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Ultrasound: A Preoperative guide in Predicting Complications of Arteriovenous Fistula in End-Stage Renal Disease

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Abstract

Introduction: Patients with end-stage renal disease require hemodialysis for clearing metabolic waste and electrolyte balance with Arteriovenous (AV) fistulas being the preferred vascular access. However, failure to mature adequately and complications are challenges associated with AV fistulas.

Objective: This observational study aimed to investigate the role of preprocedural USG in predicting the successful maturation of AV fistulas and anticipating complications in patients with ESRD.

Methods: Data were collected from 250 patients who underwent AV fistula creation at Neelam hospital Rajpura, Punjab between Jan 2023 and May 2024. Patient demographics, preprocedural2 USG findings, and procedural details were extracted from hospital medical records. High resolution USG was done to detect post-operative complications at regular intervals.

Results: 14% presented with complications following AV fistula creation. Significant associations were observed various groups and the occurrence of complications. Older age, smaller venous size, deeper venous depth, and arterial wall calcifications were found to be significant predictors of complications.

Conclusion: Pre procedure USG predicts the success of AV fistulas and identifying factors associated with complications. By using USG, clinicians can optimize patient selection, plan the surgical procedure and reduce the incidence of complications following AV fistula creation.

Keywords: EDRD, RRT, USG.

Introduction

End-stage renal disease (ESRD) is a critical stage of chronic kidney disease (CKD) characterized by irreversible loss of renal function, necessitating renal replacement therapy (RRT) for patient survival [1]. Hemodialysis, a common modality of RRT, requires efficient vascular access to facilitate the extracorporeal removal of toxins and waste products from the blood. Arteriovenous (AV) fistulas, created surgically by anastomosing an artery to a vein, are considered the optimal choice for vascular access in hemodialysis due to

their superior long-term patency rates and lower risk of infection compared to arteriovenous grafts and central venous catheters [2].

However, despite the advantages of AV fistulas, complications are not uncommon such as thrombosis, stenosis, and insufficient maturation remain significant challenges in clinical practice [3]. Suboptimal AV fistula maturation can result in difficulties with cannulation, reduced blood flow rates, and increased rates of intervention and hospitalization [4]. Therefore, identifying factors that influence AV fistula maturation and anticipating potential complications are crucial steps in optimizing patient outcomes and improving the success rate of hemodialysis.

Preprocedural ultrasound (USG) has emerged as a valuable imaging modality in the management of AV fistulas, providing detailed anatomical information about vessel caliber, depth, and morphology [5]. Preoperative assessment with USG allows clinicians to identify suitable vessels 3 for fistula creation, plan the surgical procedure more effectively, and predict the likelihood of successful fistula maturation. Additionally, USG can help identify factors such as venous stenosis, arterial calcifications, and other anatomical abnormalities that may impact fistula outcomes [6].

Several studies have demonstrated the utility of preprocedural USG in guiding clinical decision making for AV fistula creation [7, 8]. However, there remains a need for further investigation to validate these findings and identify additional predictors of successful maturation and complications. Therefore, this observational study aims to assess the role of preprocedural USG in predicting the successful maturation of AV fistulas and anticipating complications in patients with ESRD undergoing AV fistula creation.

By examining the association between preprocedural USG findings and postoperative outcomes, this study seeks to provide valuable insights into the optimal management of AV fistulas in patients with ESRD. Ultimately, the goal is to improve patient outcomes, enhance the quality of care, and reduce the burden of complications associated with AV fistula creation in this vulnerable population**.**

Types of vascular access

There are different types of vascular access for patients with end-stage renal disease (ESRD), which include arteriovenous fistula (AVF), arteriovenous graft (AVG), and central venous catheter (CVC) [9]. AVF formation involves anastomosis of an artery and vein in an end-to-end, side-to-end, or side-to-side fashion with the goal of eventual maturation of the venous outflow tract to allow repeated cannulation for hemodialysis [10]. AVF is the most preferred method due to its easy formation, successful maturation with lower risk of infection, thrombosis, and steal syndrome, fewer reinterventions, and longer access lifespans than AVGs [11]. CVCs are currently used only when an AVF or AVG is not a viable option [12]. The Kidney Disease Outcomes Quality Initiative (KDOQI) guidelines recommend creation of the initial AVF in the distal forearm at the snuffbox or distal radio-cephalic or transposed radio-basilic fistula [13]. This preserves the vascular integrity of the proximal forearm and arm for subsequent AVF creation. Another common type is the brachiocephalic fistula, where the brachial artery is 4 anastomosed to the cephalic vein in the upper arm. This type offers higher blood flow rates but may be associated with an increased risk of steal syndrome and complications [14]. The brachiobasilic fistula involves anastomosis between the brachial artery and the basilic vein, providing an alternative option when other sites are unsuitable [15]. Each type of AV fistula

has its advantages and considerations, and the choice of fistula type should be tailored to the patient's anatomy, vascular condition, and clinical needs [16].

Pre-procedural USG

Detailed anatomic evaluation and vascular mapping using USG and doppler is important for procedural planning. Pre-procedural arterial evaluation includes documentation of vessel diameter, stenosis, vessel course, wall thickness and wall alterations. For the upper extremity, the subclavian, axillary, brachial, radial and ulnar arteries are evaluated. Venous evaluation includes mapping of the entire course and branching of the superficial and deep systems including the internal jugular, brachiocephalic, subclavian, axillary, and cephalic veins. Diameter measurements are reported for the cephalic and basilic veins at the upper/mid/lower humerus, antecubital fossa, upper/mid/lower forearm and wrist as well as depth of the vein from skin. Vessel patency and wall characteristics are documented. Venous distensibility can be evaluated by measurement of vessel diameter before and at 2 minutes after placement of a tourniquet.

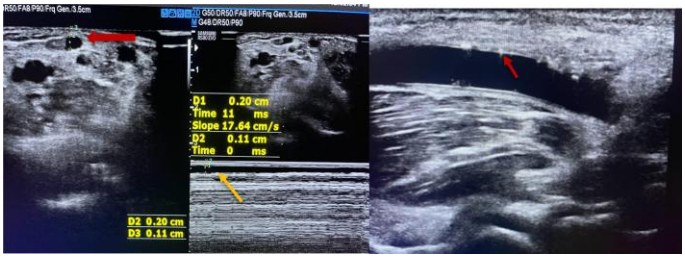


Figure 1: Showing the depth of the vein from the skin using B-mode (Thick red arrow) and M- mode (yellow arrow). Another image showing the arterial wall calcifications (thin red arrow)

Complications of AV fistula

Arteriovenous (AV) fistulas, while considered the best option for hemodialysis access, are not without potential complications. Understanding these complications is crucial for managing and improving patient outcomes. This section outlines the common complications associated with AV fistulas and discusses their impact on the patient and the healthcare system.

Primary Maturation Failure

Primary failure refers to the inability of the fistula to mature sufficiently to support adequate hemodialysis within a specified period, typically six months. This can occur due to inadequate vessel size, poor blood flow, or technical issues during surgery [3]. Primary failure necessitates additional interventions or procedures, increasing patient morbidity and healthcare costs.

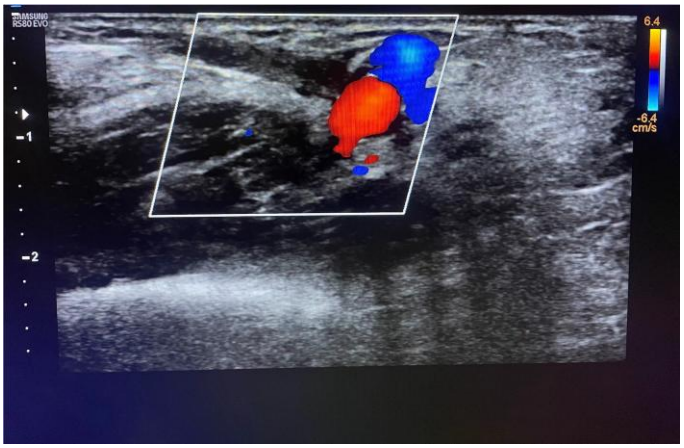


Figure 2: Showing no flow in the AV fistula after 4 weeks of surgery due to stenosis

Thrombosis

Thrombosis, or blood clot formation within the fistula, is one of the most common complications. It can lead to fistula occlusion, rendering the access unusable for dialysis. Thrombosis can occur due to stenosis (narrowing of the vessel), hypercoagulable states, or low 6 blood flow rates [17]. Timely intervention with thrombolytic therapy or surgical revision is required to restore patency.

Figure 3: Showing thrombosis of the draining vein of the fistula with no flow on color doppler

Stenosis

Stenosis, the narrowing of the blood vessel, is a frequent cause of thrombosis and reduced blood flow through the fistula. It often occurs at the anastomosis (the surgical connection between the artery and vein) or within the vein itself. Regular monitoring and early detection through ultrasound or other imaging techniques are essential for preventing severe complications [11].

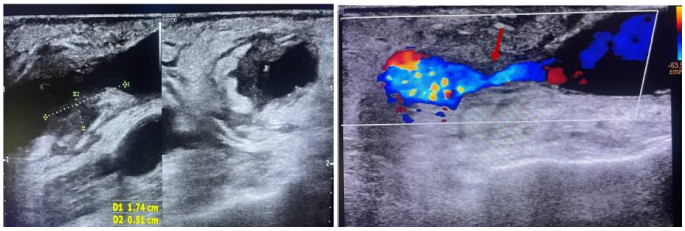


Figure 4: Showing focal narrowing of the draining vein with decreased flow of blood as shown by arrow

Infection

Infection at the fistula site, although less common than with central venous catheters, can still pose significant risks. Infections can range from localized skin infections to more severe systemic infections. Good hygiene practices and prompt treatment of any signs of infection are vital to prevent serious outcomes [12].

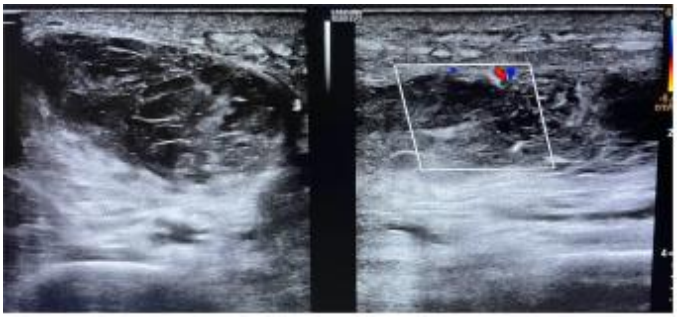


Figure 5: Showing heterogeneous collection in subcutanous plane near the fistula site

Aneurysm Formation

Aneurysms, or abnormal dilations of the vessel, can develop in an AV fistula due to the high pressure and flow rates. These can weaken the vessel wall and pose a risk of rupture. Surgical intervention may be required to repair or replace the aneurysmal segment [14].

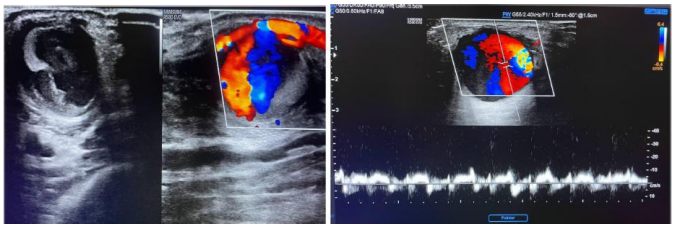


Figure 6 showing ying-yang sign of the pseudo anurysm with tro and fro blood flow

Steal Syndrome

Steal syndrome occurs when the fistula diverts too much blood away from the distal extremity, leading to ischemia (lack of blood flow) and symptoms such as pain, pallor, and even tissue loss. This complication requires careful management and, in some cases, surgical revision to balance blood flow [18].

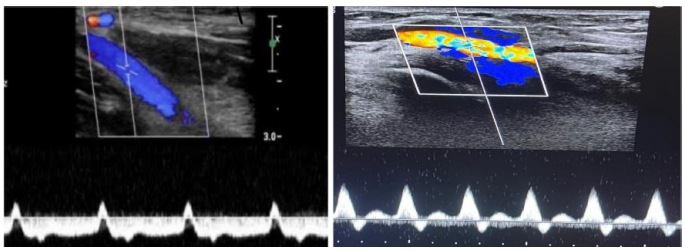


Figure 7: Showing retrograde flow in the radial artery which normalizes on compression of the fistula

Venous Hypertension

Venous hypertension results from high pressure within the venous system, often due to outflow obstruction. Symptoms include swelling, pain, and skin changes in the arm or hand. Addressing the underlying cause of the obstruction is necessary to alleviate symptoms and prevent further complications [19].

Central Venous Stenosis

Patients with previous central venous catheters are at risk for central venous stenosis, which can compromise the outflow from the AV fistula. This can lead to poor dialysis adequacy and swelling of the arm. Angioplasty or stenting may be required to treat this condition [20].

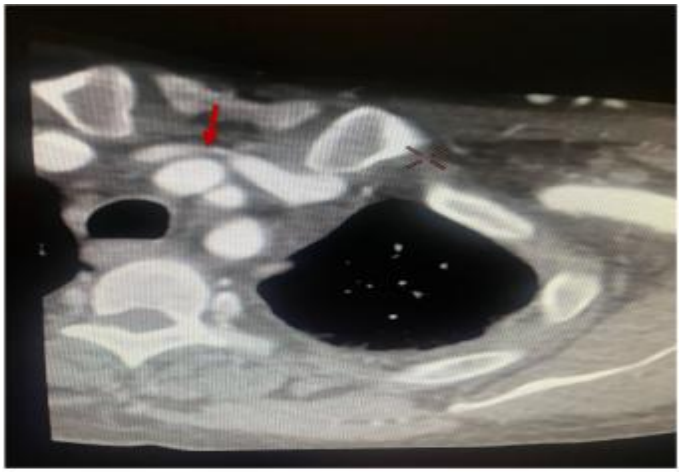


Figure 8: Shows narrowing of the left brachiocephalic vein between sternum and arch of aorta

Methodology

Study Design: This study was an observational study to investigate the role of preprocedural ultrasound (USG) in predicting the complications in patients with end-stage renal disease (ESRD) undergoing AV fistula creation.

Study Population

The study population consisted of patients with ESRD who underwent AV fistula creation at Neelam hospital, Rajpura, Punjab between Jan 2023 and May 2024. Patients were identified through hospital medical records and inclusion criteria were applied to select eligible participants for analysis.

Inclusion Criteria

1. Patients diagnosed with ESRD.
2. Patients who underwent AV fistula creation surgery. 10
3. Availability of preprocedural ultrasound data.
4. Age 18 years or older.

Exclusion Criteria

1. Patients with missing or incomplete medical records.
2. Patients with a history of AV fistula creation prior to the study period.
3. Patients who underwent AV fistula creation surgery at an external facility and lacked preprocedural ultrasound data.

Data Collection

Data on patient demographics, preprocedural ultrasound findings and procedural details were extracted from hospital medical records. Demographic information included age, gender, and comorbidities such as diabetes mellitus and hypertension. Preprocedural ultrasound findings included venous size, venous depth, and presence of arterial wall calcifications. Procedural details encompassed surgical technique, operative time, and anesthesia type. Postoperative complications were accessed using high resolution linear probe and classified according to severity and type.

Post-procedure Ultrasound

All patients included in the study underwent preprocedural ultrasound evaluation prior to AV fistula creation. Ultrasound examinations with doppler were performed by experienced radiologists or vascular surgeons using high-resolution Samsung ultrasound machine. Linear high-resolution probe 7.0MHz, pulse wave Doppler at 5.0MHz and color Doppler at 5.0MHz was used. The angle of the emitted Doppler wave was

adjusted to less than 60°.Venous size was measured in millimeters (mm) at the proposed site of AV fistula creation using transverse views with as little pressure as possible. Sonographic vascular evaluation was used to exclude stenosis or thrombosis in the planned draining vein up to the medial subclavian vein. Venous depth was assessed by measuring the distance from the skin surface to the target vein. Arterial wall calcifications were identified and characterized based on their location, extent, and severity. Measurements were performed a day before procedure.

Post-procedure USG follow-up was done at 1 week, 4 weeks and then 6 monthly after fistula construction or earlier if any complication arose. The USG was done by the same radiologists with the same machine, probe and settings.

Statistical Analysis

Descriptive statistics were used to summarize the demographic characteristics of the study population and the incidence of postoperative complications. Chisquare tests were performed to examine the association between categorical variables such as gender, age group, venous size, venous depth, arterial wall calcifications, and the occurrence of complications. Logistic regression analysis was conducted to assess the predictors of successful AV fistula maturation and complications, adjusting for potential confounding variables.

Results

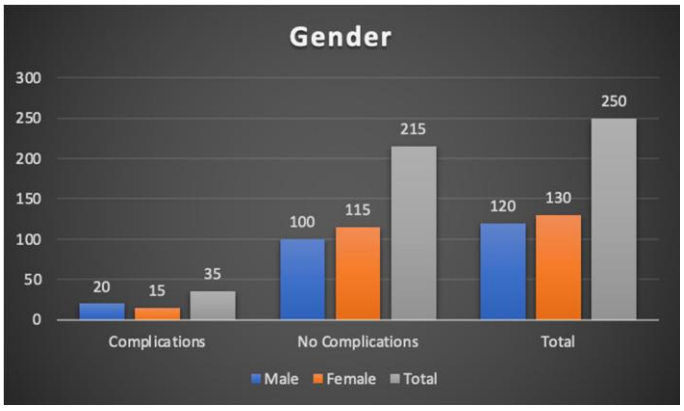
The analysis included data from 250 patients who underwent AV fistula creation for end-stage renal disease (ESRD). Construction of a radiocephalic fistula was the first choice, followed by a brachiocephalic fistula. If neither was possible based on the vein diameters, an upper arm basilic vein transposition fistula was considered. Among these patients, 35 (14%) presented with complications following the procedure which included 14 thrombosis, 6 primary maturation failure, 4 aneurysmal dilations,3 stenosis,3 venous hypertension, 2 infections, 2 central venous stenosis and 1 steal syndrome.

Variable	Group	Total patients	Patients with complications	%Patients with complications	P-value
Gender	Male	120	20	16.7%	0.87
	Female	130	15	11.5%	
Age group	<50 years	115	10	8.7%	0.003
	>50 years	135	25	18.5%	
Venous size	<3mm	148	8	5.4%	0.001
	>3mm	102	25	24.5%	
Venous depth	>4mm	118	18	15.3%	0.002
	<4mm	132	9	6.8%	
Arterial wall calcifications	Yes	120	20	16.7%	0.003
	No	130	10	7.7%	

Table 1: showing baseline characteristics and comparison between different groups

Gender

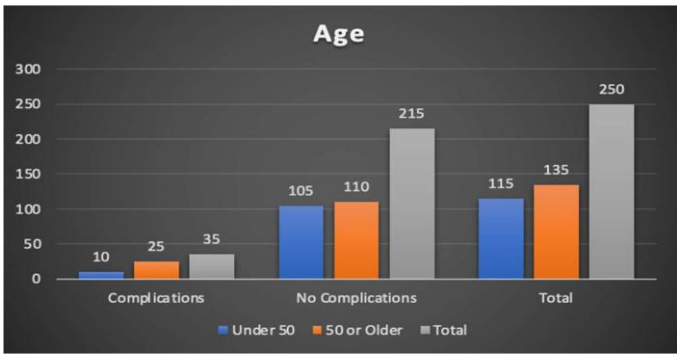
Of the 250 patients, 120 (48%) were male and 130 (52%) were female. Among males, 20 (16.7%) experienced complications, while among females, 15 (11.5%) experienced complications. The chi-square test showed no significant association between gender and complications (p = 0.8722).



Graph 1: Showing comparison of complications between males and females

Age Group

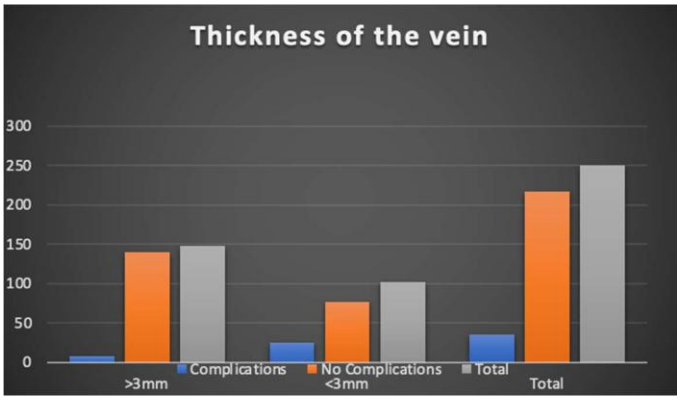
Among the patients, 115 (46%) were under 50 years old, and 135 (54%) were 50 years old or older. Median age was 61.3 years (range, 32-84 years). Complications were observed in 10 (8.7%) patients under 50 years old and 25 (18.5%) patients 50 years old or older. The chisquare test revealed a significant association between age group and complications (p = 0.0003), with older patients having a higher incidence of complications.



Graph 2: Showing comparison of complications between younger and older then 50 years

Venous Size

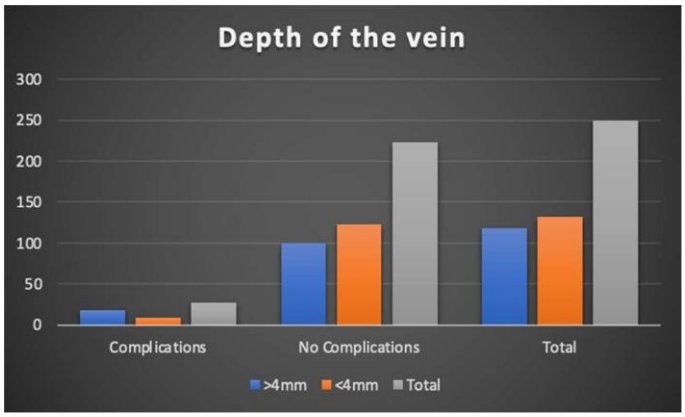
Out of 250 patients, 148 (59.2%) had a venous size greater than 3mm, and 102 (40.8%) had a venous size less than 3mm. Among those with venous size >3mm, 8 (5.4%) developed complications, while among those with venous size <3mm, 25 (24.5%) developed complications. The chi-square test indicated a significant association between venous size and complications (p < 0.0001).



Graph 2: Showing association between venous size and complications

Venous Depth

Of the 250 patients, 118 (47.2%) had a venous depth greater than 4mm, and 132 (52.8%) had a venous depth less than 4mm. Complications were observed in 18 (15.3%) patients with venous depth >4mm and 9 (6.8%) patients with venous depth <4mm. The chi-square test showed a significant association between venous depth and complications (p = 0.0002).

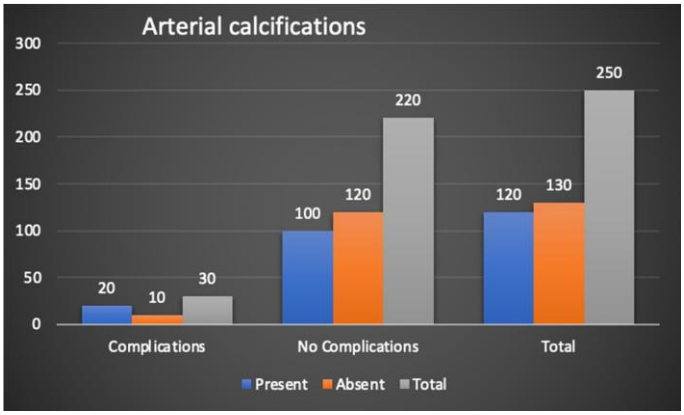


Graph 3: Showing association between venous depth and complications

Arterial Wall Calcifications

Among the patients, 120 (48%) had arterial wall calcifications, while 130 (52%) did not. Complications were observed in 20 (16.7%) patients with arterial wall calcifications and 10 (7.7%) patients without arterial wall calcifications. The chi-square test 14 revealed a significant association between arterial wall calcifications and complications (p = 0.0039).

Overall, our findings suggest that age group, venous size, venous depth, and arterial wall calcifications are significant predictors of complications following AV fistula creation in patients with ESRD.



Graph 4: Showing association between arterial calcifications and complications

Discussion

The results of our study offer compelling insights into the predictive value of preprocedural ultrasound (USG) for assessing the success and complications associated with arteriovenous (AV) fistula creation in patients with end-stage renal disease (ESRD). The implications of these findings are profound, suggesting a paradigm shift in how preoperative planning and patient management are approached in this context.

One of the most striking findings from our study is the strong correlation between advanced age and the occurrence of complications post-AV fistula creation. Older patients demonstrated a significantly higher incidence of adverse outcomes, which can be attributed to the inherent changes in vascular biology associated with aging, including increased arterial stiffness and reduced regenerative capacity. These results align with previous studies that have also identified 15 age as a significant risk factor for AV fistula complications [2][3]. These results underscore the need for age-specific preoperative assessments and interventions to mitigate risks in this demographic. Tailoring surgical techniques and postoperative care to the unique needs of older patients could significantly improve outcomes and reduce the burden of complications.

Our study also highlights the critical role of specific vascular characteristics as determined by preprocedural USG in predicting AV fistula outcomes. Notably, smaller venous size and deeper venous depth were associated with higher complication rates. These anatomical factors likely influence the ease of cannulation and the hemodynamic performance of the fistula, which are crucial for successful dialysis. Similar findings have been reported in other studies, which emphasize the importance of venous diameter and depth in predicting fistula maturation and patency[5][6].The identification of these high-risk features before surgery allows for proactive measures, such as selecting alternative sites for fistula creation or employing advanced surgical techniques to enhance fistula maturation.

The presence of arterial wall calcifications emerged as another significant predictor of complications, reflecting the broader systemic vascular calcification often seen in ESRD patients. This finding is consistent with the results of studies[7] which indicate that vascular calcifications can impede fistula maturation and increase the likelihood of postoperative complications. This finding points to the potential utility of incorporating vascular calcification assessment into routine preoperative evaluations. Addressing calcifications through medical or surgical interventions before AV fistula creation might offer a novel approach to improving vascular access outcomes.

Interestingly, our study also found that gender did not significantly impact the complication rates, contrary to some previous studies suggesting a gender bias in vascular access outcomes [6]. This finding suggests that the anatomical and physiological differences between genders may not play as substantial a role as previously thought, or that modern surgical techniques and postoperative care have mitigated these differences.

The implications of our findings are multifaceted. They advocate for the integration of comprehensive preprocedural USG evaluations into standard practice for AV fistula creation. By 16 identifying patients at higher risk for complications through detailed vascular assessments, clinicians can make informed decisions about surgical planning and postoperative management. This personalized approach not only has the potential to improve individual patient outcomes but also to optimize resource allocation and reduce healthcare costs associated with complications and secondary interventions.

Despite the strengths of our study, including a robust sample size and comprehensive data collection, certain limitations must be acknowledged. The observational retrospective design may introduce selection bias, and the reliance on hospital medical records could limit the granularity of the data. Future studies with prospective designs and larger cohorts are essential to validate our findings and further refine risk prediction models.

Conclusion

The creation of arteriovenous (AV) fistulas is a crucial procedure for patients with end-stage renal disease (ESRD) requiring hemodialysis. However, complications following AV fistula creation can lead to significant morbidity and compromise the effectiveness of hemodialysis treatment. In this study, we investigated the role of preprocedural ultrasound (USG) in predicting the successful maturation of AV fistulas and anticipating complications in patients with ESRD.

Our analysis of data from 250 patients undergoing AV fistula creation revealed several key findings. First, we observed that complications occurred in 14% of patients following the procedure, underscoring the importance of optimizing patient selection and surgical technique to minimize adverse outcomes. Second, while there was no significant association between gender and complications, we found that age group, venous size, venous depth, and arterial wall calcifications were significant predictors of complications.

Older age was associated with a higher incidence of complications, highlighting the need for careful consideration of age-related factors in the management of AV fistulas. Additionally, patients with smaller venous size, deeper venous depth, and arterial wall calcifications were more likely to experience complications, emphasizing the importance of preoperative assessment and planning.

Our findings suggest that preprocedural ultrasound can provide valuable insights into vascular anatomy and morphology, allowing clinicians to identify patients at higher risk of complications and tailor surgical strategies accordingly. By leveraging the information provided by preprocedural ultrasound, clinicians can optimize patient outcomes and reduce the incidence of complications following AV fistula creation.

In conclusion, our study highlights the importance of comprehensive preoperative assessment and the potential role of preprocedural ultrasound in guiding clinical decision-making for AV fistula creation in patients with ESRD. Further research is warranted to validate these findings and explore additional factors that may influence AV fistula outcomes. Ultimately, by identifying patients at higher risk of complications and implementing targeted interventions, we can improve the overall management and outcomes of AV fistulas in this patient population.

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