy is important in case of a successful creation and maturing of AVF. The radial and brachial arteries are the most utilized with the radial artery being the most convenient and the brachial artery to give greater flow[5]. Preferred veins are cephalic veins and basilic veins because they are large and dilatable with the former as the first option. The tripod of successful AVF maturation is based on proper vessel caliber, elasticity and hemodynamic changes[6]. Adverse influence of systemic disorders on the vascular remodeling may be associated with hypertension and diabetes, among which the risk of failure is higher. To overcome the problems associated with conventional method, preoperative vascular ultrasonography (USG) has been as a valuable tool for assessing vascular anatomy and predicting AVF outcomes[7]. Ultrasonography enables the objective evaluation of vessel size, wall characteristics, arterial flow dynamics, and venous dispensability, providing critical information that can guide surgical decision-making[8]. It has been suggested in literature that certain preoperative USG-derived parameters, such as vein diameter ≥2.5 mm and arterial diameter ≥2.0 mm, are associated with higher rates of AVF maturation and long-term patency[9].

The subjective methods are now being replaced by duplex ultrasonography (DUS), which offers real-time imaging, allowing objective measurement of vessel diameter, wall thickness, blood flow velocity, and presence of stenotic lesions[10,11]. It demonstrated that preoperative ultrasonography mapping significantly improves AVF maturation rates and reduces failure rates by guiding optimal vascular site selection. The incorporation of routine preoperative ultrasonography into AVF planning has significantly improved surgical decision-making and clinical outcomes[12]. Ultrasonography evaluation significantly reduces primary AVF failure rates leading to fewer secondary interventions and improved long-term hemodialysis access[13]. Furthermore, ultrasonography guidance allows patient specific vascular access planning, particularly in individuals with diabetes, peripheral arterial disease, or prior vascular access failures, where anatomical variations may impact AVF success. In addition to the diameter of the vessel, the important hemodynamic variables such as flow velocity and resistive indices are the crucial predictors of AVF maturation. A PSV >50cm/s in a brachial artery is associated with increased patency whereas RI >0.7 is associated with arterial stiffness[7]. Venous reflux or thrombosis lowers the success of an AVF which can be detected with duplex ultrasound. Past catheter-related stenosis can necessitate a secondary access way. Therefore, thorough ultrasound evaluation prior to the surgery is necessary[14].

However, despite these advancements, variability in ultrasonography expertise, lack of standardized criteria, and patient specific anatomical variations remain challenges in universalizing these predictors. Further research is required to refine ultrasonography thresholds and integrate into routine clinical practice for personalized AVF planning and improved hemodialysis access outcomes[10]. Therefore, the objective of the current study is to assess the value of preoperative color Doppler characteristics, i.e., the vein diameter, arterial diameter, and arterial flow velocity as the predictors of postoperative outcomes in upper limb arteriovenous fistulae.

METHODS

This prospective, hospital-based study was conducted at the Department of Radio-diagnosis, Government medical Srinagar, over a duration of 18 months. Prior to initiation, ethical approval was taken from the Institutional Ethics Committee in accordance with standard regulatory guidelines. Additionally, written informed consent was obtained from all participants after a detailed explanation of the study objectives and procedures, ensuring voluntary participation and adherence to ethical research practices.

The participants were patients who needed the AVF to be constructed and to conduct hemodialysis were selected from Departments of Nephrology and Urology. The patients included in the evaluation were patients with CKD who required maintenance hemodialysis, and could undergo surgery, or had depleted access through catheters. Acute illness, which could have been caused by venous disease, severe vasculopathy, recent thrombosis, allergy to local anesthetics, inability to consent, or being on peritoneal dialysis were the exclusion criteria. Based on 95% confidence level and a 6% margin of error, a minimum sample size of 270 patients was obtained by using G-Power software.

Doppler ultrasonography was done prior to the surgery on an ESAOTE machine with supervision of a radiologist to examine the vessel diameter, pulse, and patency of the vessel. Vascular mapping was performed conventionally to measure the size of the draining vein, arterial diameter and flow velocity. Collateral circulation was measured by having the Modified Allen Test.

Vascular surgeons participated in AV fistula surgery on aseptic conditions. The maturation and functioning of Doppler were done after 6 weeks and 3 months and it was determined that less than 5mm and poor flow rate indicated a failure. Patients were grouped into three groups, A (2-2.5 mm), B (2.5-3 mm) and C (>3 mm) with reference to the pre-tourniquet draining vein diameter and was compared.

The analysis of data was made with the help of SPSS v20.0 and Microsoft Excel. The continuous variables were provided as Mean±SD and categorical data as percentage. The statistical inferences were done by ANOVA and chi- square tests with $p<0.05$ as significance.

RESULTS

The results of this study give a comprehensive overview of the demographic data, clinical features, comorbidities, and group-wise comparisons among patients who underwent arteriovenous (AV) fistula creation. Out of 270 patients that were included in the study, the demographic characteristics showed that the overall mean age was 60.7 ± 8.51 years, with an age range of 38 to 74 years. Maximum patients (N=106; 39.3%) had belonged to the 61-70-year age group, whereas those aged between 51-60 years had the second highest proportion (N=101; 37.4%). Minimum number of patients (N=29; 10.7%), (N=34; 12.6) had belonged to the age group of ≤ 50 and 70 years, respectively as shown in Table 1. The results highlights that most of the patients belonged to an older group of people. Patients were also compared based on their gender as demonstrated in Fig 1, results showed that female showed the (N=158; 59%) the predominance over the males (N=112; 41%) in the study population.

Table 1: Age distribution of study patients

Age (Years)	Number	Percentage
≤ 50 Years	29	10.7
51-60 Years	101	37.4
61-70 Years	106	39.2
> 70 Years	34	12.5
Total	270	100
Mean±SD (Range)=60.7±8.51 (38-74)		

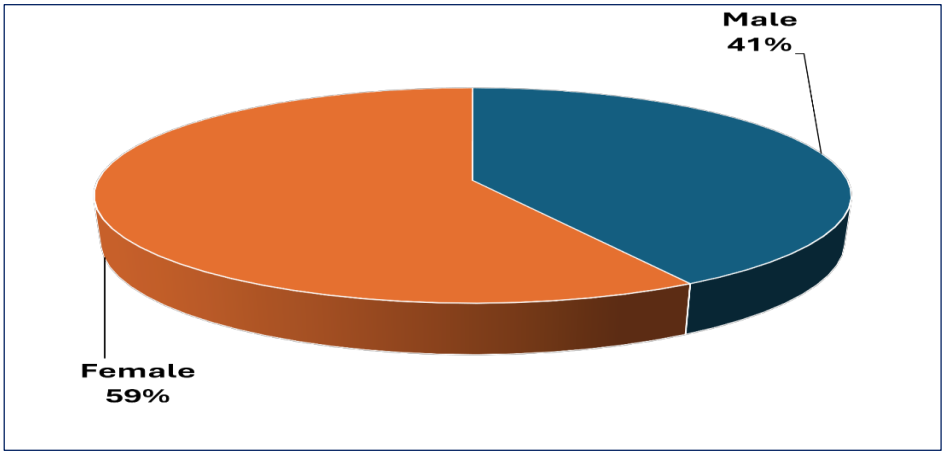

Figure 1: Percentage contribution of gender of the study patients

The most prevalent clinical symptom reported was edema, which was observed in 76.3% patients, followed by weakness in 68.9%, and headache 54.8% of the patients. Other prevalent symptoms were sleep disturbances which were reported in 48.9% patients, whereas skin changes in 43.7% drowsiness in 39.0%, pruritus or itching in 35.6%, anxiety in 32.2% and loss of appetite 27.4% of the patients as represented in Table 2. These clinical symptoms are usually observed in patients with chronic renal disease, showing the clinical burden usually experienced by the patient of this disease.

Table 2: Presenting symptoms of study patients

Presenting Symptoms	Number	Percentage
Edema	206	76.2
Weakness	186	68.8
Headache	148	54.8
Difficulty in sleeping	132	48.8
Skin changes	118	43.7
Drowsiness	105.3	39.0
Pruritius	96	35.5
Anxiety	87	32.2
Lack of appetite	74	27.4

Comorbidity conditions of patients were also assessed as part of the study. Hypertension proved to be the most common comorbidity, affecting 167 patients (61.9%), followed by the second most prevalent diabetes mellitus which was observed in 141 patients (52.2%). Glomerulonephritis was reported in 31 patients (11.5%), while other conditions were observed in 19 patients (7.0%) as shown in Fig 2. These findings showed a consistent link between systemic disorders such as hypertension and diabetes and chronic renal disease.

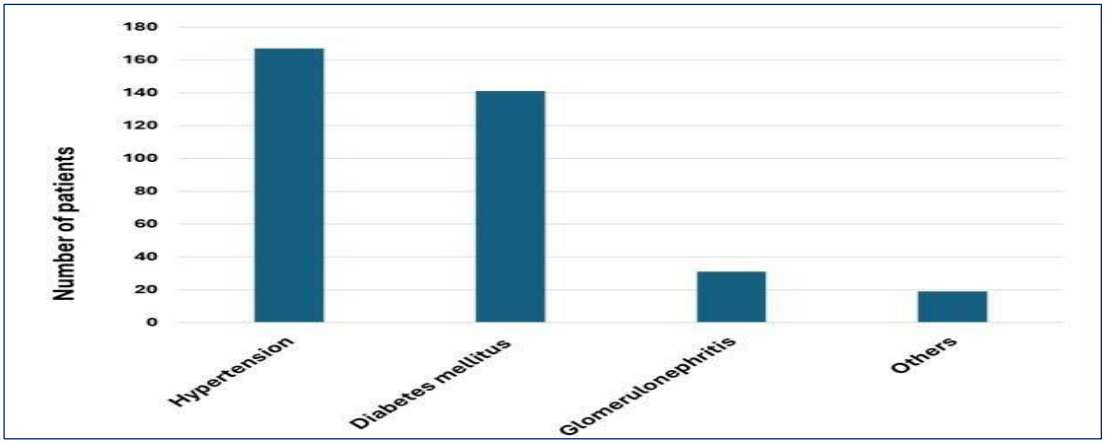

Figure 2: Demonstration of comorbidities prevalence among study patients, highlighting that hypertension and diabetes being the most common.

Furthermore, the study patients were divided into three groups according to their preoperative vascular parameters, specifically the diameter of the draining vein, feeding artery diameter, and venous flow rate. Group A consisted of draining vein diameter of 2.0-2.5 mm, feeding artery diameter 2 mm and above and similar flow rates of 25-50 cm/sec. Group B had a vein of 2.5-3.0 mm, and Group C comprised veins of 3.0 mm and above but both with the feeding artery diameter being 2 mm and above with similar flow rates. According to Table 3, the largest number of patients out of 100 (56.3%) belonged to Group A, 32.2% of patients were in Group B and 11.5% of patients were in Group C. This classification highlights that the major proportion of patients had relatively smaller vein diameters.

Table 3: Distribution of study patients in various groups

Group	Number	Percentage
Group A	152	56.3
Group B	87	32.2
Group C	31	11.5
Total	270	100

Age distribution across the three groups was also compared. The mean age of patients in Group A was 60.5 ± 8.38 years (95% CI: 59.1–61.8), slightly lower than Group B, which had a mean age of 61.4 ± 9.15 years (95% CI: 59.6–63.4). Group C had the lowest average age of 59.6 ± 7.24 years (95% CI: 56.9–62.2). However, the result of statistical analysis indicated no significant difference (P = 0.498) in mean age among all the three groups, indicating that age was not a confounding factor as shown by Fig 3.

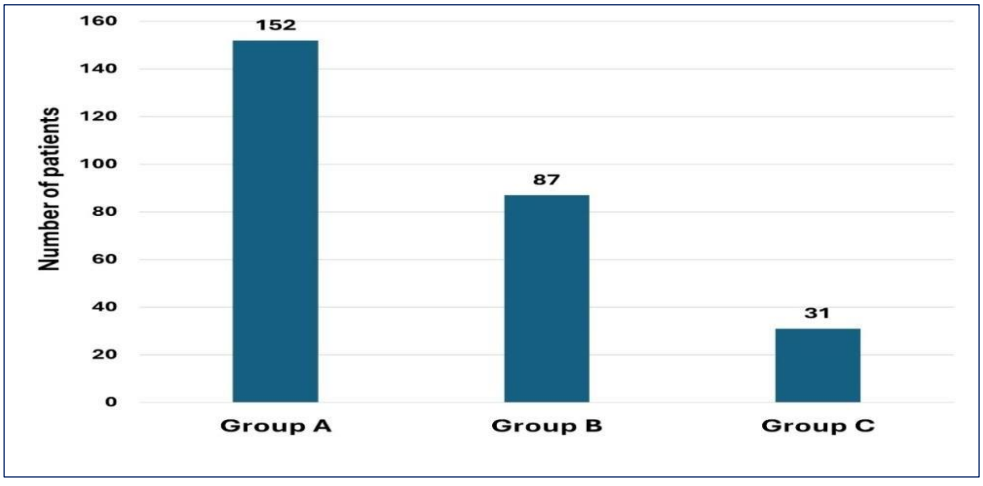

Figure 3. Demonstration of comparison of mean age among Groups A, B, and C showing significant difference of P = 0.498, suggesting that age was not a confounding factor in the present study

Comparison of the gender distribution among the three study groups can be seen in Fig 4. But this distribution also showed no significant value. As out of the 152 patients in Group A, 61 (40.1%) were male and 91 (59.9%) were female. In group B, the size of male population was little higher in comparison to their size in other 2 groups which was 38 (43.7%) and for females it was 49(56.3%) respectively. Whereas, Group C had 13 males (41.9%) and 18 females (58.1%). These findings showed that gender distribution was relatively balanced across the groups because statistical analysis indicated that the difference between the groups did not signify a significant contrast in gender distribution (P = 0.865), which ultimately implies that gender was unlikely to be a confounding variable among 3 groups.

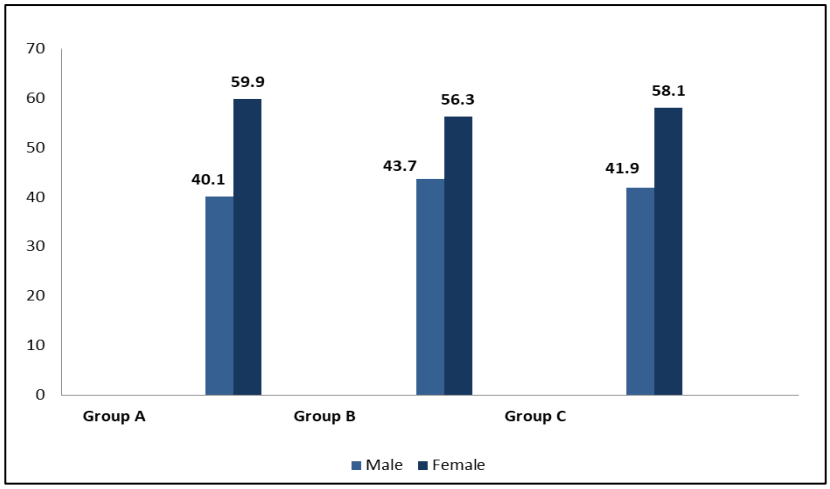

Figure 4: Demonstration of gender distribution across Groups A, B, and C. The size of male and female patients' population was relatively similar in all three groups, suggesting that gender is not a confounding factor in the analysis.

The distribution of comorbidity conditions was comparable among patients across the 3 study groups as shown in Table 4. Hypertension was found to be most prevalent, with the highest proportion 64.4% can be seen in Group B, followed by 61.3% in Group C and 60.5% in Group A, even though the difference observed was not very significant (p = 0.839). On the other hand, Diabetes mellitus was the second most prevalent condition, reported in 52.0% of Group A, 51.7% of Group B, and a maximum of it in 54.8% in Group C (p = 0.953). Whereas Glomerulonephritis was the one which was least observed, with 11.8%, 10.3%, and a slightly higher 12.9% in Groups A, B, and C, respectively (p = 0.908). Other conditions were seen in 6.6% of Group A, 6.9% of Group B, and 9.7% of Group C (p = 0.826). Overall, hypertension remained the most prevalent comorbidity across all the 3 groups, while other conditions were observed to be relatively less frequent in the groups. Though the difference was clear among groups based on comorbidity distribution still the statistical analysis showed no significant differences, suggesting that these factors were uniformly distributed and does not influence AVF outcomes.

Table 4: Comparison based on comorbidities in three groups

Group	N	Mean	SD	95% CI	P-value
Group A	152	60.5	8.38	59.1-61.8	0.498
Group B	87	61.4	9.15	59.6-63.4	
Group C	31	59.6	7.24	56.9-62.2	

Doppler ultrasonography was done prior to the and Patients of group A, B, and C were examined to have vein diameters of (2-2.5 mm), (2.5-3 mm), and (>3 mm), respectively. Then the comparison of the success of arteriovenous (AV) fistula creation surgeries between these 3 groups was observed as can be seen in Table 5. Group A noted the lowest success rate of 34.9% with just 53 patients and 99 (65.1%) reports showed surgical failure. On the other hand, Group B had a significant increase and 59.8% of the patients (52 cases) showed success in the AVF creation. Whereas, the highest successful rate was observed in the Group C patients, where 25 patients underwent successfully through surgery and only 6 patients (19.4%) reported to have unsuccessful surgery. According to statistical analysis, there was a significant difference between each of the 3 groups, Group A and B (P = 0.0002), Group B and C (P = 0.036), and Group A and C (P < 0.001). These results support a solid correlation between the groups and the probability of AV fistula success that suggests that the vascular conditions have strong on the success of the surgery.

Table 5: Comparison based on success rate of AV fistula creation surgery in three groups

AVF Creation	Group A		Group B		Group C	
	No.	%age	No.	%age	No.	%age
Successful	53	34.9	52	59.8	25	80.6
Unsuccessful	99	65.1	35	40.2	6	19.4
Total	152	100	87	100	31	100
Group Comparison	Group A vs. Group B		Group B vs. Group C		Group C vs. Group A	
	0.0002*		0.036*		<0.001*	

DISCUSSION

Chronic kidney disease (CKD) has become a major health issue, globally and majority patients end up in end-stage renal disease (ESRD) necessitating the renal replacement therapies[15]. The most frequently used modality to CKDs is hemodialysis, the success of which depends on vascular access. For patients with end-stage renal disease (ESRD) undergoing hemodialysis, establishing reliable and durable vascular access is crucial for effective treatment[16]. Among the available options, the arteriovenous (AV) fistula remains the preferred choice due to its superior patency rates and lower risk of complications[17]. Preoperative Doppler ultrasonography (USG) plays a vital role in evaluating vascular parameters, assisting in the selection of optimal vessels for AV fistula creation[18]. This study aimed to assess the prognostic value of preoperative USG-derived parameters in predicting postoperative outcomes following AV fistula creation, thereby contributing to improved surgical success and long-term vascular access viability.

Among 270 AVF surgery patients, common symptoms that can cause problems in the AVF creation were observed such as edema (76.3%), weakness (68.9%), and headache (54.8%). Edema aligns with ESRD-related fluid overload also noted by two studies Bobkova et al.,[19] & Hashmi et al.,[20]. Whereas weakness stems from anemia, electrolyte imbalance, and uremia. Headaches, though less studied in AVF, may be linked to hypertension. In addition to this, drowsiness (39%) was lower than typical dialysis fatigue rates (60–97%) but still notable[21-22]. Sleep disturbances (48.9%) matched findings by Pawar et al.,[23]. Skin issues like pruritus (35.6%) and changes (43.7%) reflected the findings of Masmoudi et al.,[24]. Anxiety (32.2%) fit the 27.9–49.6% range noted by de Brito et al.,[25] and Nagy et al.,[26]. Appetite loss (27.4%) varied from previously reported findings by Ohri-Vachaspati et al.[27], possibly due to nutritional or cultural differences.

In this study, the influence of comorbidities on postoperative outcomes following upper limb AVF creation was carefully evaluated to ensure that associations with preoperative color Doppler parameters were not confounded. The most prevalent of them were hypertension (61.9%) and diabetes mellitus (52.2%) with glomerulonephritis (11.5%) and others (7.0%). Nevertheless, the prevalence of comorbidity in each of the three groups was not significantly different ($p > 0.8$ in each comparison), which suggests that comorbidity was not a confounder of group allocation. Therefore, observed differences in outcomes can be attributed to preoperative Doppler parameters (vein diameter, arterial diameter, and flow velocity).

The study patients were categorized into three groups based on pre-tourniquet vascular parameters. Group A (56.3%) included patients with vein diameter of <2.5 mm, Group B (32.2%) patients had a vein diameter of 2.5–3.0 mm, while Group C (11.5%) included patients with a vein diameter ≥3.0 mm. All groups had a feeding artery diameter >2 mm and a flow rate of 25–50 cm/sec. The mean age of patients in Group A was 60.5 ± 8.38 years (95% CI: 59.1–61.8), while Group B had a slightly higher mean age of 61.4 ± 9.15 years (95% CI: 59.6–63.4). Group C exhibited a mean age of 59.6 ± 7.24 years (95% CI: 56.9–62.2). In this study, age distribution across groups was compared to determine if is a confounding factor in the assessment of success rate of AVF maturation. Statistical analysis revealed no significant impact of age among the three groups ($P = 0.498$). But the alignment was crucial, as numerous studies have reported the influence of age on outcomes of AVF. Such as a study by Beaulieu et al.,[28], including 525 patients investigated that 75 years old or above individuals had similar rates of primary failure and complications in comparison to the younger people. But it was also reported that a much higher secondary and functional patency rate was achieved in this younger group in a three-year period, which indicates that there might be no inherent effect on initial maturation; however, they might adversely affect the long-term working efficiency of AVFs in the older patient population.

Conversely, some other research has shown AVF maturation is not significantly influenced by age. A study by Chan et al., [29] on 146 patients, reports that age has no significant impact and there no association between age and AVF maturation success. Given these mixed findings, the comparable age distribution in our study groups makes the age unlikely to confound evaluation of factors that affect AVF maturation. Moreover, gender distribution across the three AVF groups was also

compared (P = 0.865), with females slightly predominating: Group A (59.9%), Group B (56.3%), and Group C (58.1%). This aligns with CKD epidemiology, where women often require vascular access. Although female gender is linked to lower AVF maturation rates e.g., Hoffstaetter et al.,[30] reported 80% maturation in females vs. 87% in males, and Siddiqui M et al.,[31] found males were twice as likely to achieve successful maturation. Our study's balanced gender distribution minimizes confounding. In this manner, instead of age and gender other variables, including the diameter of the veins and arterial inflow, can be better assessed in defining AVF success.

This study demonstrated a significant association between preoperative vein diameter determination and the success rates of arteriovenous fistula (AVF) formation and its maturation. Patients with a vein diameter of 2.0–2.5 mm (Group A) showed the lowest success rate at 34.9% (53 out of 152 patients), while those with 2.5–3.0 mm (Group B) had a moderate success rate of 59.8% (52 out of 87 patients). The highest success rate was observed in patients with a vein diameter of ≥3.0 mm (Group C), achieving 80.6% (25 out of 31 patients). These findings strongly support the fact that larger preoperative vein diameter is highly linked with improved AVF creation outcomes. Results of the respective study are supported by several studies that emphasize the important of vein diameter in AVF formations and its maturation. McGrogan et al.,[32], reports that veins with a luminal diameter greater than 2.5 mm, or smaller veins that dilated to 2.5 mm with tourniquet application, were more likely to mature successfully This aligns with our finding that success rates were improved significantly in Group B (2.5–3.0 mm). Similarly, Bashar et al.,[33], showed that 76% of the fistula created using cephalic veins larger than 2 mm was able to mature more successfully, as compared to only 16% when the vein measured ≤2 mm. This also supports our finding that the lowest success rates were seen in Group A having vein diameter of 2.0–2.5 mm, which highlights risk of AVF failure is more in smaller veins. Our findings also align with conclusions made by Oprea et al.,[34], who noted that AVF maturation rates are proportionally associated with vein diameter. Their study demonstrated that patients with a preoperative vein diameter of ≥1.9 mm and an artery diameter of ≥1.5 mm showed maturation rates of more than 60%, closely aligning with the rate observed in Group B of our study.

Furthermore, the results of this study also align with the other findings described by Zhang et al.,[35] who found that preoperative vein diameter was an independent predictor of AVF maturation and patency, with its cutoff set at 3.0 mm. They reported that the veins with a diameter of <2.5 mm posed a higher risk of AVF failure which also reflects our finding that the success rate was the least in Group A. In the same way, Kim et al.,[36] concluded that patients whose cephalic vein diameter measured greater than or equal to 3.0 mm showed a high early (98.8 percent) patency than those with smaller diameters (88.4 percent), which underscores our discovery that Group C was the most successful. Thus, results show that the higher the preoperative vein diameters largely contribute to AVF success since it decreases vascular resistance and increases the blood flow, as put by the law of Poiseuille. On the other hand, smaller veins pose an increased risk of maturation failure since they have an increased resistance and are accompanied by complications.

CONCLUSION

This study concludes the fact that Doppler ultrasound before surgery is important and contributes to the success of arteriovenous (AV) fistula formation. Doppler USG was found to be quite effective in evaluating vascular parameters, with much more success rates found in the larger veins (mean), 80.6% in Group C (≥3.0 mm), 59.8% in Group B (2.5-2.9 mm), and 34.9% in Group A (<2.5 mm). Therefore, Doppler USG is important in screening patients to identify the right patients capable of undergoing such a procedure and to boost the conventional methods of fistula formation in long term hemodialysis patients.

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