“ROLE OF DOPPLER ULTRASOUND IN EVALUATION OF ARTERIOVENOUS HEMODIALYSIS FISTULA AND MATURATION, COMPLICATIONS OF HEMODIALYSIS VASCULAR ACCESS ”

DR. POLAVARAPU PRAMA

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UNDER THE GUIDANCE OF

DR. SATISH D. PATIL
PROFESSOR, DEPARTMENT OF RADIODIAGNOSIS

DR. SANDEEP PATIL

ASSOCIATE PROFESSOR,

DEPARTMENT OF MEDICINE

B.L.D.E (DEEMED TO BE UNIVERSITY), SHRI B M PATIL MEDICAL COLLEGE HOSPITAL & RESEARCH CENTRE,

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SHRI B. M. PATIL MEDICAL COLLEGE, HOSPITAL & RESEARCH CENTRE, VIJAYAPURA

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Date:

Place: Vijayapura

DR. POLAVARAPU PRAMA
Post Graduate Student,
Department of Radiodiagnosis,
B.L.D.E.U' s Shri B. M. Patil Medical
College, Hospital & Research Centre,
Vijayapura.

B.L.D.E. UNIVERSITY'S

SHRI B. M. PATIL MEDICAL COLLEGE, HOSPITAL & RESEARCH CENTRE, VIJAYAPURA

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Date:

Place: Vijayapura

DR. SATISH D. PATIL
Professor,
Department of Radiodiagnosis,
B.L.D.E.U' s Shri B. M. Patil Medical College,
Hospital & Research Centre, Vijayapura.

DR.SANDEEP PATIL
Associate Professor,
Department of Medicine
B.L.D.E.U' s Shri B. M. Patil Medical College,
Hospital & Research Centre, Vijayapura.

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SHRI B. M. PATIL MEDICAL COLLEGE, HOSPITAL & RESEARCH CENTRE, VIJAYAPURA

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Date:

Place: Vijayapura

DR.RAJASHEKHAR MUCHCHANDI
Professor and HOD
Department of Radiodiagnosis,
B.L.D.E.U' s Shri B. M. Patil Medical College,
Hospital & Research Centre, Vijayapura.

B.L.D.E. UNIVERSITY'S

SHRI B. M. PATIL MEDICAL COLLEGE, HOSPITAL & RESEARCH CENTRE, VIJAYAPURA

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Date:

Place: Vijayapura

DR. ARAVIND PATIL
Principal,
B.L.D.E.U' s
Shri B. M. Patil Medical College,
Hospital & Research Centre, Vijayapura.

B.L.D.E. UNIVERSITY'S

SHRI B. M. PATIL MEDICAL COLLEGE, HOSPITAL & RESEARCH CENTRE, VIJAYAPURA

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Date:

Place: Vijayapura

DR.POLAVARAPU PRAMA
Post Graduate Student,
Department of Radiodiagnosis,
B.L.D.E.U' s Shri B. M. Patil Medical
College, Hospital & Research Centre,
Vijayapura.

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Date:

Place: Vijayapura

Dr. Polavarapu Prama

ABBREVIATIONS

AVF - Arteriovenous Fistula

CKD - Chronic Kidney Disease

DBP - Diastolic Blood Pressure

DM - Diabetes Mellitus

ESRD - End-Stage Renal Disease

Hb - Hemoglobin

HD - Hemodialysis

HTN - Hypertension

KDOQI - Kidney Disease Outcomes Quality Initiative

mm - Millimeter

ml/min - Milliliters per Minute

NKF - National Kidney Foundation

PSV - Peak Systolic Velocity

RA - Radial Artery

RRT - Renal Replacement Therapy

SBP - Systolic Blood Pressure

SD - Standard Deviation

US - Ultrasound

VA - Vascular Access

ABSTRACT

Introduction: Arteriovenous fistula (AVF) is the preferred vascular access for hemodialysis due to its superior long-term patency and lower complication rates. However, primary failure and delayed maturation remain significant challenges. Doppler ultrasound offers a non-invasive method for evaluating vascular anatomy and hemodynamics, potentially improving AVF outcomes. This study aimed to assess the utility of Doppler ultrasound in evaluating AVF maturation and predicting complications in hemodialysis patients.

Methods: This prospective study included 109 patients undergoing AVF creation for hemodialysis access. Preoperative Doppler ultrasound was performed to assess cephalic vein and radial artery diameters and flow parameters. Postoperative evaluations were conducted on day 1, day 7, and at 4 weeks to monitor vein diameter, flow rates, and complications. Patients were followed until successful cannulation or determination of primary failure.

Results: The cohort comprised 57.8% males with a mean age of 52.4 years. Diabetes mellitus (54.1%) and hypertension (52.3%) were the predominant comorbidities. Preoperative mean cephalic vein diameter was 1.98±0.58 mm, increasing to 9.07±0.75 mm at 4 weeks post-operation. Fistula flow rates progressively increased from 261.1±106.3 ml/min on day 1 to 689.7±138.09 ml/min at 4 weeks. By 4 weeks, 51.4% of AVFs achieved adequate maturation. Primary failure occurred in 24.8% of cases and was significantly associated with diabetes, hypertension, smaller preoperative vessel diameters, and lower flow rates at 4 weeks ($p<0.001$). The mean time to maturation was 38.03±6.8 days, with first successful cannulation at 50.4±8.1 days. Thrombosis (9.17%), infection (5.5%), and stenosis (1.83%) were the most common complications, all being significantly more prevalent in the primary failure group.

Conclusion: Doppler ultrasound parameters, particularly preoperative vessel diameters and 4-week flow rates, are significant predictors of AVF maturation and primary failure. Routine ultrasound evaluation facilitates optimal vascular access planning, timely detection of complications, and improved AVF outcomes in hemodialysis patients.

Keywords: Arteriovenous fistula, Doppler ultrasound, Hemodialysis, Maturation, Primary failure, Vascular access

CONTENTS

INTRODUCTION

Chronic kidney disease (CKD) represents a significant global health burden, with end-stage renal disease (ESRD) affecting millions of patients worldwide who require renal replacement therapy for survival. Among the available treatment modalities, hemodialysis remains the cornerstone of renal replacement therapy, with approximately 70% of ESRD patients depending on this life-sustaining procedure.[1] The success of hemodialysis critically depends on establishing and maintaining adequate vascular access, with arteriovenous fistula (AVF) being universally acknowledged as the preferred access method due to its superior patency rates, lower infection risks, and reduced morbidity compared to other access types.[2]

The creation of a functional AVF requires surgical anastomosis between an artery and a vein, typically in the upper extremity, followed by a crucial maturation period. During maturation, the vein undergoes significant hemodynamic and structural changes, including vessel dilation and wall thickening, to accommodate the increased blood flow necessary for effective hemodialysis.[3] However, AVF maturation failure remains a significant clinical challenge, with failure rates reported between 20-60% in various studies.[4]

Doppler ultrasound has emerged as an invaluable tool in the evaluation and monitoring of AVF, offering numerous advantages including its non-invasive nature, absence of radiation exposure, and real-time imaging capabilities.[5] This imaging modality provides detailed information about vessel anatomy, blood flow dynamics, and various parameters crucial for assessing fistula maturation and detecting complications.[6] The ability to measure vessel diameter, blood flow velocity, and volume flow rates allows for objective assessment of AVF maturation and functionality.[6]

Furthermore, Doppler ultrasound plays a pivotal role in the early detection of AVF complications such as stenosis, thrombosis, aneurysm formation, and steal syndrome.[8] Early identification of these complications enables timely intervention, potentially preventing access failure and reducing morbidity associated with vascular access dysfunction.[9] Regular surveillance using Doppler ultrasound has been shown to improve AVF outcomes and reduce the need for emergency interventions.[10]

AIM & OBJECTIVES

Objectives:

1. To provide the possible applications of DUS during the creation and postoperative follow-up of AVFs, with particular emphasis on the following aspects:
    a) Preoperative vascular mapping.
    b) Maturation of the AVF.
    c) Monitoring/surveillance of AVF (follow-up and early detection of complications).

REVIEW OF LITERATURE

HAEMODIALYSIS

“Dialysis comes from the Greek words dia, which means "through," and lysis, which means loosening or splitting." It is a type of renal replacement therapy in which artificial devices that eliminate excess water, solutes, and toxins replace the kidney's function in filtering the blood. Dialysis helps persons who are losing kidney function quickly maintain homeostasis, or a stable internal environment. The prevalence of end-stage renal disease (ESRD), early detection of chronic kidney disease (CKD), and steps to halt the progression of ESRD are the factors that determine the incidence of renal replacement therapy (RRT). Planned RRT initiation is made easier by the systematic identification of patients with a history of acute renal injury episodes, high proteinuria, and a lowering estimated glomerular filtration rate (eGFR). This slows the rising trend in emergency RRT occurrence.”

All patients who are at risk of developing end-stage renal disease (ESRD) and their carers need to be psychologically and physically prepared, and they need to have easy access to information about available treatment choices. A failing catheter or a poorly functioning fistula, which can result in the temporary insertion of a vascular access and cause sepsis, thrombosis, haemorrhage, and an increased risk of death, can be prevented with advanced preparation. “Because home-based dialysis therapy has social benefits, lower costs, and an enhanced quality of life, patients who participate in educational programs are more likely to adopt it. For the patient to have enough time and mental capacity to make wise decisions and carry out RRT preparations, these programs should start no later than stage 4 CKD. About 2.5 million persons received chronic RRT globally in 2010, with Taiwan and Japan having the highest prevalence and North America having the highest absolute rates. Monitoring the population reliant on RRT is aided by the upkeep of regional and national dialysis registries that contain information on rates, results, and national dialysis practice trends. They also offer resources for clinical research, safety and quality reporting, and information unique to the institution. Both societal and socioeconomic factors influence the decision to use dialysis. White people have CKD and African Americans have ESRD at significantly greater rates. In addition to less common causes such polycystic kidney disease, obstructive nephropathy, and glomerulonephritis, diabetes mellitus accounts for 45% of the burden of end-stage renal disease (ESRD), as does hypertension (30%). Men are more likely to get ESRD, but women are more likely to develop CKD. Due to their effects on wealth or the availability of health insurance, racial differences may restrict access to healthcare. High prevalence of kidney illness, limited access to transplantation, and worse outcomes are among Indigenous people in Australia, New Zealand, the US, and Canada. “Dialysis can be divided into three main categories”:

- Hemodialysis (HD)
- Peritoneal dialysis (PD)
- Continuous renal replacement therapy (CRRT)

With lengthier dialysis sessions and slower blood flow rates in Japan, the dynamics of this specific type of renal replacement treatment differ between nations. While Home HD is commonly used in Australia and New Zealand, PD is very common in Hong Kong and the Jalisco region of Mexico. After weighing the hazards of early commencement (unnecessary exposure to IV lines and intrusive procedures with infection risks) versus late initiation (avoidable volume, metabolic, and electrolyte consequences of AKI), the date of dialysis initiation is determined.”

“Due to individual differences in the severity of uremia symptoms and renal function, it is not recommended to assign an arbitrary urea nitrogen or creatinine level for the start of dialysis. Even with the best CKD care, patients eventually require RRT, particularly if their eGFR falls below 20 ml/min/1.73 m2 or if they quickly worsen to end-stage renal disease (ESRD) within a year. In recent years, the eGFR at the start of dialysis has risen steadily”. Thirteen percent of incident ESRD patients in the US began RRT in 1996 when their “eGFR was 10 ml/min/1.73 m2 or more. In 2010, this rose to 43%, but by 2015, it had fallen to 39%. Waiting for uremic signs to appear before starting RRT enhanced the patient's risk of malnutrition and death. It is possible to prevent the loss of awareness by asking patients to compare their present eating patterns and levels of physical activity with those from six to twelve months ago. Prolonged survival is linked to the idea of a "healthy start," when dialysis starts before the onset of severe uremia symptoms. An early start will increase healthcare expenses and preempt the need for additional treatments or a change of modality without improving quality of life. The following criteria are used by the Renal Physicians Association (RPA) to determine which dialysis patients over 75 have a bad prognosis”:

“Provider's estimation of the likelihood of patient mortality in the next six months”

1. Greatly impaired functional status
2. High comorbidity score
3. Severe chronic malnutrition (low serum albumin)

Mortality is also highly predicted by quality of life. It offers an extensive toolkit to promote collaborative decision-making. Younger age groups have significantly higher mortality rates among dialysis patients, which are mostly attributable to infectious causes (10%) and cardiovascular causes (40%). Common risk factors include dystrophic vascular calcification, substantial extracellular volume changes, chronic inflammation, and altered cardiovascular dynamics during dialysis may be linked to high cardiovascular mortality in dialysis patients. Simvastatin-ezetimibe medication reduced cardiovascular death and significant “cardiovascular events by 17% in the Heart and Renal Protection (SHARP) research, which included dialysis and non-dialysis dependent CKD patients. Dialysis patients are advised to use cardioprotective measures such beta-blockers, aspirin, and renin-angiotensin-aldosterone system inhibitors according to their cardiovascular risk profile”. Being both a cause and an effect of CKD, hypertension has a graded connection with ESRD risk. The largest fatality rates occur during the first three months following the start of dialysis, particularly in elderly patients. This might be brought on by more serious comorbidities that worsen renal function and hazards related to starting dialysis (central venous catheter placement). For patients with ESRD who need dialysis, effective interprofessional teamwork is essential to improving overall outcomes.[11]

Anatomy and Physiology[11]

Figure 1: Anatomy of Upper Limb Arteries

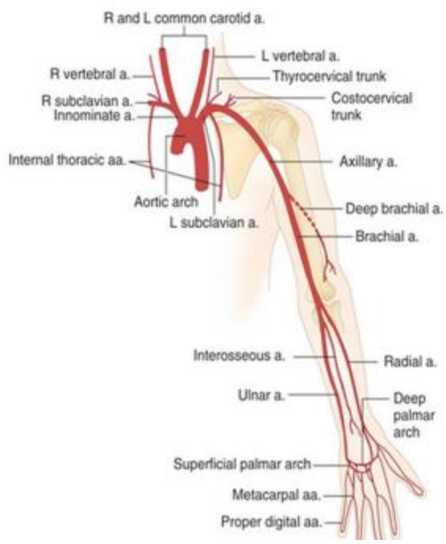
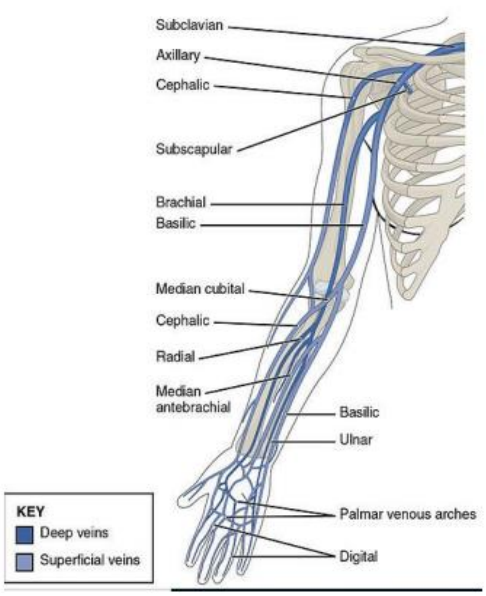


Figure 2: Anatomy Of Upper Limb Veins



Dialysis uses two methods to remove solutes from a semipermeable membrane along a concentration gradient:

1. Diffusive clearing brought on by erratic molecular movements. The pace at which small molecules diffuse through the membrane is higher.
2. Convective clearance happens when solutes are forced through the membrane by the water's osmotic force (solvent drag).

"Highly refined water including sodium, potassium, magnesium, calcium, bicarbonate, chloride, and dextrose makes up dialysate. The low-molecular-weight waste compounds found in uremic blood are absent from it. The flux rate of waste solutes from blood to dialysate is greater than the back-flux from dialysate to blood when uremic blood and dialysate are separated by a semipermeable barrier. With no more net removal of the waste products, the concentrations of permeable waste products in the blood and dialysate eventually equalise. By constantly adding new dialysis solution to the dialyser and swapping out dialysed blood for undialyzed blood, a concentration equilibrium is avoided during dialysis and the gradient is preserved. "Countercurrent" flow optimises the waste product concentration differential between dialysate and blood. The size of the concentration gradient, the membrane's mass transfer coefficient, and the surface area of the membrane all affect a solute's rate of diffusion. The thickness of the membrane, the size of the solute, and the flow conditions on both sides of the membrane all affect the transfer coefficient. Gotch and Sargent established the Kt/V urea as a metric in their National Cooperative Dialysis Study (1985). In contrast to a Kt/V of more than 1.0, which yielded a favourable result, a Kt/V of less than 0.8 was found to be linked to increased morbidity or treatment failure. A dimensionless ratio, the urea-free plasma volume is a product of blood urea clearance (K) and dialysis session duration (t). It is calculated by dividing the amount of plasma cleared of urea (Kt) by the distribution volume of urea (V). A Kt/V of 1.0 indicates that the urea distribution volume and the total blood volume cleared during a session are equal. Dialysis can be continuous or sporadic. Continuous intravascular operations are better for people with severe volume overload or haemodynamic instability".

Indications

"Hemodialysis initiation is needed for acute illness associated with:

- Acute kidney injury
- Uremic encephalopathy
- Pericarditis
- Life-threatening hyperkalemia
- Refractory acidosis
- Hypervolemia causing end-organ complications (e.g., pulmonary edema)
- Failure to thrive and malnutrition
- Peripheral neuropathy
- Intractable gastrointestinal symptoms
- Asymptomatic patients with a GFR of 5 to 9 mL/min/1.73 m^2[12]
- Any toxic ingestion"

"These disorders result in immunosuppression, end-organ damage, haemodynamic instability, or delayed renal recovery due to dysregulation and reduced clearance of cytokines (immune response modulators), which also causes vasodilation and cardiac depression". In high-cytokine conditions like sepsis, RRT improves cytokine elimination. Intradialytic hypotension, electrolyte imbalances, and catheter problems can all be harmful. The 2015 update of the guidelines for haemodialysis adequacy was released by the "Kidney Disease Outcomes Quality Initiative (KDOQI) of the National Kidney Foundation.[13] Patients who reach CKD stage 4 (GFR, 30 mL/min/1.73 m^2) and those who have an impending need for maintenance dialysis at the time of the initial evaluation are advised to receive counselling regarding renal failure and its treatment options, including kidney transplantation, in-center or home haemodialysis, PD, and conservative measures. Education is also necessary for family members and carers. An evaluation of the signs and symptoms of renal failure (pruritus, acid-base or electrolyte abnormalities, serositis), volume or blood pressure dysregulation, a progressive decline in nutritional status despite dietary intervention, or cognitive impairment should be the basis for the decision to start maintenance dialysis. The degree of renal function in an asymptomatic person should not be the basis for the decision to start dialysis. Dialysis is necessary for cardiac diseases such as uremic pericarditis, fluid overload from severe congestive heart failure brought on by inadequate kidney function, and arrhythmias from electrolyte imbalances. Electrolyte (calcium, magnesium, and potassium) imbalances are the most frequent arrhythmias, followed by structural heart abnormalities. Potassium imbalances are caused by metabolic acidosis and reduced renal excretion in patients with chronic kidney disease or renal failure. The inappropriate use of aldosterone antagonists, ACE inhibitors, and angiotensin-receptor blockers are iatrogenic causes in cardiac patients. Elevated urea levels can potentially cause uremic pericarditis in people with renal failure. Fluid retention in patients with heart failure and chronic kidney disease (CKD) exacerbates heart failure and causes pulmonary oedema".

Technique

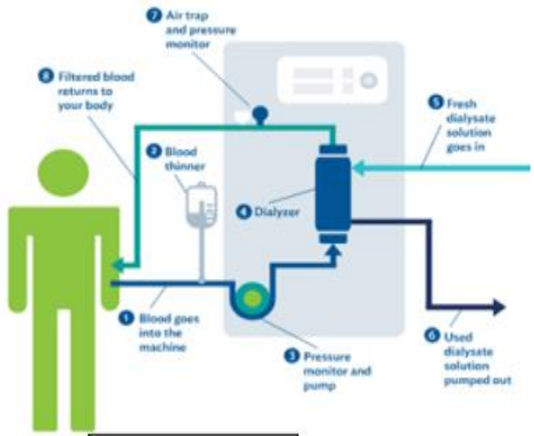
Haemodialysis is used by about 430,000 people in the United States. Arteriovenous fistulas (AVFs), arteriovenous grafts (AVGs), and catheters are available access options. [14–16] To access circulation, a 15 gauge needle is inserted. In order to give most patients dependable access to the circulation, the "fistula first" effort promotes the formation of an arteriovenous fistula. Nonetheless, the majority of patients undergo an arteriovenous graft, which involves placing a polytetrafluoroethylene prosthesis between a vein and an artery. Dialysate flows counter-currently at 500 to 800 ml/min, while blood is pushed through the dialyser at 300 to 500 ml/min. To accomplish sufficient fluid removal or ultrafiltration, the dialysate side's negative hydrostatic pressure is employed. “The urea reduction ratio, or the percentage of blood urea nitrogen reduced per haemodialysis session—ideally between 65 and 70%—determines the dialysis goals. Once the effectiveness of ultrafiltration, the management of hyperkalaemia, hyperphosphatemia, acidosis, and fluid removal have been taken into consideration, the haemodialysis dosage should be customised”.[17]

“Haemodialysis patients experienced a greater degree of disease intrusion than those receiving peritoneal dialysis, which is thought to be more appropriate for elderly patients with numerous comorbidities. Dialysis modality was an independent predictor of illness intrusion. Compared to the thrice-weekly regimen, the six-times-a-week haemodialysis was linked to better control of hypertension, hyperphosphatemia, and decreased left ventricular mass with improved self-reported physical health”. However, after the prolonged intradialytic intervals throughout the dialysis weekend, there was a noticeable increase in heart failure hospitalisation and mortality. For those who want it due to lifestyle reasons, home haemodialysis is performed three to six evenings a week for six to eight hours each. “It is linked to a faster reduction in residual renal function, carer stress, and an increased risk of problems from vascular access. For women with end-stage renal illness, long-term, frequent hemodialysis—either at home or in the center—is advised during pregnancy. Select haemodialysis three times a week for at least three hours each time if there is little to no residual renal function. Patients who experience severe weight gain, poorly managed blood pressure, high ultrafiltration rates, poor metabolic management, or trouble reaching dry weight may be eligible for additional or longer sessions. Achieving euvolemia, solute clearance, and sufficient blood pressure management with little haemodynamic instability and intradialytic symptoms should all be possible with the ultrafiltration rate used for each session."

Patients receiving dialysis experience higher rates of morbidity and mortality and a lower health-related quality of life (HRQoL). The types of HRQoL are as follows:

1. Physical: It is characterised by role constraints and restricted or impaired movement, which might show up as sleep disturbances (fatigue, restless legs, obstructive sleep apnoea).
2. Mental: This includes worry and melancholy thoughts. By raising the physical and mental component scores, intensive haemodialysis (HD) has a positive effect on HRQoL.

Additionally, it is linked to a noticeably shorter recovery period following dialysis. 18 To guarantee their spot, patients who need dialysis while on the go can schedule an appointment at transitory centres, which are nearby dialysis facilities, six to eight weeks in advance. "The transitory centre must receive information from the patient's regular dialysis facility, including the patient's medical history, bloodwork and treatment records, prescription list, insurance details, and any special needs".



Complications

"The most common complications associated with hemodialysis are":[11]

- Intraradialytic hypotension: This results in poor long-term outcomes because it raises mortality and the incidence of myocardial stunning, or anomalies in regional wall motion during dialysis. Mortality has a high correlation with a nadir systolic blood pressure of less than 90 mmHg. Usually, it manifests as nausea, lightheadedness, dizziness, or other mild symptoms. The goal of management is to keep the patient in the Trendelenburg posture while quickly giving them a 100 mL bolus of regular saline via bloodline. After the patient's vitals have stabilised, lower the ultrafiltration rate and keep an eye on them.

• The pathophysiology of muscle cramping is uncertain. Low-sodium dialysis solution, hypovolemia, high ultrafiltration rate, and hypotension all increase the risk of cramping. These elements cause muscular hypoperfusion and vasoconstriction, which subsequently hinder muscle relaxation. 0.9% saline therapy works well when it occurs along with hypotension. Relief may be obtained by forcing the affected muscle to stretch.

Factors associated with maturation disorder

An essential first step and "lifeline" for ESRD patients is the establishment of an AVF/AVG access. As a result, access maturation and ongoing function are essential to the health of these people. Research has been done on predictors of a successful maturation of an arteriovenous access. Due to their disparate focus and use of varied "definitions of maturation, study design, clinical criteria, and patient samples, research investigations on target factors influencing maturation have not been able to come to a consensus". Age and gender are examples of natural characteristics that are beyond our control. Peripheral vascular disease and diabetes are predicted to be more common in older adults. "Elderly people with radiocephalic arteriovenous fistulas (RC AVF) had a greater main failure rate and lower patency, according to findings from a meta-analysis of 13 cohort studies.[19] However, the included studies defined elderly as being between 50 and 70 years of age. The impact of the radial artery's intima-media thickness on early failure (caused by vessel luminal constriction and loss of vascular elasticity) has been compared. In this study, higher age and greater AVF maturation failure were associated with greater feeding artery intima-media thickness. [20] Therefore, it is difficult to draw firm conclusions on the relationship between age and the level of AVF success. A meta-analysis revealed that the 1-year patency level and maturation for RC AVF are comparable for men and women, providing some specific evidence for gender differences in AVF patency. [21] Prior studies have shown that a lower body mass index (BMI), the absence of peripheral vascular disease, no history of smoking, and no diabetes are associated with a greater rate of AVF maturation.[19] The functional development of AVF involved several blood indicators." Thrombophilia patients are more likely to experience primary patency failure. Preoperative identification of patients with combination thrombophilia or hypercoagulable states is necessary to customise antithrombotic treatment and step up surveillance. While inflammation also plays a role in thrombosis in AVF, hypoalbuminemia is more commonly used to determine AVG blockage.[22] It was discovered that hypoalbuminemia is a symptom of inflammation in addition to being an indication of dietary deficiencies in uremic individuals. There is ongoing discussion regarding the impact of serum lipid levels on AVF maturation. A three-year retrospective study was carried out by Kirkpantur et al.[23] to examine the relationship between serum lipid and fistula thrombosis. [24] "According to the findings, patients with fistula thrombosis and those with functional fistulae had comparable serum levels of triglycerides and cholesterol. Following the establishment of an access, Doppler ultrasonography (DUS) allows for early examination". As we show below, DUS helps to improve the prognosis for the success of vascular access maturation. A successful vascular access can be planned with the aid of adequate pre- and intraoperative ultrasound imaging planning and use.

"Indications for arteriovenous fistula/graft creation and timing of preoperative mapping/creation arterio-venous fistula"

The necessity of starting haemodialysis in the recent past is the reason behind the development of both AVF and AVG. Accordingly, a favourable consequence of treating patients with chronic kidney disease (CKD) is the timely initiation of haemodialysis through mature and functional VA. This isn't a typical situation in real life, though. "A significant portion of patients continue receiving haemodialysis (HD) using a central venous catheter (CVC), according to data from the DOPPS 5 research. Compared to 55% in the US, between 71 and 81% of CKD patients in the UK, Japan, Germany, Italy, and Sweden who saw a nephrologist at least four months before to the onset of HD underwent preemptive AVF. 25 These findings support previous claims that the most common factor influencing the proportion of CKD patients who would start dialysis via matured AVF is late referral.[26] As CKD progresses, prompt referral and frequent visits to a nephrologist allow us sufficient time to evaluate the patient's overall health, predict when renal replacement therapy (RRT) will be necessary, and account for factors such as the rate at which glomerular filtration rate (GFR) declines, the time needed for preoperative preparation and access to vascular surgery, and the extra time needed for successful AVF maturation. Early (GFR>10 ml/min per 1.73 m2) and late HD initiation (GFR<10 ml/min per 1.73 m2) did not vary in survival or clinical outcomes, according to the Initiating Dialysis Early and Late (IDEAL) randomised controlled trial. Additionally, several investigators found no difference in morbidity, mortality, or quality of life between early and late onset dialysis, particularly in older adults. The current US and European guidelines[27], which state that RRT should not be initiated until patients exhibit symptoms, clearly supported the IDEAL experiment. This won't occur in the majority of patients until they reach stage 5 of CKD". When CKD reaches stage 5, it is essential to plan the establishment of a permanent vascular access. In either scenario, subsequent progression may be accelerated or steady. Tangri's kidney failure risk equation, one of the many suggested formulas for predicting CKD to ESRD, was found to be effective in identifying and separating those who would need renal replacement therapy (RRT) from those who did not, particularly in the elderly. It also helped patients get ready for RRT. Patients and healthcare professionals should be advised to avoid cannulations and punctures to the cubital and cephalic "veins, particularly on the non-dominant arm".[28]

“Preoperative mapping

DUS is a non-invasive, easily repeatable, safe, and economical technique that gives us important details about the morphology” and functionality of the blood arteries. 29 The information obtained allows us to:

1. Determine the best location for the future access (upper arm or forearm), thereby attempting to lower the risk of failure to mature;

2. “Assess the anatomical possibility for vascular access creation (AVF as the first choice and AVG as the second choice according to the Guidelines)”.

“Preoperative DUS mapping is advised for all patients scheduled for AVF/AVG, per the recently released European Society of Vascular Surgery Guideline on Vascular Access. This recommendation is based on the findings of randomised controlled studies and meta analyses, which give the DUS strength of the recommendations class I and the highest level of evidence—A”.[30]

“Arterial and venous cut-off values for the decision of the appropriate access”

“Before performing an access operation, an ultrasound assessment of the maturation of an arteriovenous fistula should be conducted with a baseline awareness of the vessel state. When using normal vascular surgical techniques, the guidelines[30] recommend a minimum internal radial artery diameter of 2 mm for the successful construction of an autogenous radiocephalic fistula. This recommendation is backed by a systematic review. However, if the arterial artery wall is primarily healthy, has a low load of calcification, and exhibits a reasonable reduction in resistive index in response to reactive hyperaemia, then effective fistula constructions are possible with even narrower lumen sizes down to 1.5 to 1.6 mm30. The latter is accomplished by inflating a sphygmomanometer cuff over the forearm for a brief period of time (4–5 minutes). Using microsurgery and a tourniquet, excellent outcomes have been achieved for the formation of AVFs in both adults and children using smaller vessels. Internal diameter is also acknowledged as a crucial factor in determining venous compatibility. In this case, a proximal tourniquet-adjusted minimum internal venous diameter of 2.0 mm is deemed sufficient. The vein's correct position (including depth), its distensibility above 0.35 to 0.4 mm with proximal tourniquet augmentation, and a Doppler flow pattern with respiratory variation and reactivity to distal limb pressure are additional criteria for venous suitability testing. To avoid compression by the ultrasonic probe, all measurements must be taken in a zoomed-in image and with a sufficient quantity of ultrasonic gel. While more recent ESVS guidelines recommend a minimum arterial and venous diameter of 3 mm, the preceding EBPG statement offered no clear direction for more proximal brachiocephalic and brachiobasilic fistulas. Once more, when there is no specific fibrotic stenosis of veins, which typically results from vein punctures in the elbow region, acceptable fistula constructions are achievable with venous diameters in the cubital region below this recommended minimal threshold. Additionally, up to 20% of participants have a high brachial artery bifurcation. The degree of evidence was not stated, however a minimum target of 4 mm for the outflow vein diameter is set for arteriovenous grafts. We also lack information on the presumed minimum brachial artery sizes linked to a potential risk reduction of access-related distal ischaemia for proximal fistulas and grafts; nevertheless, in this case, the condition of the downstream forearm arteries may be just as crucial”.[30]

"Early postoperative complications following the creation of a hemodialysis vascular access"

"Adverse events that occur within a month of the development of a vascular access are considered early postoperative problems. DUS is significant during this time. Early intervention to promote maturation or even replacement with new vascular access is necessary when an AVF/AVG with a poor probability of maturation is detected. This method reduces the length of time a central venous catheter is exposed and the related morbidity".[32]

Thrombosis and failure to mature

An AVF that fails during the first three months of use or is never usable is referred to as a primary AVF failure. Correctable issues are common in AVF/AVG with main failure; once these issues are resolved, a high success rate is anticipated. Native AVFs are nearly invariably affected by non-maturation that might result in early thrombosis.[33] "Each study had a different incidence of this problem. For example, Ravani and colleagues found that 11.9% of AVFs failed early. Preoperative DUS examination ought to be required in order to prevent failed attempts". Preoperative DUS can offer vital information for maturation, including vein distensibility, in addition to vascular diameters and patency. Early vascular access thrombosis can be caused by a number of factors, including inadequate feeding artery flow, limited draining venous outflow, hypercoagulability, hypotension, surgical errors, tiny vessel diameters, and external compression. The two main factors influencing early thrombosis are hypotension and smaller vessel sizes. In certain situations, preoperative plasma expanders may be useful.[34] A tangible sense of excitement at the conclusion of the procedure is a reliable indicator of effective maturation. The DUS-provided intraoperative access blood flow (Qa) measurement provides reliable information for success prediction as well. "The maximal intraoperative Qa rates for functional

(573.6 ± 103 mL/min) and non-functional (216.8 ± 35.8 mL/min) AVFs varied significantly, according to Berman et al. One day following surgery, a Qa measurement may also be able to predict good maturation in the early postoperative period". The primary patency of radiocephalic AVFs was substantially predicted by the first week postoperative Qa in Ladenheim and colleagues' study. According to Robin et al., measurements of Qa taken two weeks after the construction of the access "were more indicative of 6-week diameter and Qa than those taken one day later. The surgeon should determine whether to build a new vascular access or modify an existing one (endovascular or open surgery) in order to address early thrombosis. The underlying cause or causes should be identified and addressed prior to revision and thrombectomy. It is best to establish a new vascular access at a different, typically closer location when the artery and/or vein diameter is tiny and there is no chance of sufficient distension. Regular DUS observation should be required during the period of AVF maturation".[35]

Incisional bleeding, hematoma and pseudoaneurysm

Patients with chronic renal disease have poor coagulation, which makes them both prothrombotic and prone to bleeding. Patients who have already begun haemodialysis (HD) should not have surgery within the first 24 hours of beginning HD in order to prevent or reduce bleeding and haematoma formation. It is advised to wait for the recovery of platelet function and the removal of heparin, which is utilised in the HD circuit to prevent blood clotting. Anticoagulation during surgery and the use of antiplatelet medications before and after surgery are still debatable topics. 36 Large haematomas, pseudoaneurysms, and severe incisional bleeding are uncommon and may result from a surgical technical error. When blood pressure rises too much, anastomosis may be disrupted. Close intraoperative and postoperative blood pressure monitoring is therefore advised. "Overuse of antiplatelet and/or anticoagulant medications, poor haemostasis following surgery, uncontrolled arterial hypertension, hemorrhagic diathesis, and undiagnosed outflow stenosis are some of the several causes of postoperative haematoma formation. Early postoperative haematomas should be differentiated from pseudoaneurysms, which are non-clotted haematomas that communicate with the vasculature and are brought on by leaking at an anastomotic location. Using colour Doppler (CD) analysis, a pseudoaneurysm usually manifests as a pulsating echolucent sac in B-mode with a swirling flow pattern and a distinctive "to-and-from" flow pattern in the pseudoaneurysm neck. If there is significant bleeding, a growing haematoma, or a big pseudoaneurysm, haemostasis and surgical revision are required. A cautious approach could be used to treat a small haematoma without vein compression that was verified by DUS. Surgery is the best course of treatment for pseudoeurysms because thrombin instillation and compression can result in “access loss”.[37]

“Infection, seroma and lymphatic collection”

“The incidence of these problems is minimal (0.8%). Just 6% of all VA site infections occur in the early postoperative period. Patients with big incisional wounds, those who have already begun HD, and those who have had an arteriovenous graft insertion are more at risk for infection. It seems feasible to use prophylactic antibiotic medication in this group at the time of vascular access construction. In the operating room, wound coverings used to prevent surgical site infections serve as a barrier against any external bacterial contamination. When it comes to dry wounds, the dressings may remain in place until the stitches are taken out. The right balance between medicinal and surgical treatment must be struck for each unique infection. An skilled vascular surgeon should make the decision, mostly depending on the type of access involved and the severity of infection. DUS can offer objective information on the degree of infected perivascular tissue and concomitant thrombosis, even though VA infection is typically diagnosed clinically. Although they are uncommon, seroma and lymphatic collection can appear in bigger incisional wounds especially following graft placement. Aspirating needles can be both a diagnostic and therapeutic procedure. Infected fluid collections that do not respond to antibiotic medication and aspirations require surgical revision and graft removal".[38]

"Steal syndrome and ischemic monomelic neuropathy"

"Steal syndrome, also referred to as distal hypoperfusion ischaemic syndrome (DHIS), haemodialysis access-induced distal ischaemia (HAIDI), or hand ischaemia, is a condition in which the arterial inflow to a vascular bed is redirected to AVF/AVG, thereby decreasing inflow to the hand and producing ischaemic symptoms. In proximal localisation and following graft insertion, this incapacitating consequence occurs more frequently (2–7%) than in distal vascular access (1–2%). When diagnosing underlying reasons, ultrasound is the first choice and can occasionally take the place of angiography. [39] There are numerous methods for treating ischaemia and maintaining access. When there is significant ischaemia or severe acute cardiac decompensation after the establishment of a vascular access, access blockage is a possible choice. Steal syndrome typically develops following arterial and vein dilation. Ischaemic symptoms may manifest in the initial hours following surgery in patients with arteries impacted by atherosclerosis or medial calcinosis and inadequate hand circulation (occlusion of one artery or severe stenosis). Preoperative DUS may identify patients at risk for steal syndrome. When evaluating blood flow in palmar arches, Allen's technique using duplex scanning is more objective than a physical examination alone. [40] In angioaccess surgery, ischaemic monomelic neuropathy is the most severe consequence. It typically appears right after the proximal VA is created and is brought on by either an arteriovenous anastomosis that steals arterial blood or insufficient vascularization of the vasa nervorum following arterial clamping. Axonal loss and decreased motor and sensory nerve conduction velocities in the radial, ulnar, and median nerves are observed in nerve conduction investigations in individuals with ischaemic monomelic neuropathy. Acute ischaemia of the nerve trunks causes these signs to appear. Often, the ischaemic episode is too short to result in noticeable ischaemia of the skin or muscles. When there is no critical hand ischaemia, the hand and forearm muscles become weak or paralysed due to significant sensomotoric dysfunction of the nerve trunks. In the absence of severe ischaemia or necrosis to non-neurologic tissue in the extremity, ischaemic monomelic neuropathy develops. The hand is typically warm, and there is frequently an audible Doppler signal or a palpable radial pulse. It is an obvious sign that the access should be blocked right once, but occasionally the damage is irreparable and only a partial recovery of nerve function occurs. Thankfully, such a drastic circumstance is uncommon. Patients with diabetes are more likely to have it, particularly women".[41]

Maturation

"The maturation period is the time between the development of the AVF/AVG and the initial cannulation, and the ideal length of this period varies greatly between nations. The median time until the first successful AVF cannulation was 10 days in Japan, 46 days in Europe/ANZ, and 82 days in the United States, according to data from the DOPPS 5 research; the median time until the first successful AVG use was 6, 24, and 29 days, respectively. [42] According to a recent retrospective analysis by Wilmink and colleagues, early AVF puncture is not linked to a lower survival rate; rather, it is linked to increased blood flow during the first week of dialysis and the inability to obtain six consecutive successful cannulations from the start of dialysis. 43 Given that Japan has the greatest rate of AVF in both accidental and prevalent haemodialysis patients, these statistics further corroborate the findings and suggestions of the Japanese guideline on vascular access”.[42]

“Definition of mature access—ultrasonographer’s point of view”

“The ultrasonography parameters used to determine if a fistula is developed are controversial. According to some writers, an outflow vein that is broader than 4 mm and permits an extracorporeal circuit/blood pump flow of more than 250 to 500 mL/min might be deemed mature. 44 Depending on whether HD is recommended intermittently daily or three times a week, blood pump flow rates range from 100 to 500 mL/min. A healthy fistula should be able to provide the flow required for sufficient dialysis without experiencing a lot of recirculation. Intra-access blood flow thus emerges as one of the key factors influencing the maturation of AVF/AVG. Good cannulation segment quality is the other characteristic (i.e., adequate length and diameter, suitable depth for ease of cannulation). The fistula blood flow must be at least 250 to 350 mL more than the dialysis flow rate in order to prevent recirculation and provide the 350 to 500 mL/min flow needed for dialysis. In order to avoid the cannulation segment from contracting during dialysis, the minimum autologous fistula flow is 500 mL/min, and the minimum AVG flow is 600 mL/min. The flow rates of the majority of healthy fistulas range from 800 to 1500 mL/min. A straight cannulation section that is at least 10 cm long is necessary. Two straight segments that are at least 4 cm long should be present if the outflow section is convoluted. Under these circumstances, two needles can be positioned so that their tips are sufficiently separated to avoid recirculation. The typical diameter of an AVG is 6 mm. Cannulation becomes challenging when the vein is more than 6 mm below the skin's surface. These parameters can offer an objective guidance, although none of them are absolute. These characteristics are referred to as "The Rule of 6s" in the 2005 NKF-K/DOQI Guidelines for Vascular Access, which are 600 mL/min blood flow, 6 mm diameter, and 6 mm depth”.[45]

AVF development has improved as a result of the use of DUS in preoperative vascular mapping (i.e., a reduction in premature failure and a rise in the incidence of successful native fistula). There are extremely few patients who do not require preoperative ultrasound mapping. Both proximal and distal fistula planning can benefit from the identification of anatomical anomalies. A high brachial artery bifurcation (20–25% of patients) may result in a longer maturation period by reducing distal artery output. We can anticipate issues with fistula maturation given anatomical variances and vascular abnormalities. “Following the formation of the anastomosis with the cephalic vein, vascular abnormalities, such as a mild stenosis of the radial artery (20–30%) without haemodynamic importance, may have a haemodynamic effect, leading to the failure of a vascular access or maturation impairment”.[46]

Arteriovenous fistula maturation evaluation

Ten to fourteen days following the development of the fistula, the patient should be checked. “Infection and vascular or neurological problems that can occasionally arise during access surgery and jeopardise the fistula can be detected with a thorough clinical examination (see above). Four weeks should pass before the second postoperative examination, which consists of a comprehensive clinical examination and DUS. The clinician can decide during this evaluation if the fistula is developed and ready for usage or if it will require a procedure (such as balloon angioplasty or surgery) to further mature. The following groups of fistulas can be distinguished based on their level of maturity at week four”:[47]

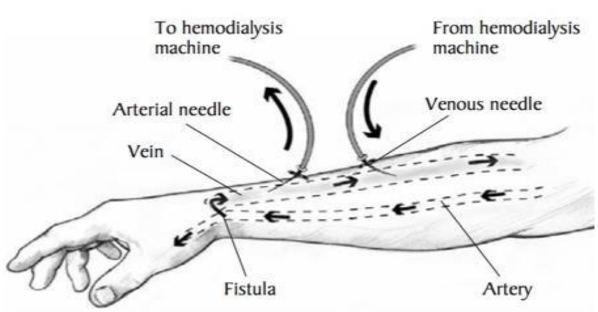
- AVFs that are mature and meet all objective maturation requirements:

• “AVFs are maturing well, but they do not meet all maturation criteria (i.e. borderline Qa 400 to 600 mL/min, inner diameter of outflow segment 4 to 6 mm, larger depth from skin surface 6–8 mm). Qa > 600 mL/min, cannulation segment straight, at least 10 cm long, or two straight segments at least 4 cm in length, > 6 mm in diameter, <6 mm deep from skin surface. If there isn't a specific issue that can be fixed, these AVFs should be followed for a further four weeks before being reassessed”.

• AVF cannot be employed, but blood flow is sufficient. Even though “AVFs may have enough blood flow for dialysis, the fistula cannot be used since the output veins do not match maturation requirements. Despite having a sufficient diameter, the outflow veins may be located farther from the skin's surface and are therefore not yet usable. These patients benefit from either ultrasound-guided punctures for haemodialysis or a further surgical operation called vein superficialization. Because the main outflow vein is stenotic, some patients have branching outflow veins or outflow veins collateralising. For these fistulas to be used, additional assessment (angiography) and secondary treatments are primarily required.

• Issues found during DUS and/or clinical assessment that suggest surgical or radiological intervention for AVFs with blood flow rates more than 400 mL/min”. There may be anomalies such juxta-anastomototic stenosis or outflow vein blockage with insufficient collateralization, or a feeding artery with an undiagnosed proximal stenotic lesion. Percutaneous transluminal angioplasty (PTA) is a treatment option for the majority of these issues. Ultrasound-guided PTA is a safer option for patients with residual kidney function, those recovering from kidney transplantation, or those who are allergic to iodine contrast agents. The Robbin's ultrasonography criteria for maturation are used by certain authors as indicators of sufficient AVF. The likelihood of successful use is 89% for outflow veins larger than 4 mm and 44% for those smaller. More than 500 mL/min of fistula blood flow has an 84% likelihood of being used successfully, compared to 43% if it is less. When these two requirements are combined, our success rate is 95% as opposed to 33% if they are not met. The final usefulness of a fistula for dialysis can be predicted with 80% accuracy by skilled haemodialysis nurses. [48]

In one study, 205 individuals had their postoperative ultrasonography criteria at 6 and 12 weeks after construction compared in order to predict the unsupported use of arteriovenous fistulas for haemodialysis. [49] Two criteria for ultrasound were evaluated: The Kidney Disease Outcome Quality Initiative criteria (NKF-KDOQI) are set by the National Kidney Foundation. “AVF outflow vein lumen diameter ≲6 mm and blood flow ≲600 mL/min; University of Alabama at Birmingham (UAB) requirements: blood flow ≲500 mL/min and vein lumen diameter ⩾4 mm. Unsurprisingly, the UAB criteria demonstrated a lower specificity (42% vs 70%) and a greater sensitivity (89% vs 68%) for unassisted AVF use when compared to the KNKF-KDOQI criteria. The UAB criteria demonstrated a lower specificity (58% vs. 83%) and a higher sensitivity (86% vs. 46%) for radiocephalic AVFs. Both NKF-KDOQI and UAB demonstrated limited specificity (21% vs. 53%) and excellent sensitivity (90% vs. 80%) for brachiocephalic AVFs. Clinical examination alone can readily overlook early troublesome lesions when there is good access flow. Ultrasound postoperative examination makes it simple to pinpoint the issue”.



Ultrasound evaluation of matured AVF /AVG

Clinical investigations are frequently thought to be adequate for determining the function of vascular access with an acceptable level of assurance. A continuous thrill should be seen for several centimetres over the outflow vein, close to the anastomosis, if an AVF is operating properly. However, there are a number of restrictions with clinical assessment. It depends on the examiner's experience and is unreliable in cases when the outflow veins are deeply located. Although it is a good tool for identifying obstructive issues, it is not very good at assessing the anatomical cause or compensatory mechanism. Compared to access angiography, DUS has been shown time and time again to be a reliable and accurate way to diagnose access problems. 50 It is an easy, affordable, and precise way to see perivascular masses and extraluminal processes in addition to intraluminal ones. "Although there aren't any definitive reasons why an ultrasound examination shouldn't be done, there are some physical restrictions that prevent a full DUS, such as recent surgery or open wounds, indwelling catheters, severe oedema, contractures, and immobility. The elements of the ultrasonographic protocol of both AVFs and AVGs are similar, regardless of whether an evaluation is required for failure to mature or dysfunction in a previously useable haemodialysis access. A request outlining the clinical query and the diagnostic suspicion should be made in conjunction with the DUS assessment of vascular access".

Ultrasound evaluation of native arteriovenous fistulas

The longest segment of the outflow vein should be evaluated during a DUS examination of an AVF, which typically follows the blood flow direction. As a result, it covers the following: distal feeding artery, arterial anastomosis, venous outflow side of the fistula, and proximal arterial input side of the fistula (including AVF blood flow calculation).

• Regardless of whether a brachial artery is a feeding artery or not, the evaluation of feeding arteries starts in the proximal region of the arm. To detect the brachial artery, track its journey, and then split it into the radial and ulnar arteries, it is preferable to begin with a transversal scan in B-mode. It is important not to overlook the brachial artery's high bifurcation or any other anatomical anomalies or variations in calibre. For an accurate measurement of blood flow, the proximal brachial bifurcation should be noted. The terms "feeding artery" and "arterial inflow" are frequently used to refer to the artery supplying the anastomosis. The feeding artery often has a thin, two-layered wall and is dilated. The artery lumen should be represented uniformly by Colour Doppler, hence the scale should typically be set broader. The feeding artery of the vascular access has a steady antegrade flow and a medically low-resistant spectral Doppler curve. We proceed with a longitudinal scan, and using the brachial artery's diameter and temporal average mean velocity (TAVM), we calculate the flow rate (mL/min), which corresponds to blood flow in the vascular access. A longitudinal scan can be used to assess the brachial artery's diameter, or M-mode can be used to determine the average diameter in relation to pulsatility. The (radial) feeding artery is inspected from the bifurcation to the anastomosis in radiocephalic arteriovenous fistulas (RC AVF). Both the radial and ulnar arteries supply blood to the forearm accesses nearly equally. The colour Doppler mapping of the anastomosis area by the inverse colour made it simple to see the reverse of the blood flow distal to the anastomosis. Identification of potential radial artery stenosis requires extra care. Just 5% of patients have inflow stenosis, which is uncommon in newly constructed AVFs.[51] Severe medial calcinosis, however, restricts both the diagnostic potential of DUS and the radial artery's dilatation. It is technically challenging for DUS to evaluate the palmar arches and digital arteries.

• The two terms that define anastomosis are maximal peak systolic velocity (PSV, cm/s) and width of anastomosis (mm). Using the established diagnostic criteria, the anastomosis is assessed for haemodynamically significant stenosis: an anastomotic stenosis should be suspected if the anastomosis's peak systolic velocity ratio (PSR) is more than 3:1 when compared to the feeding artery 2 cm upstream. When the absolute PSV at the anastomosis is greater than 400 cm/sec, some labs use a PSR greater than 3 to indicate stenosis. [52] The measurement quality may be poor due to turbulent flow and the angle of insonation. Particularly when there is no outflow vein stenosis, a high-resistant spectral Doppler curve pattern, and a low brachial artery flow volume, an overly narrow anastomosis is indicated.

• In order to rule out artificial pseudostenosis, the outflow vein needs to be inspected using a lot of ultrasound gel and with extreme caution to prevent transducer pressure.

Vein depth, minimum diameter, and cannulation segment length are among the measurements. Collateral vessels that can disperse blood flow are identified; their size and distance from the anastomosis should be taken into consideration while describing them. It is also necessary to document extraluminal alterations, such as haematoma, seroma, and soft tissue oedema. “The most common cause of fistula failure in peripheral native AVFs is juxta-anastomotic outflow vein stenosis. [53] Usually, this kind of stenosis develops in the outflow vein between 1 and 5 cm from the anastomosis. Stenoses in cannulation segments are frequently brief and can occasionally form at the location of venous valves. The most common stenoses are found in other locations on upper arm AVFs. Central venous lesions are less common, occurring in 6–8% of patients, and typically appear in those who have had an ipsilateral subclavian vein catheter. Very low-flow AVFs may fail to show velocity increase in the presence of lumen diameter reduction by B-mode imaging; this is typically caused by inflow stenosis, but it can also happen as a result of dehydration. A thorough evaluation of the stenosis is required, as is accurate and timely indication of the PTA technique. Although DUS has limitations in this area and some central stenoses may be missed, the central veins of the chest should be examined if there is a clinical suspicion of central venous stenosis (dilated shoulder and thoracic subcutanoues venous collaterals, arm swelling, lack of any other aetiology for access dysfunction, history of subclavian vein catheterisation).[54] Central venous stenosis is essentially ruled out by the subclavian vein's ability to collapse after deeper inspiration. The development of aneurysms or pseudoaneurysms is one of the additional vascular access issues that DUS can identify. Since a pseudoaneurysm usually develops at the site of multiple punctures, at the anastomoses, or following PTA due to prolonged bleeding, it is an uncommon occurrence during the maturation stage. It is challenging to define aneurysmal development in this context because the goal of VA formation is abnormally dilated vasculature. Aneurysms are often taken into consideration when a dilatation is 1.5–2 times broader than the non-dilated artery".[55]

"Ultrasound examination of arteriovenous grafts"

"As with AVFs, DUS assessment of an AVG comprises a description of the arterial anastomosis (AA) of the graft itself as well as the venous anastomosis in addition to the evaluation of the input artery and outflow vein. To avoid hand ischaemia, the surgeon may create a typical constriction in the arterial anastomosis of AVG between the artery and graft. Compared to the upstream feeding artery, the graft's arterial anastomosis may exhibit more Figure 1 fluctuation in flow velocity than AVF. [56] According to "The Rule of 6s," the average diameter of the cannulation segment, its depth from the skin, and its course are all considered while studying a transplant. [58] Even known risk variables, such as starting AVG blood flow <600 ml/min, feeder artery mediocalcinosis, and early intimal hyperplasia, influence the degree of early AVG affection, which is indirectly correlated with lifespan. [59] As previously stated, we describe any alteration in two distinct scan planes (seroma, haematoma, lymphocele accumulation) in order to offer the greatest follow-up for the access maturation. Graft stenoses typically appear where cannulations occur frequently (using the area method rather than the recommended rope ladder method). We employ the same standards as stated in the AVF evaluation to quantify a stenosis. Regular descriptions of venous anastomosis (VA) should include the height of intimal hyperplasia (mm), PSV (cm/s), and diameter (mm). The most frequent site of AVG stenosis is the venous anastomosis (47% of instances), with 11% occurring in the immediate proximal portion of the outflow vein within 1 cm".[59] "Once more, internal diameter reduction, PSR, and blood flow measurement are used to grade the severity of stenosis. A transverse scan is required to determine the remaining diameter or the percentage of lumen decrease in cases of asymmetric stenosis. To avoid underestimating or overestimating, a combination of morphological and haemodynamic criteria is used to define severe stenosis with high risk of thrombosis. According to this notion, substantial stenosis occurs when there is a lumen reduction of more than 50%, a PSR greater than 2, and at least one of the following extra criteria: low blood flow of less than 600 mL/min, remaining diameter less than 2 mm, or a blood flow reduction of more than 25%. PTA only receives referrals for certain important stenoses. In the absence of other criteria, stenosis is deemed borderline, and the patient is referred for a follow-up DUS scan six to eight weeks later. The watch-and-wait approach—direct referral to PTA in the event of any (clinical or ultrasound) suspicion of stenosis progression—is maintained during this time. Using the watch-and-wait technique to postpone PTA for borderline asymptomatic stenosis is safe, especially for individuals with higher relative risk (female gender, prior PTA, blood flow <800 mL/min)".

Ultrasound calculation of blood flow

One of the requirements for duplex Doppler ultrasonography is the determination of the AVF/AVG flow volume (Qa). [61] One crucial indicator of a severe stenosis is this hemodynamical measure. Every centre should validate the DUS measurement of vascular access flow using a dilution approach.[62]

"The calculation of the volume flow rate is based on the following equation":

$$\text{“QVA”} = \pi \times r^2 \times \text{TAVM}$$

"where TAVM is the time-averaged velocity integral of the mean velocity and r is the vessel radius. The lumen area, assuming it is round, is calculated in the first part of the equation (π × r 2). The mean blood flow velocity through the blood artery, averaged over time (integral value), is represented by the second part of the equation (TAVM). The vascular access flow volume is measured directly in the graft in AVGs. Regardless of whether artery serves as the vascular access's feeding artery, the brachial artery should be used to assess the vascular access flow in native AVFs. Both the radial and ulnar forearm arteries supply the distal AVF (also known as the RC AVF) through palmar arches, with collateral circulation accounting for up to 25% to 30% of the flow".[63]

The most frequent causes of inaccurate vascular access flow calculations are:

• Incorrect ultrasonography machine settings (inappropriate sample volume, interrogation angle greater than 60°)

• Inappropriate vascular location of calculation (curvature, dilatation, anastomosis, or adjacent stenosis)

• Ultrasound method (probe compression of the vein)

• Haemodynamic instability, including hypotension, tachycardia, and arrhythmia

• The DUS examination was performed too soon (less than 24 hours following the dialysis treatment).

REVIEW OF RELATED STUDIES

Suraj H et al (2024)[64] sought to ascertain how Doppler assessment functions in evaluating AVF. 33 haemodialysis patients who had an AVF formation operation participated in an 18-month prospective observational research. 33 patients in all, with an average age of 54.6 ± 7.8 years, were assessed. Nine (27.3%) of the 33 participants were female, and 24 (72.7%) were male. Ten (29%) of the subjects had both diabetes mellitus and hypertension, eight (24%) had hypertension, and the majority (47%, n=16) had both conditions. 33.33% of individuals experienced radiocephalic anastomoses, and 45.5% developed a brachiocephalic fistula. Five individuals received a diagnosis of AVF complications: three had a cephalic vein thrombosis, and two had a pseudoaneurysm. Age, vascular features, and comorbidities were clinical and demographic factors that did not significantly correlate with AVF development. They came to the conclusion that Doppler ultrasound is crucial for preoperatively choosing vessels for AVF and for postoperatively evaluating AVF maturation, which lowers the initial fistula failure rate.

According to the results, Doppler evaluation may be a useful method for determining AVF maturation and forecasting surgical success, which may assist medical professionals in choosing the optimal treatment plan for their patients.

Abou-Rashed et al (2023)[65] The purpose of the current study was to evaluate the function and usefulness of CDUS in determining vascular access and shunt problems for haemodialysis. This is a randomised controlled experiment that is prospective. The vessel diameters of most patients were normal. Fistulas in 6 patients (20%), 8 patients (26.7%), and 15 patients (50%) are BB, RC, and BC, respectively. According to the study, the average age at which an AVF matures is 2.17 ± 0.379 weeks following its initial formation. Twenty-seven patients experienced 90% shunt problems, while three patients experienced an uncomplicated 10%. Venous thrombosis (12 patients, 40%), stenosis (9 patients, 30%), aneurysmal dilatation (6 patients, 20%), pseudoaneurysmal development (3 patients, 10%), and steal syndrome (3.3%, 1 patient) were all shown to be significantly prevalent during the examination. They came to the conclusion that haemodialysis treatment quality can be raised by promptly identifying and repairing a failing haemodialysis fistula. The CDUS data from this series were helpful in deciding on additional therapeutic care for patients with AV dysfunction.

“Hassan, M.H et al (2019)[66] Our study's goal is to identify how colour Doppler ultrasonography can be used to assess arteriovenous fistulas (AVFs). Overall, the findings showed that 19 patients had no shunt complications (63.3%) and 11 patients out of 30 who had been referred to tertiary centres had complicated AVF (36.7%). Out of the 30 patients that were referred to primary HD centres, 22 had complex shunts. At tertiary centres, thrombosis accounts for 13.3% of cases, stenosis for 3.3% of cases, aneurysmal formation for 6.6% of cases, haematoma for 6.6% of cases, infection for 3.3% of cases, venous hypertension for 3.3% of cases, thrombosis and haematoma for 16.6% of cases at primary centres (5 patients each), aneurysmal formation and infection for 13.3% of cases, and stenosis for 10%. They came to the conclusion that CDUS is a widely accessible, non-invasive, risk-free, bedside technique that provides accurate anatomic knowledge and qualitative and quantitative data of the upper limb vascular system. These factors significantly aid in preoperative planning of the creation of an AVF, determining the prime time for puncture (maturation), detecting complications early, and selecting the best therapeutic approach for their treatment".

"Robbin, Michelle L et al (2018)[67] examined the associations between ultrasonography parameters and the clinical maturation of newly generated AVF in 602 people in a multicenter observational cohort research, as evaluated at 1 day and at 2 and 6 weeks. AVF blood flow, diameter, and depth were all statistically significant predictors of both unaided and total clinical maturation at each ultrasonography measurement period. Furthermore, although maturation probability varied among clinical centres before and after controlling for blood flow, diameter, and depth, neither the other ultrasonography characteristics nor case-mix factors were linked to clinical AVF maturation. For models built with these three ultrasound parameters, the crossvalidated area under the receiver operating characteristic curve was 0.69, 0.74, and 0.79 at 1 day and 2 and 6 weeks, respectively, for unassisted AVF clinical maturation, and 0.69, 0.71, and 0.76 for overall AVF maturation. They came to the conclusion that unaided and overall AVF clinical maturation were somewhat predicted by AVF blood flow, diameter, and depth. The prediction of AVF maturation was not further enhanced by the other parameters taken into account".

Zhu, Y et al (2016)[68] investigated the ideal blood flow and vascular diameter as determined by ultrasonography to forecast fistula maturity in Chinese patients. Nineteen fistulas were categorised as failure and 113 as mature during a six-month follow-up. Within two weeks following surgery, both groups' brachial and radial artery diameters grew progressively ($p<0.05$), and within four weeks, both the diameter and blood flow of the cephalic veins increased ($p<0.05$). From the first day following creation, the mature group's blood flow was substantially higher than that of the failed group. “For the two parameters combined in predicting fistula maturity, the area under the receiver operating characteristic (ROC) curve was 0.95 (529 ml/min, the ideal cut-off value) for blood flow, 0.83 (5.2 mm) for cephalic vein diameter, and 0.96 for both. They came to the conclusion that cephalic vein diameter >5.2 mm could be utilised as a supplement when needed and that blood flow >529 ml/min could be used to predict fistula maturity in Chinese patients”.

Da Fonseca, J. H et al (2015)[69] assessed the Doppler ultrasound's (USD) accuracy in determining the maturity of haemodialysis arteriovenous fistulas (AVFs). 51 out of the 76 patients who were included finished the study. They divided them into two groups: those who had satisfactory haemodialysis adequacy (45), and those who hadn't (6). Both groups' average draining vein diameter (DVD) and flow volume (FV) were 325 mL/min (95% CI: 140-510) and 940 mL/min (95% CI: 829-1052), respectively; and 0.48 cm (95% CI: 0.45-0.52) and 0.33 cm (95% CI: 0.27-0.40). FV and DVD had respective area under the ROC curves of 0.926 and 0.766. They came to the conclusion that 85% of the volume flow measurements at the draining vein were accurate in assessing the haemodialysis arteriovenous fistula's maturation.

MATERIAL AND METHODS

- **Study design:** Prospective observational study
- **Study area:**
- **Study period:** Research study was conducted from May 2023 to December 2024. Below is the work plan.

- **Sample size**:
- **Inclusion criteria:**

1. "Dialysis –dependent patients between 15 and 70 years of age undergoing primary RC-AVF and those willing for follow up".

- **Exclusion criteria:**

1. Dialysis –dependent patients with grafts and central venous catheter and those refusing to take part in the study.

METHODOLOGY:

The study included dialysis-dependent patients aged 15-70 years who underwent primary radiocephalic arteriovenous fistula (RC-AVF) creation. Written informed consent was obtained from all participants prior to their enrollment in the study. The study protocol was approved by the institutional ethics committee.

Equipment and Technical Setup

Two ultrasound systems were utilized for the study: GE VOLUSON S8 BT18 and GE VERSANA PREMIER. Both systems were equipped with high-frequency linear transducers capable of performing B-mode examination at 7 MHz and Doppler studies at 5 MHz. The examination room was maintained at a comfortable temperature, and ultrasound gel was pre-warmed to prevent vasoconstriction of the vessels under examination.

Examination Protocol

All examinations were performed with patients in a supine position with moderate trunk elevation to optimize visualization of upper extremity vasculature while maintaining patient comfort. The systematic evaluation included both pre-operative and post-operative Doppler ultrasound (DUS) examinations. During each examination, arterial assessment was conducted from the arm root towards the hand, while venous assessment proceeded from the periphery towards the thorax. Both transverse and longitudinal scans were performed to ensure comprehensive evaluation.

The examination protocol included:

1. B-mode assessment for morphological evaluation
2. Color Doppler imaging for flow patterns
3. Spectral Doppler analysis for velocity measurements
4. Volume flow calculations

Maturation Assessment

AVF maturation was evaluated using the "Rule of 6" criteria, which included:

- Flow volume measurements exceeding 600 mL/min
- Outflow vein diameter greater than 6 mm
- Assessment of outflow vein depth

Flow Volume Calculation

Blood flow measurements were obtained from the brachial artery just above the elbow crease, where the vessel segment runs obliquely. This location was chosen for its optimal angle of insonation and laminar flow characteristics. The flow volume was calculated using the formula: Area × Mean Velocity × 60. Care was taken to maintain the Doppler angle at 60 degrees or less to ensure accuracy of velocity measurements.

Surveillance Protocol

Post-operative surveillance was conducted to monitor AVF functionality and detect potential complications. Blood flow measurements were used as the primary surveillance parameter. Flow rates between 700-1,300 mL/min were considered indicative of well-functioning fistulas. Values below 500 mL/min triggered additional investigation for access dysfunction, while measurements below 300 mL/min were treated as indicators of imminent thrombosis requiring immediate intervention.

Quality Control Measures

To ensure consistency and reliability of measurements, all examinations were performed by experienced sonographers who had received standardized training in vascular access assessment. Regular calibration of ultrasound equipment was performed according to manufacturer specifications. Multiple measurements were taken for each parameter to ensure reproducibility, and the average of three consistent readings was recorded for analysis.

Data Collection and Documentation

Standardized forms were used to record all measurements and observations, including vessel diameters, flow volumes, and any detected complications. Digital images and video clips were stored in the hospital's Picture Archiving and Communication System (PACS) for future reference and analysis.

STATISTICAL ANALYSIS

"Data was entered in excel sheet and analyzed using SPSS version 21. Results were presented in tabular and graphical forms Mean, median, standard deviation and ranges were calculated for quantitative data. Qualitative data were expressed in terms of frequency and percentages. Student t test (Two Tailed) was used to test the significance of mean and P value <0.05 was considered significant.

RESULTS

The present study was conducted in the department of Radiodiagnosis at Shri B.M.Patil Medical College, Vijayapura from May 2023 –December 2024 to study the role of doppler ultrasound in evaluation of arteriovenous haemodialysis fistula and maturation , complications of haemodialysis vascular access. Total of 109 patients were considered for the study.

Following were the results of the study:

Table 1: Distribution of patients according to age

Age (in years)	Frequency	Percentage
<20	0	0
20-40	10	9.17%
41-60	62	56.9%
>60	37	33.9%
Total	**109**	**100%**

Table 1 and graph 1 shows the age distribution of the 109 patients in the study, with the majority (56.9%) falling in the 41-60 years age group, followed by 33.9% of patients being older than 60 years, while only 9.17% were between 20-40 years, and no patients were younger than 20 years.

Graph 1: Distribution of patients according to age

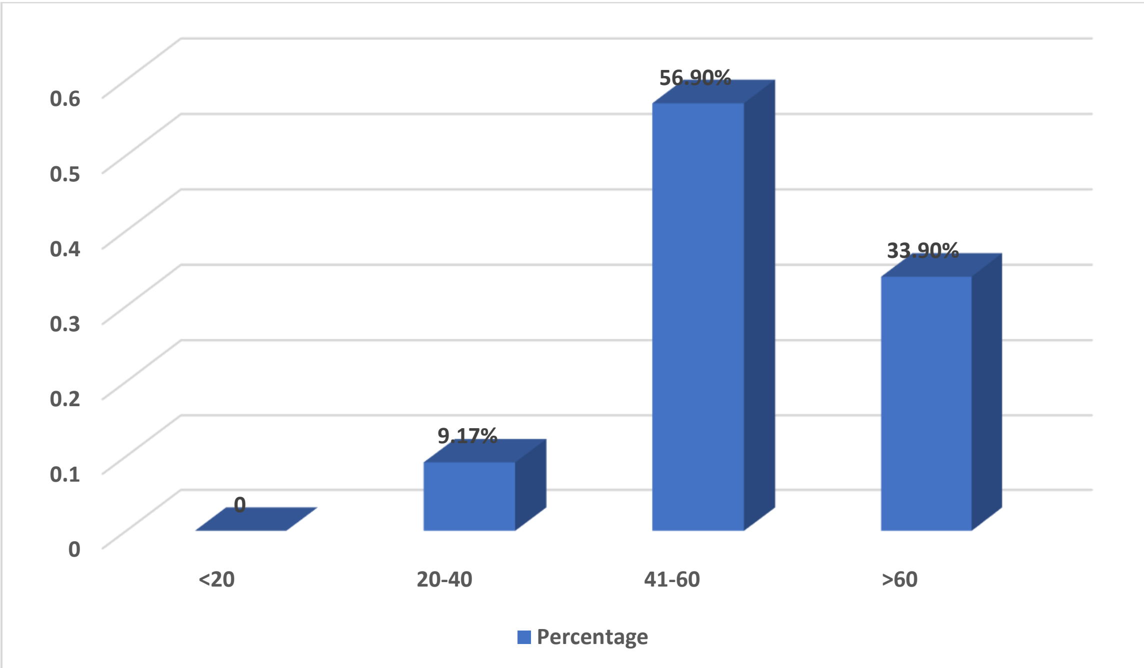


Table 2: Distribution of patients according to gender

Gender	Frequency	Percentage
Female	46	42.2%
Male	63	57.8%
Total	**109**	**100%**

Table 2 and graph 2 reveals the gender distribution of patients, indicating that males constituted the majority at 57.8% (63 patients), while females accounted for 42.2% (46 patients) of the total study population.

Graph 2: Distribution of patients according to gender

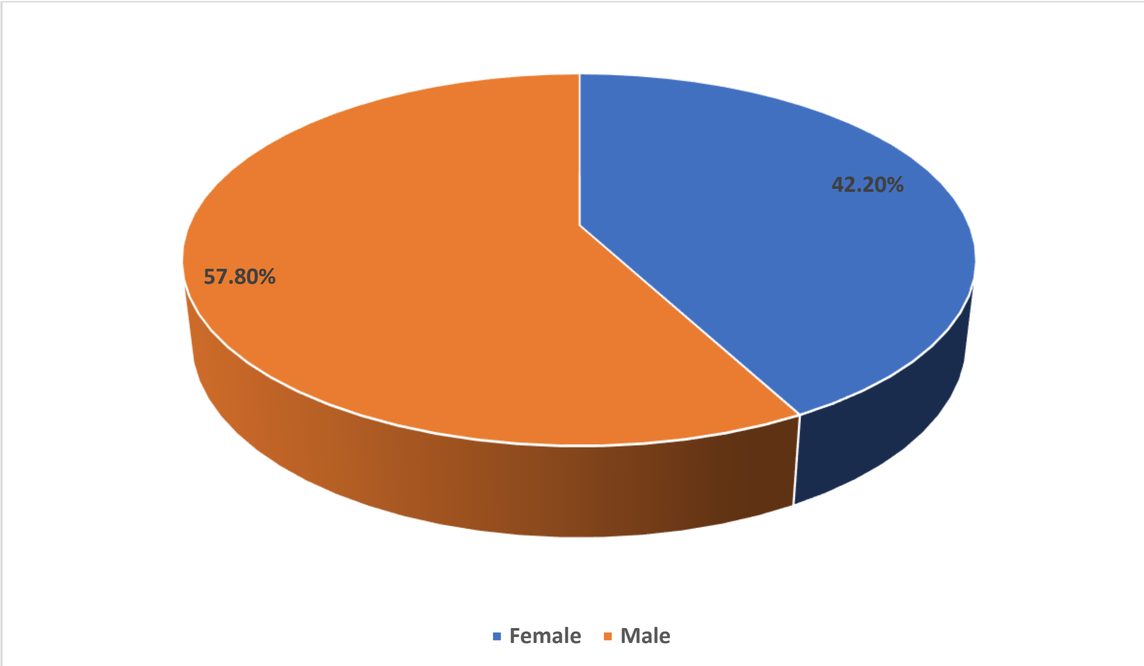


Table 3: Distribution of patients according to co-morbidities

Co-morbidities	Frequency	Percentage
Diabetes mellitus	59	54.1%
Hypertension	57	52.3%
Diabetes+hypertension	27	24.8%

Table 3 and graph 3 presents the distribution of co-morbidities among the patients, showing that diabetes mellitus was present in 54.1% of patients, hypertension in 52.3%, and 24.8% of patients had both diabetes and hypertension concurrently.

Graph 3: Distribution of patients according to co-morbidities

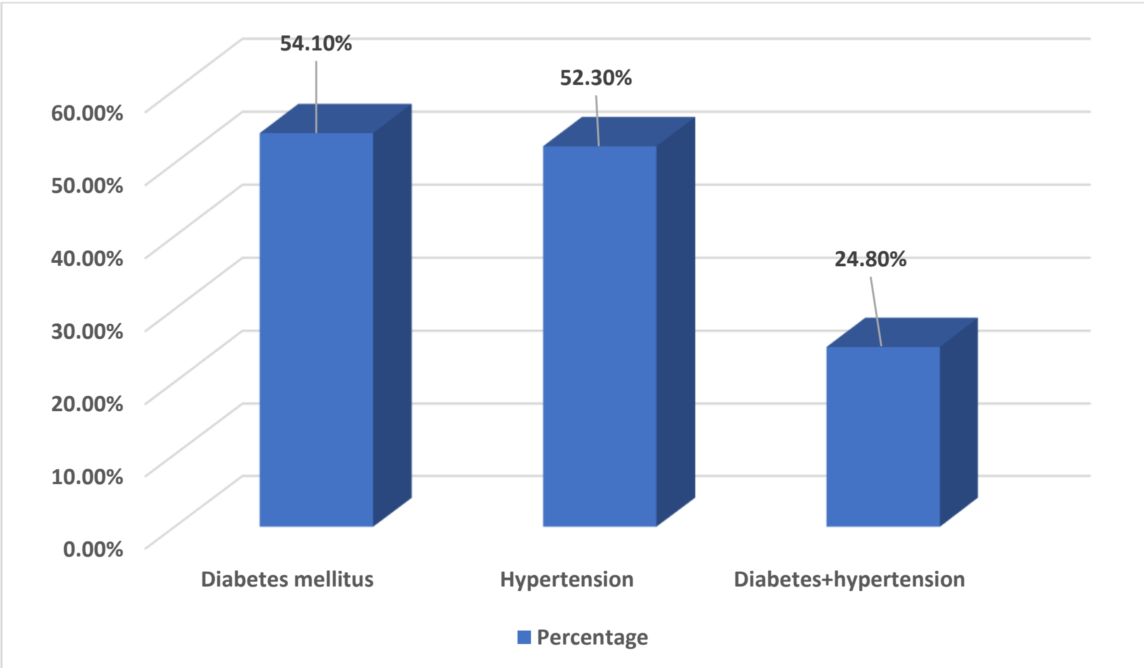


Table 4: Distribution of patients according to weight

Weight	**Weight**
Mean	68.6
SD	13.9

Table 4 and graph 4 provides information about the weight distribution of patients, with a mean weight of 68.6 kg and a standard deviation of 13.9 kg.

Graph 4: Distribution of patients according to weight

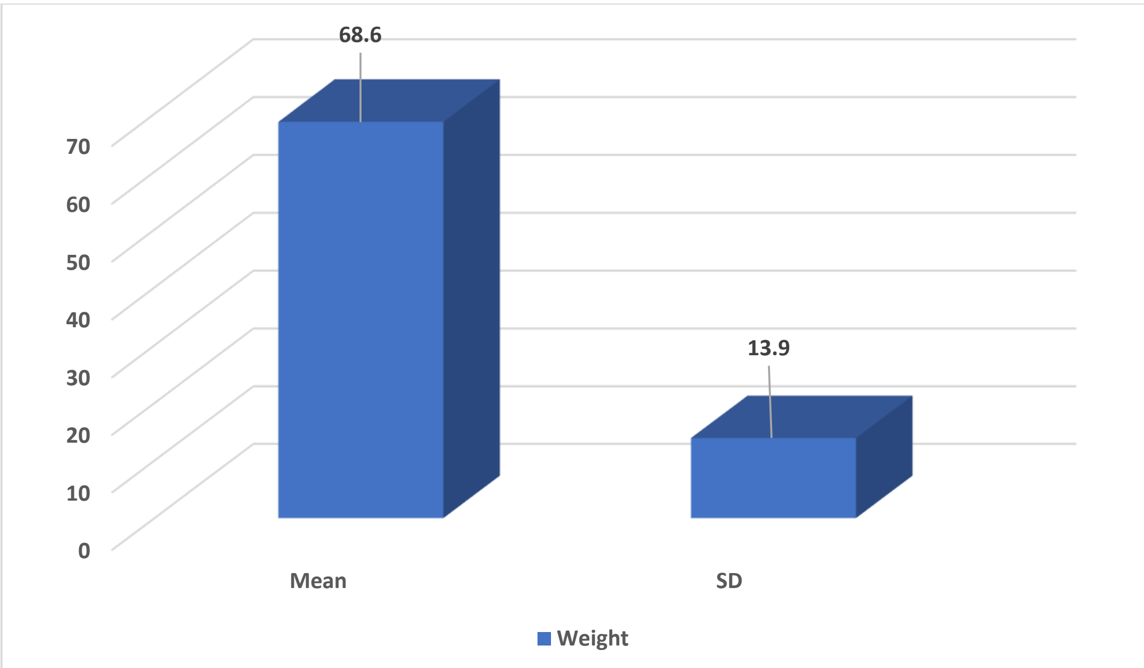


Table 5: Distribution of patients according to blood pressure

blood pressure	SBP	DBP
Mean±SD	140±15.2	90±10.04

Table 5 and graph 5 displays the blood pressure measurements of the study population, with a mean systolic blood pressure of 140 mmHg (SD ±15.2) and a mean diastolic blood pressure of 90 mmHg (SD ±10.04).

Graph 5: Distribution of patients according to blood pressure

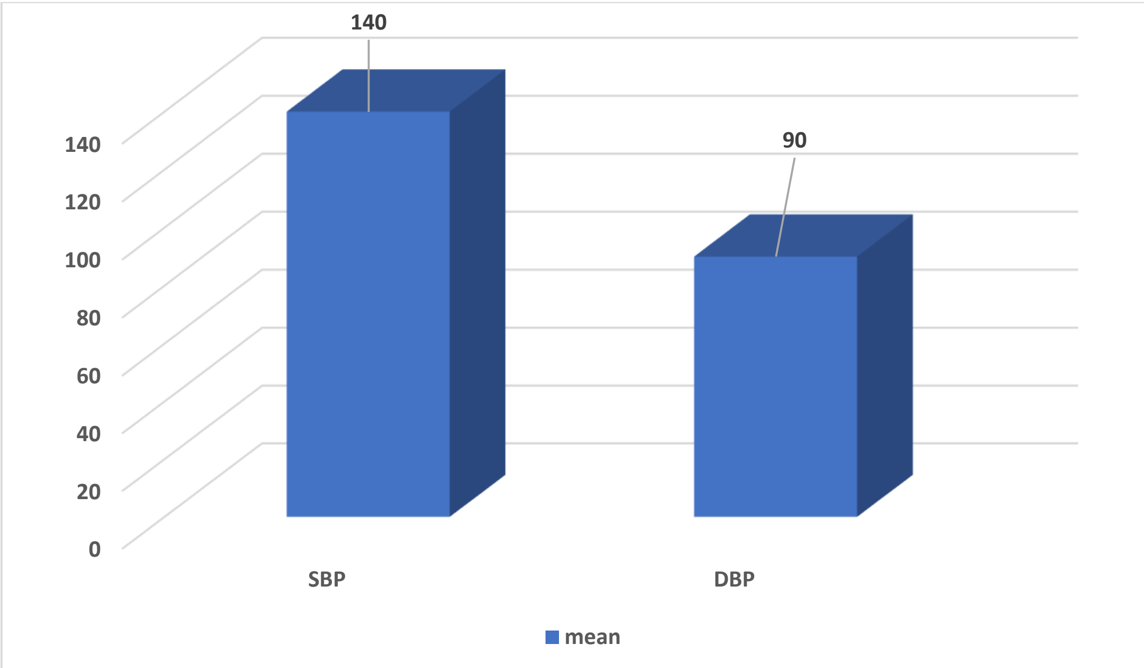


Table 6: Distribution of patients according to Hb and serum creatinine

Variables	Hb	Creatinine
Mean±SD	10.5±1.2	8.6±2.03

Table 6 and graph 6 shows the laboratory values of the patients, indicating a mean hemoglobin level of 10.5 g/dL (SD ±1.2) and a mean serum creatinine of 8.6 mg/dL (SD ±2.03).

Graph 6: Distribution of patients according to Hb and serum creatinine

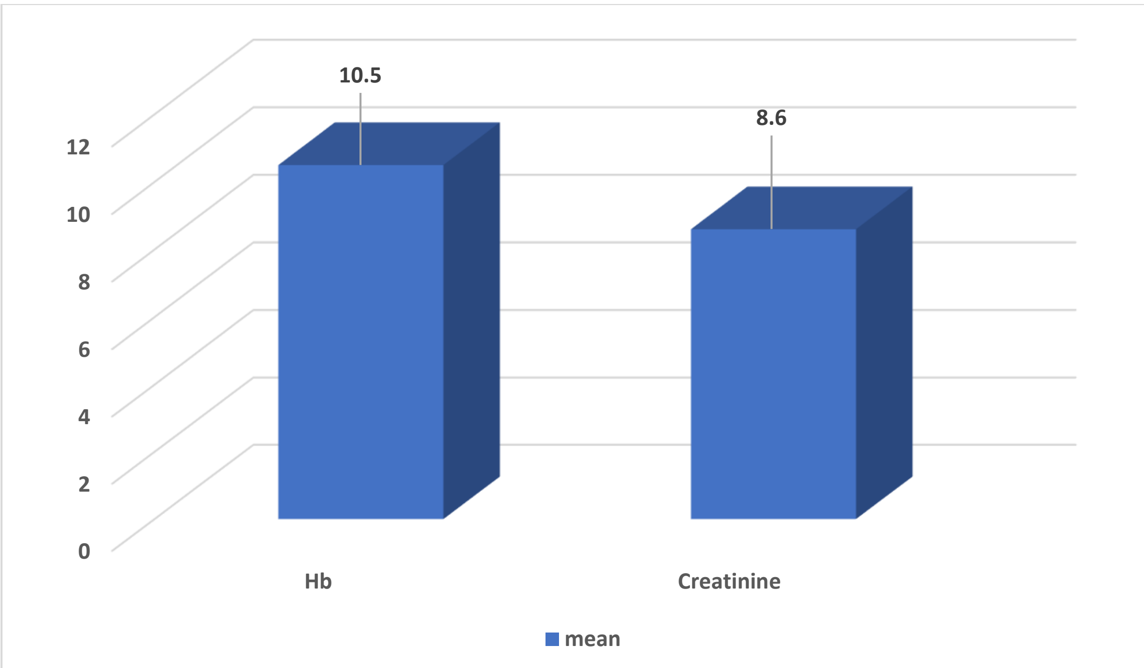


Table 7: Distribution of patients according to vein diameter

vein diameter (mm)	Preoperative	Postoperative day 1	Postoperative day 7	Postoperative 4 weeks
Mean±SD	1.98±0.58	1.98±0.58	7.45±0.68	9.07±0.75

Table 7 and graph 7 presents the progression of vein diameter measurements, starting at a preoperative mean of 1.98 mm (SD ±0.58), remaining unchanged on postoperative day 1, then increasing significantly to 7.45 mm (SD ±0.68) by day 7, and further increasing to 9.07 mm (SD ±0.75) by 4 weeks post-operation.

Graph 7: Distribution of patients according to vein diameter

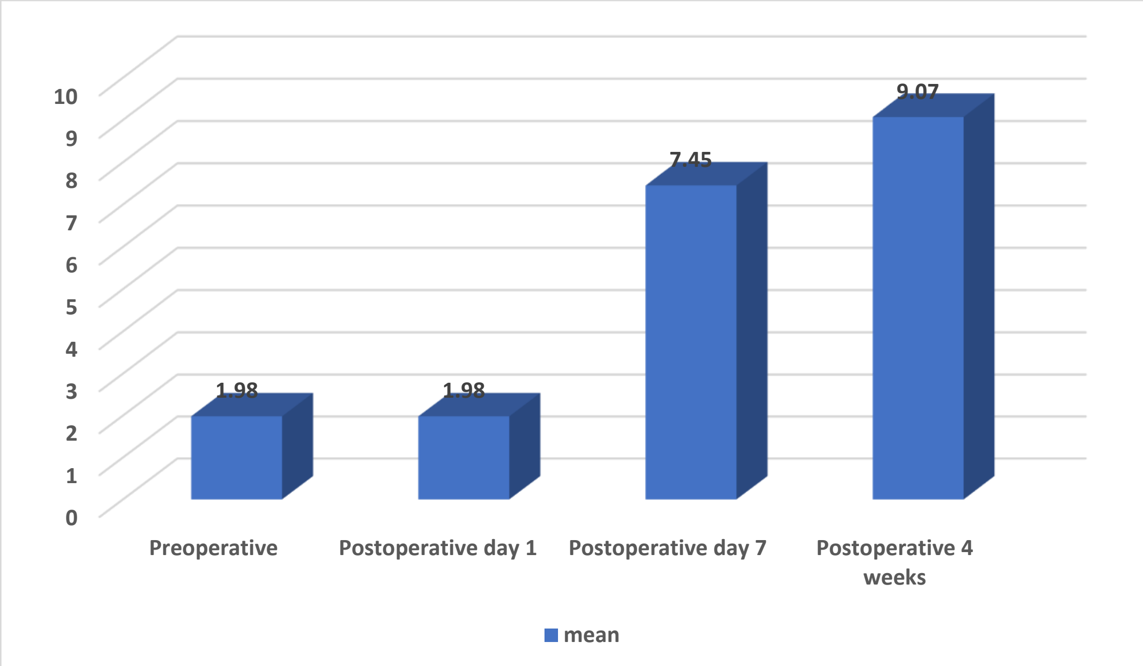


Table 8: Distribution of patients according to preoperative radial artery diameter and flow volume

Variables	radial artery diameter (mm)	Arterial flow volume (ml/min)
Mean±SD	1.98±0.63	42.2±15.8

Table 8 and graph 8 shows the preoperative measurements of radial artery parameters, with a mean diameter of 1.98 mm (SD ±0.63) and a mean arterial flow volume of 42.2 ml/min (SD ±15.8).

Graph 8: Distribution of patients according to preoperative radial artery diameter and flow volume

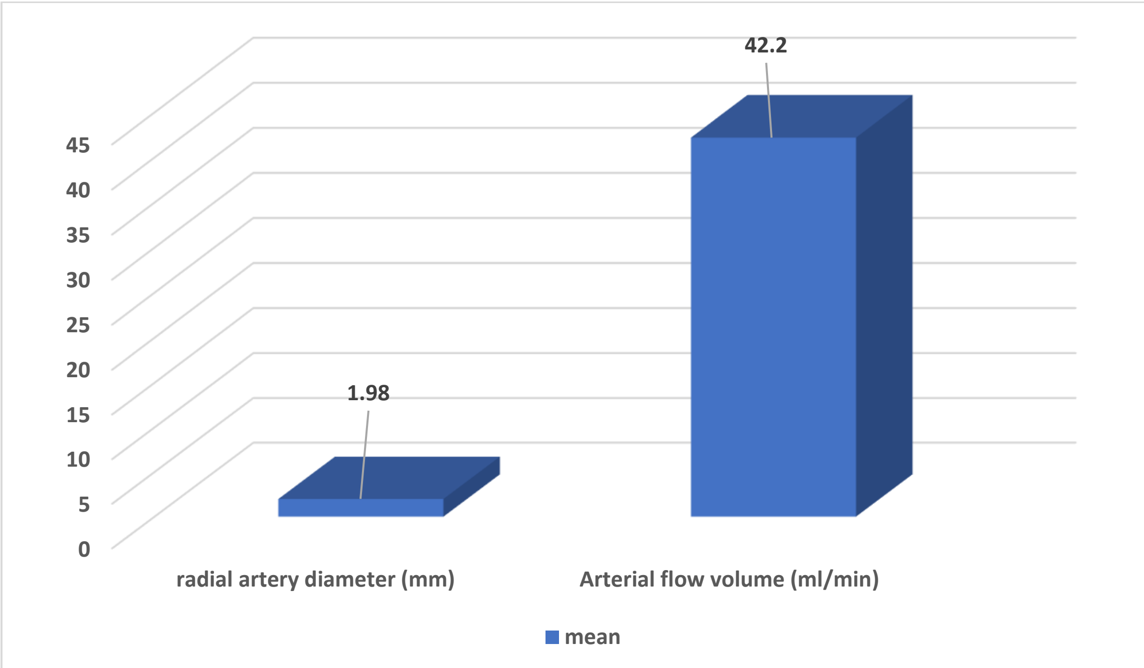


Table 9: Distribution of patients according to pre operative arterial flow volume

Pre operative arterial flow volume	Frequency	Percentage
Normal flow	35	32.1%
Intermediate flow	64	58.7%
High failure risk	10	9.2%

Table 9 and graph 9 categorizes patients based on preoperative arterial flow volume, with 58.7% having intermediate flow, 32.1% having normal flow, and 9.2% presenting with high failure risk flow patterns.

Graph 9: Distribution of patients according to pre operative arterial flow volume

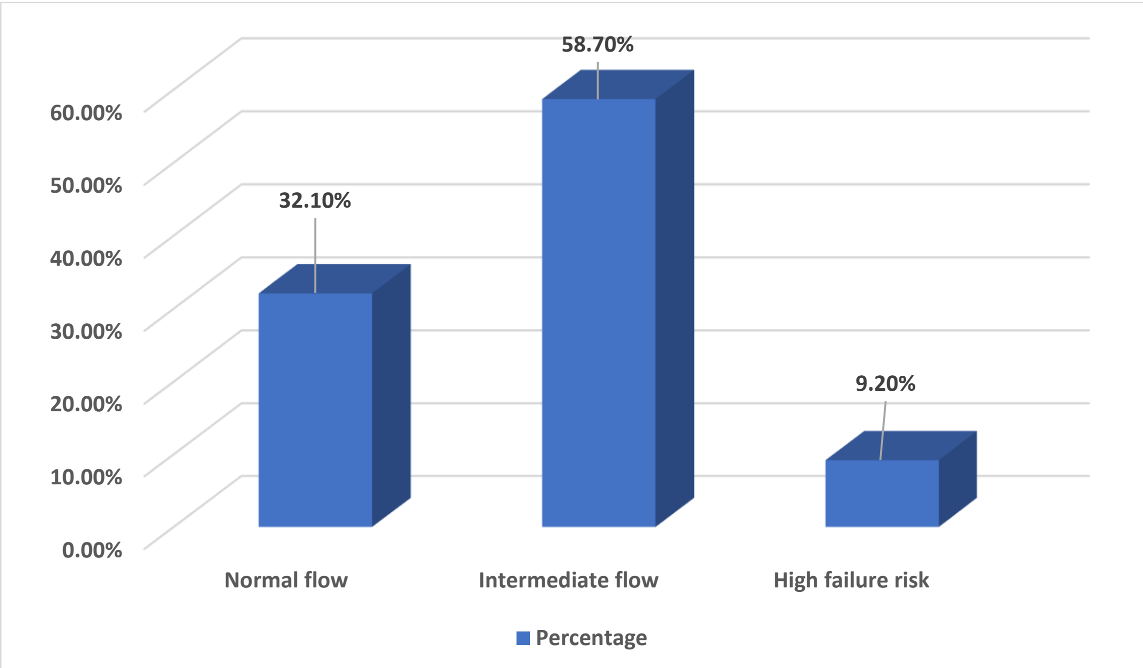


Table 10: Distribution of patients according to post operative fistula flow rate

fistula flow rate (ml/min)	Day 1	Day 7	4 weeks
Mean±SD	261.1±106.3	391.06±124.3	689.7±138.09

Table 10 and graph 10 demonstrates the progression of fistula flow rates over time, starting at a mean of 261.1 ml/min (SD ±106.3) on day 1, increasing to 391.06 ml/min (SD ±124.3) by day 7, and reaching 689.7 ml/min (SD ±138.09) by 4 weeks post-operation.

Graph 10: Distribution of patients according to post operative fistula flow rate

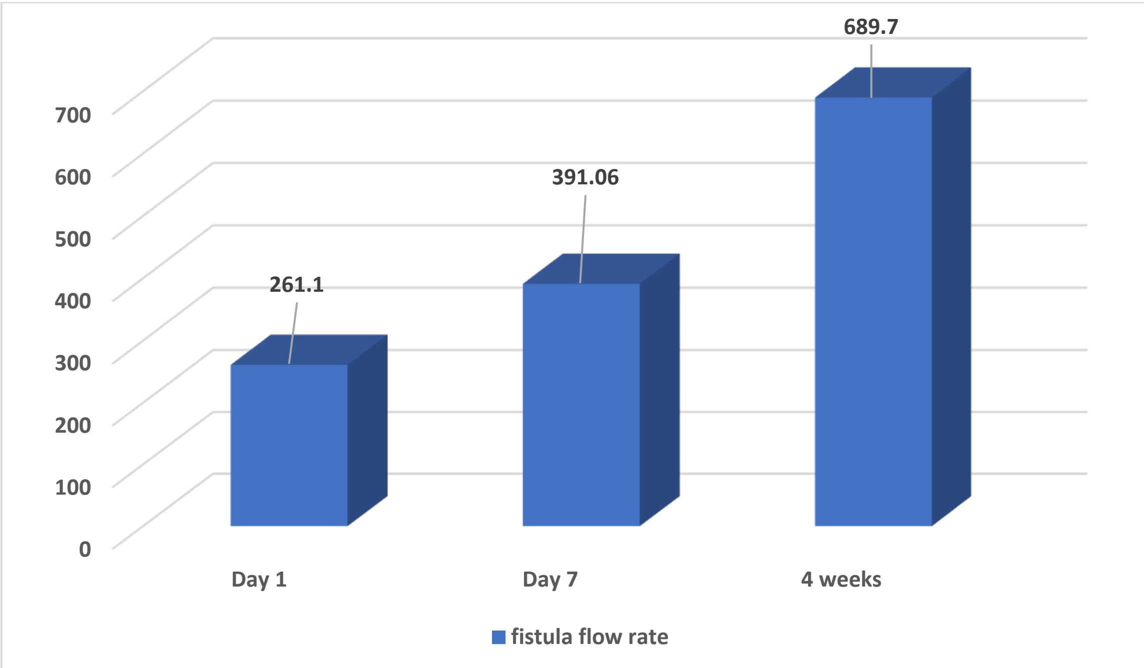


Table 11: Distribution of patients according to maturation status

Maturation status	Day 1	Day 7	4 weeks
Adequate	0	0	56 (51.4%)
Inadequate	109(100%)	109 (100%)	53 (48.6%)

Table 11 and graph 11 tracks the maturation status of the arteriovenous fistulas, showing that adequate maturation achieved in 51.4% by 4 weeks.

Graph 11: Distribution of patients according to maturation status

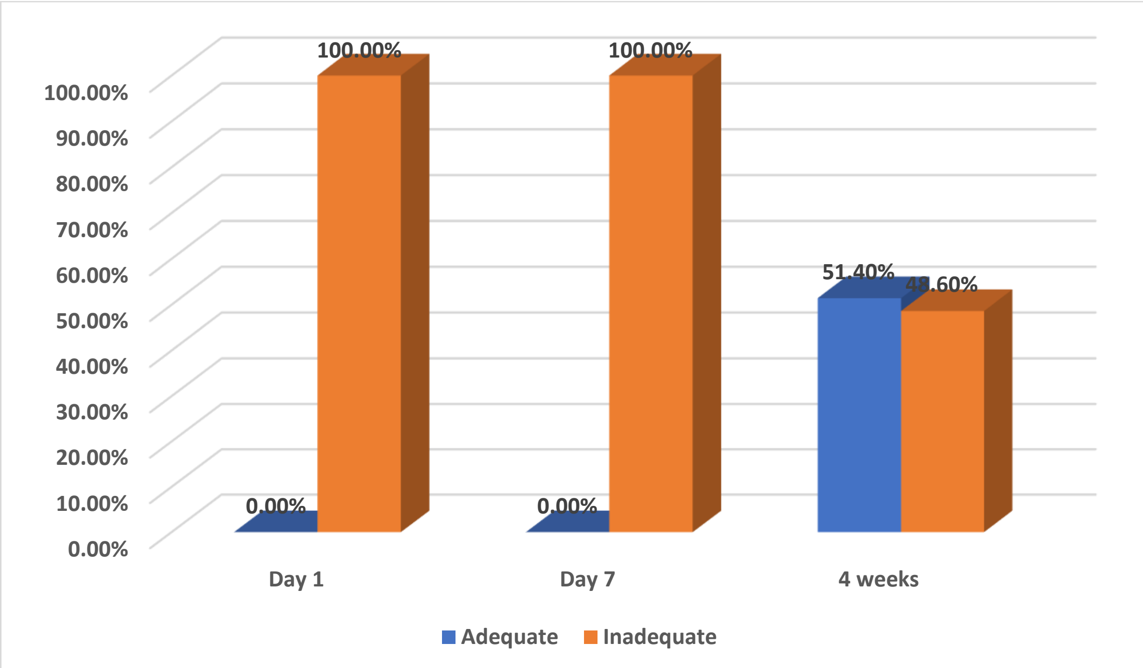


Table 12: Distribution of patients according to complications

Complications	Frequency	Percentage
Thrombosis	10	9.17%
Stenosis	2	1.83%
Infection	6	5.5%
Steal syndrome	0	0

Table 12 and graph 12 outlines the complications observed in the study, with thrombosis occurring in 9.17% of patients, infection in 5.5%, stenosis in 1.83%, and no cases of steal syndrome reported.

Graph 12: Distribution of patients according to complications

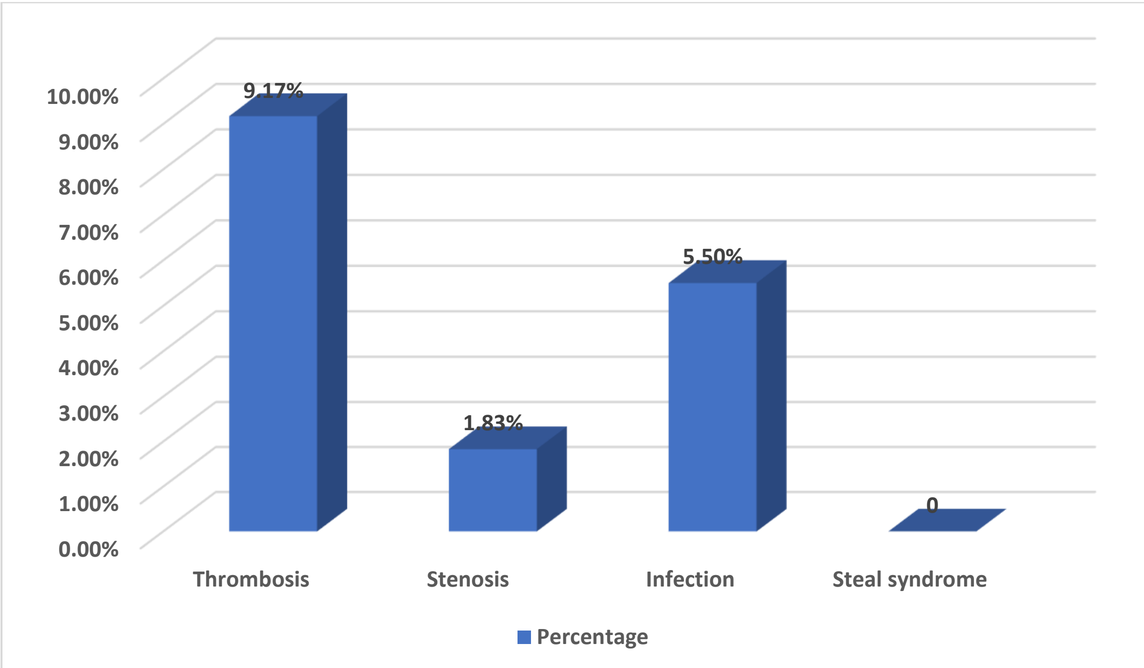


Table 13: Distribution of patients according to outcomes

Outcome	Time to maturation (days)	1st successful cannulation (days)
Mean±SD	38.03±6.8	50.4±8.1

Table 13 and graph 13 presents key outcome metrics, showing a mean time to maturation of 38.03 days (SD ±6.8) and a mean time to first successful cannulation of 50.4 days (SD ±8.1).

Graph 13: Distribution of patients according to outcomes

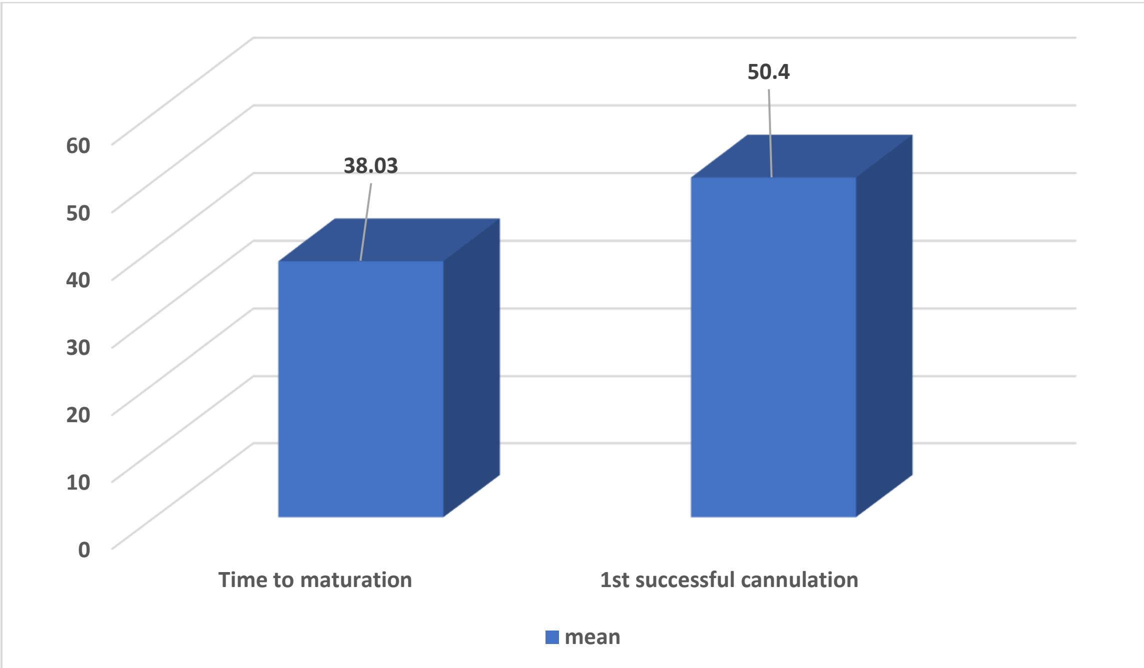


Table 14: Distribution of patients according to Primary failure

Primary failure	Frequency	Percentage
Yes	27	24.8%
No	82	75.2%
Total	**109**	**100%**

Table 14 and graph 14 indicates the primary failure rate of arteriovenous fistulas, with 24.8% of patients experiencing primary failure while 75.2% had successful outcomes.

Graph 14: Distribution of patients according to Primary failure

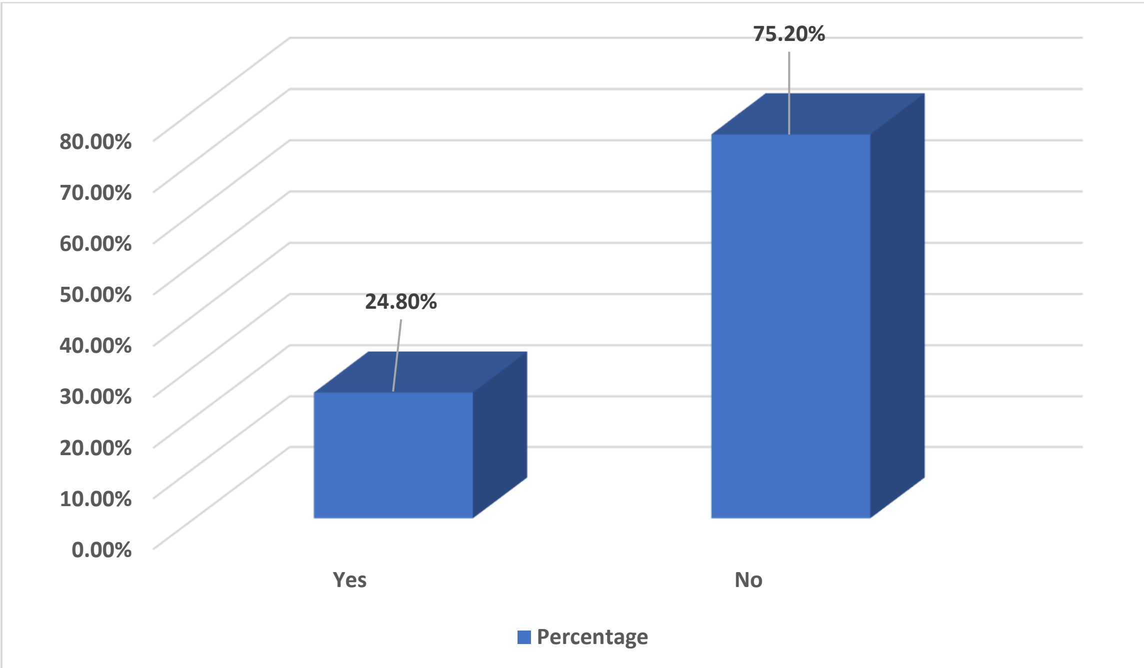


Table 15: Association of primary failure of AVF with age

Age (in years)	Primary failure		p-value
	No	Yes	
20-40	10 (12.2%)	0	0.16
41-60	45 (54.9%)	17 (62.9%)	
>60	27 (32.9%)	10 (37.1%)	
Total	**82 (100%)**	**27 (100%)**	

Table 15 and graph 15 examines the association between age and primary failure, showing that primary failure occurred in 37.1% of patients over 60 years and 62.9% of patients aged 41-60 years, with no primary failures in the 20-40 years group, though this association was not statistically significant (p=0.16).

Graph 15: Association of primary failure of AVF with age

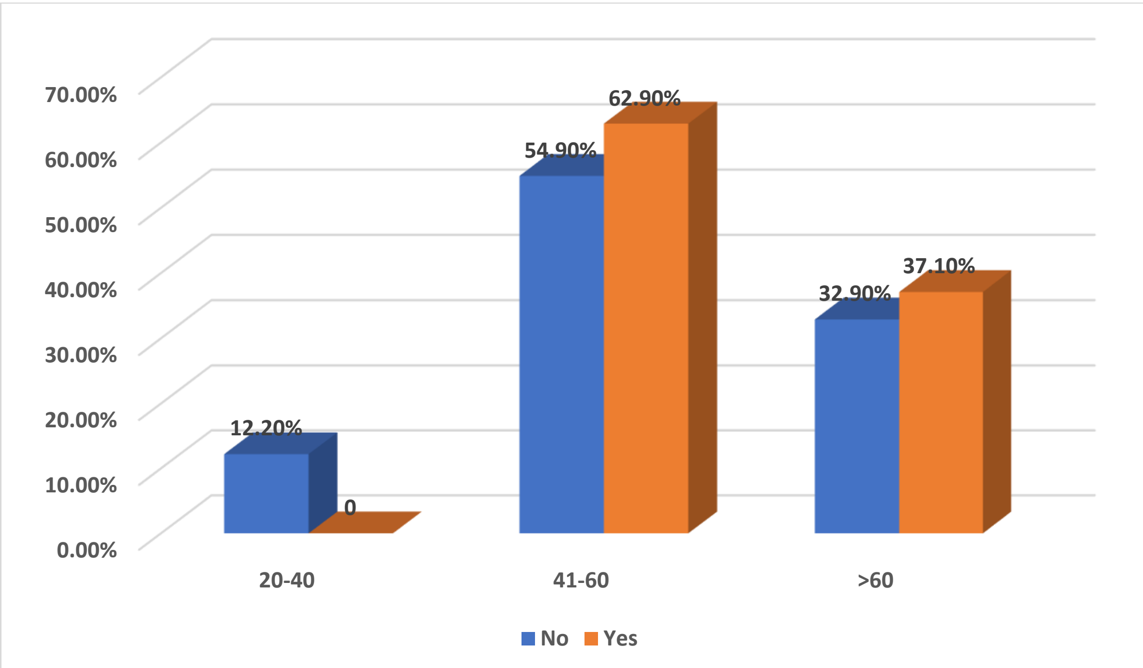


Table 16: Association of primary failure of AVF with co-morbidities

Co-morbidities	Primary failure		p-value
	No	Yes	
Diabetes	40 (48.8%)	19 (70.4%)	**0.05**
Hypertension	36 (43.9%)	21 (77.8%)	**0.002**
DM+Hypertension	7 (8.5%)	20 (74.1%)	**<0.001**

Table 16 and graph 16 reveals significant associations between primary failure and co-morbidities, with primary failure more common in patients with diabetes (p=0.05), hypertension (p=0.002), and most significantly in those with both conditions (p<0.001).

Graph 16: Association of primary failure of AVF with co-morbidities

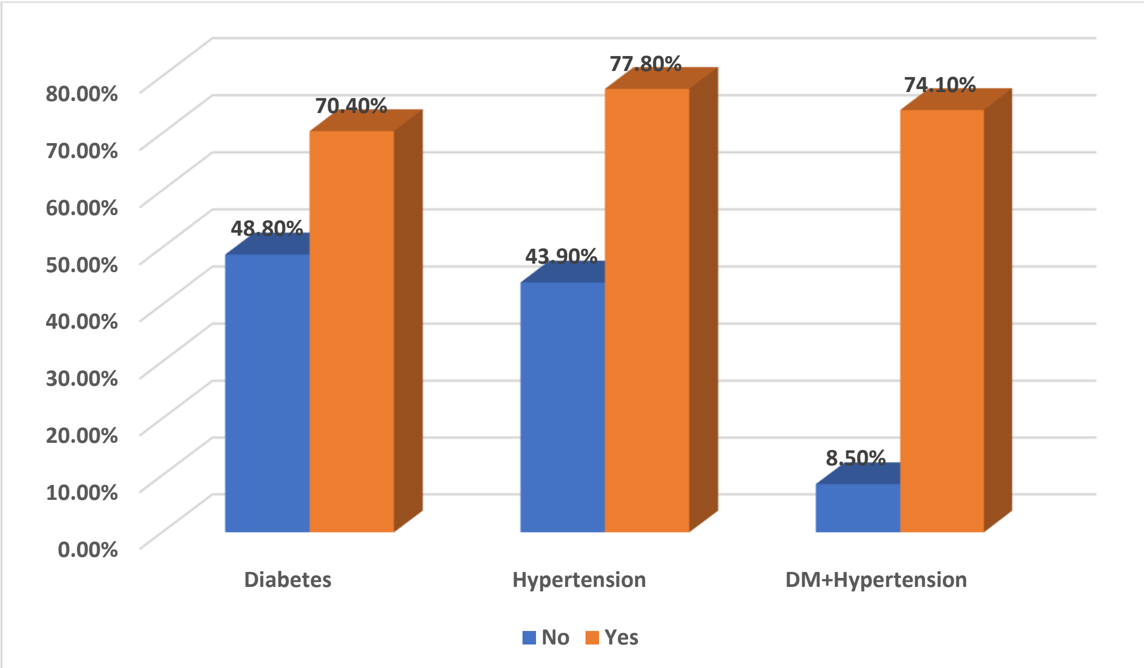


Table 17: Association of primary failure of AVF with cephalic vein diameter

Cephalic vein diameter (mm) (Mean±SD)	Primary failure		p-value
	No	Yes	
Preoperative	2.5±0.29	1.5±0.27	**<0.001**
Post op day 1	2.5±0.29	1.5±0.27	**<0.001**
Post op day 7	7.41±0.7	4.48±0.67	**<0.001**
Post op 4 weeks	9±0.72	5.13±0.77	**<0.001**

Table 17 and graph 17 demonstrates that preoperative and day 1 postoperative cephalic vein diameters were significantly smaller in patients who experienced primary failure (1.5 mm vs 2.5 mm, p<0.001) and later measurements at day 7 and 4 weeks also showed significant differences.(P<0.001)

Graph 17: Association of primary failure of AVF with cephalic vein diameter

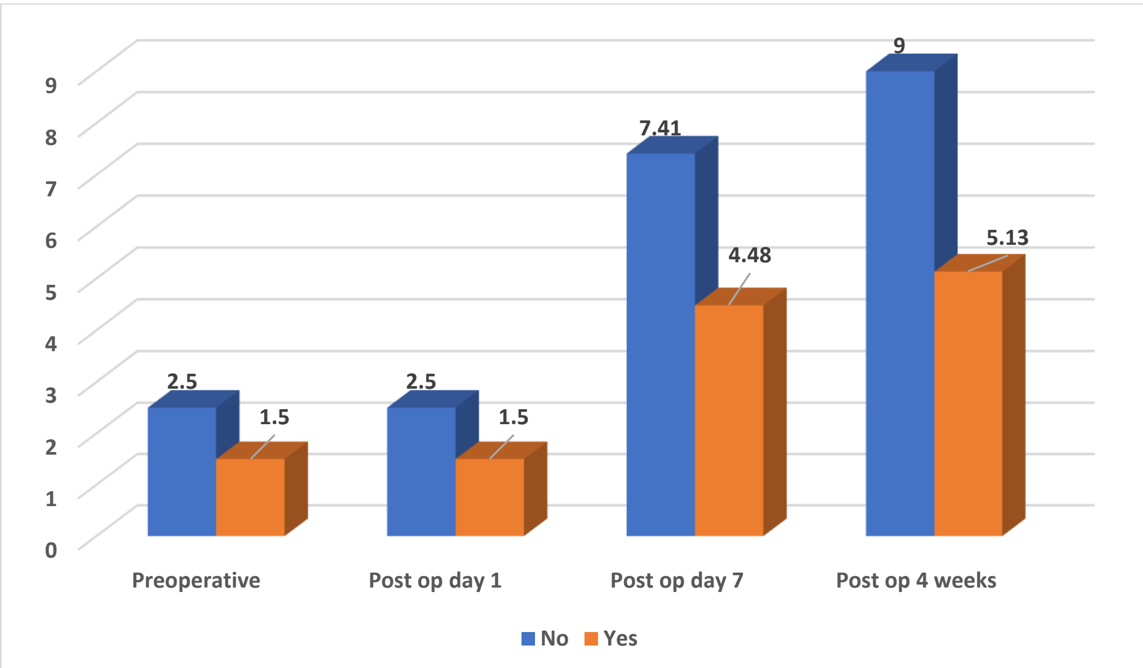


Table 18: Association of primary failure of AVF with preoperative arterial parameters

arterial parameters (Mean±SD)	Primary failure		p-value
	No	Yes	
Radial artery diameter (mm)	2.58±0.27	1.45±0.29	**<0.001**
Arterial flow volume (ml/min)	43.5±16.3	41.05±15.4	0.49

Table 18 and graph 18 shows that a smaller preoperative radial artery diameter was significantly associated with primary failure (1.45 mm vs 2.58 mm, $p<0.001$), while arterial flow volume showed no significant association.

Graph 18: Association of primary failure of AVF with preoperative arterial parameters

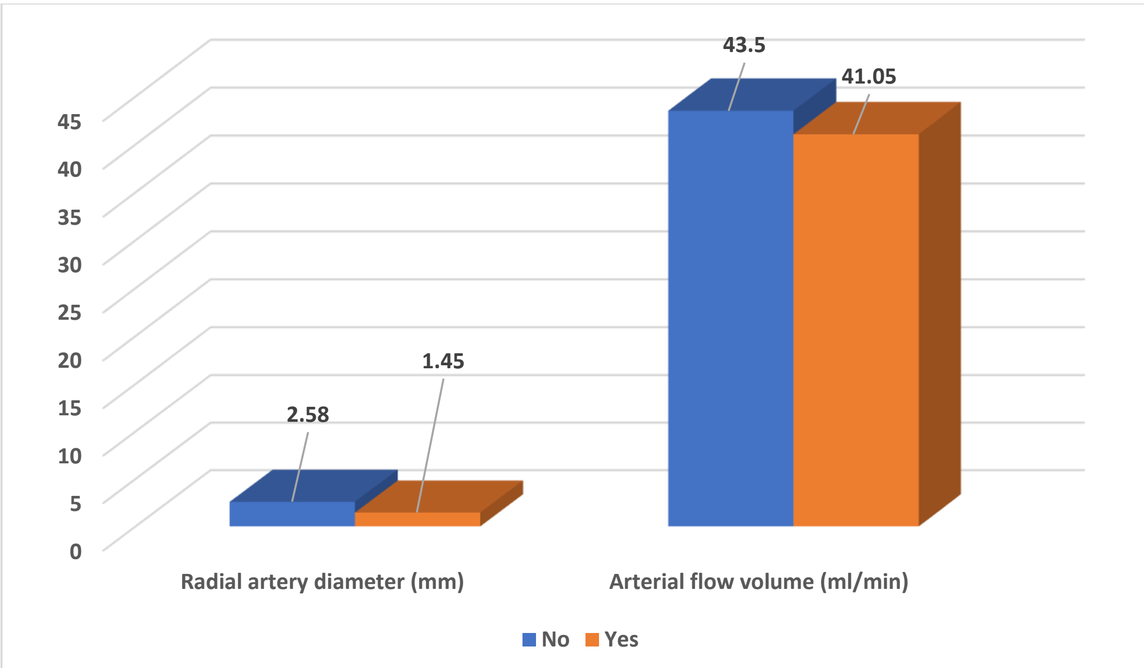


Table 19: Association of primary failure of AVF with fistula flow rate

fistula flow rate (ml/min) (Mean±SD)	Primary failure		p-value
	No	Yes	
Day 1	228.8±115.6	200±121.8	0.27
Day 7	389.3±129.2	350±121.02	0.167
At 4 weeks	774.06±100.1	615.6±124.04	**<0.001**

Table 19 and graph 19 indicates that fistula flow rates at day 1 and day 7 were not significantly different between successful and failed cases, but by 4 weeks, patients with primary failure had significantly lower flow rates (615.6 ml/min vs 774.06 ml/min, $p<0.001$).

Graph 19: Association of primary failure of AVF with fistula flow rate

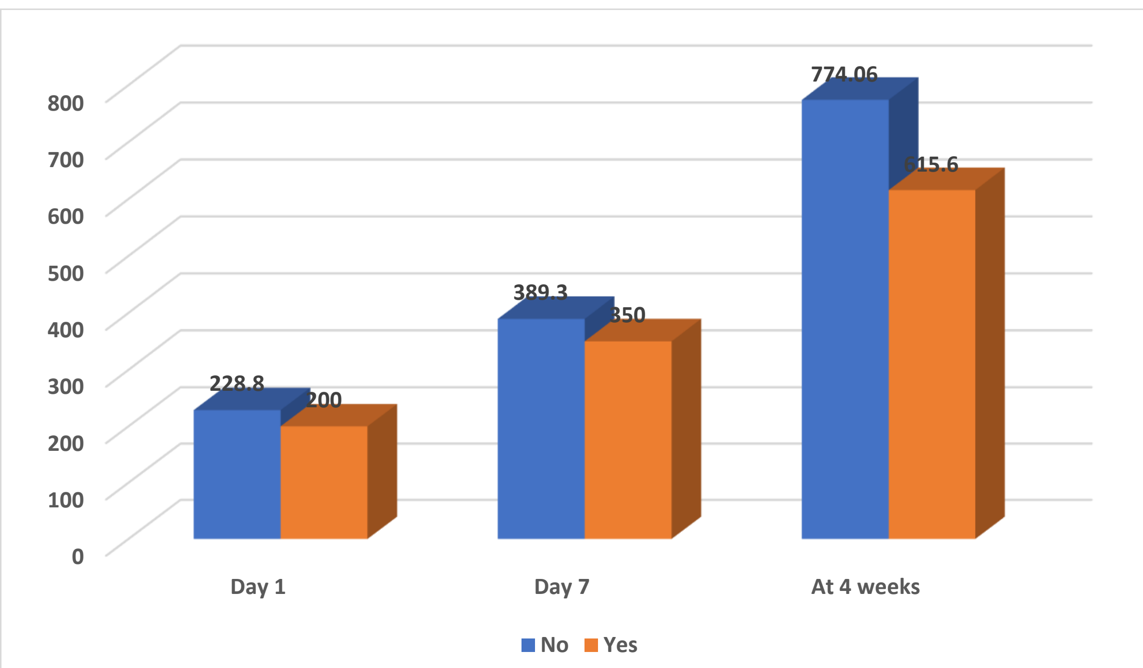


Table 20: Association of primary failure of AVF with outcome

Outcome (days) (Mean±SD)	Primary failure		p-value
	No	Yes	
Time to maturation	32.6±6.4	42.7±1.4	**<0.001**
1st successful cannulation	43.4±6.6	56.5±2.5	**<0.001**

Table 20 and graph 20 demonstrates that primary failure was associated with significantly longer time to maturation (42.7 vs 32.6 days, $p<0.001$) and longer time to first successful cannulation (56.5 vs 43.4 days, $p<0.001$)

Graph 20: Association of primary failure of AVF with outcome

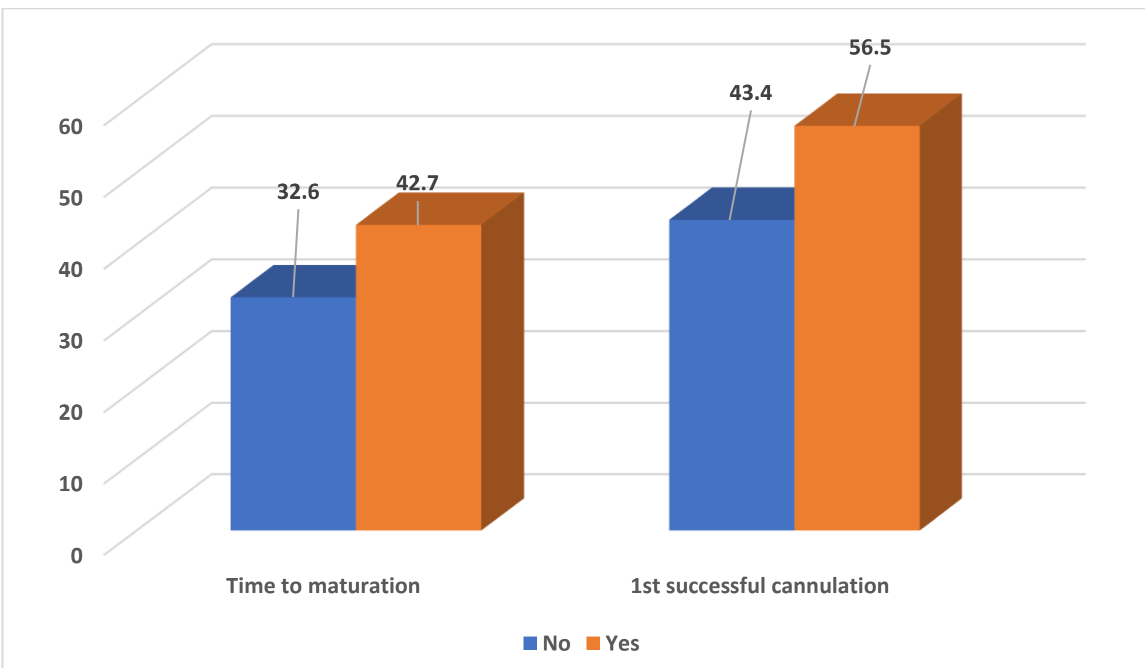
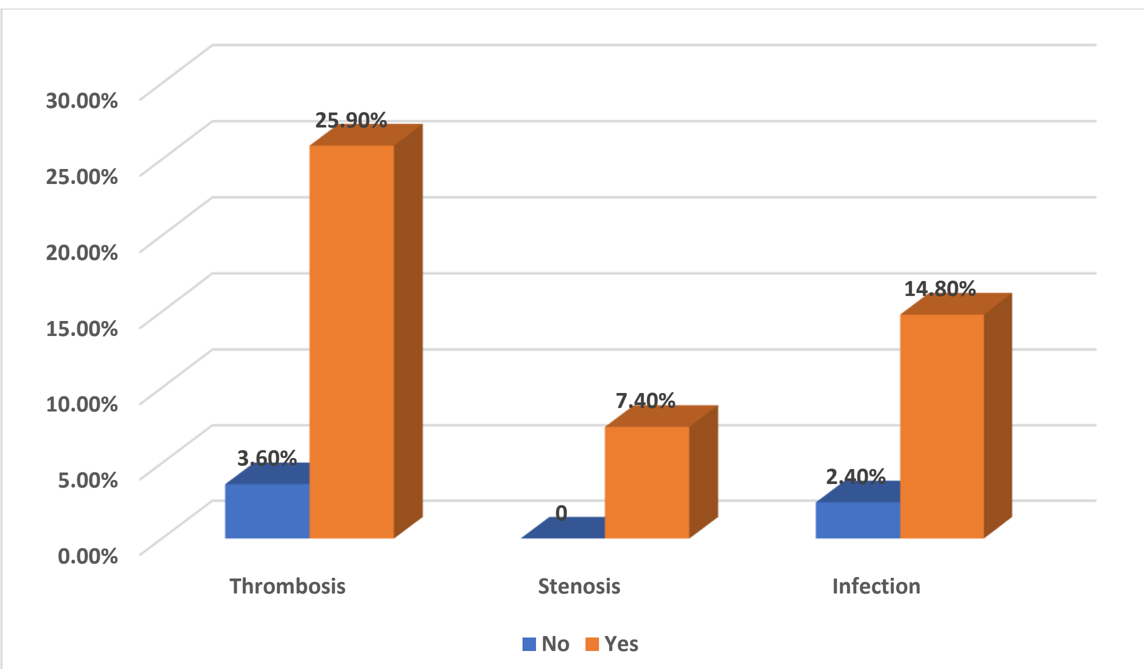


Table 21: Association of primary failure of AVF with complications

Complications	Primary failure		p-value
	No	Yes	
Thrombosis	3 (3.6%)	7 (25.9%)	**<0.001**
Stenosis	0	2 (7.4%)	**0.01**
Infection	2 (2.4%)	4 (14.8%)	**0.01**

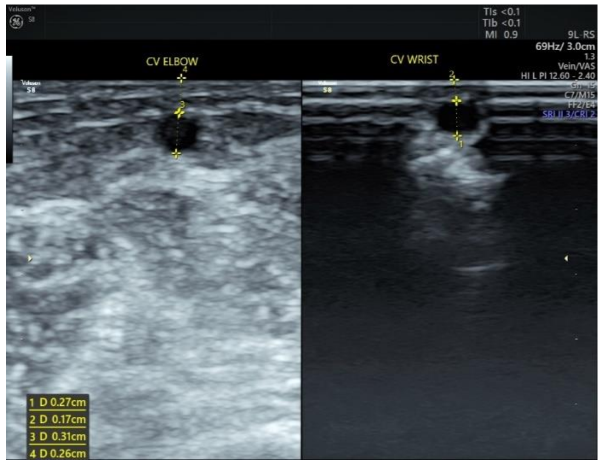
Table 21 and graph 21 shows that complications were significantly more frequent in patients with primary failure, including thrombosis (25.9% vs 3.6%, p<0.001), stenosis (7.4% vs 0%, p=0.01), and infection (14.8% vs 2.4%, p=0.01).

Graph 21: Association of primary failure of AVF with complications



OBSERVATIONS DURING STUDY:-

Normal findings:



A)Showing diameter of cephalic vein at elbow with anechoic lumen and distance from skin. B) showing diameter of cephalic vein at wrist with anechoic lumen and distance from skin.

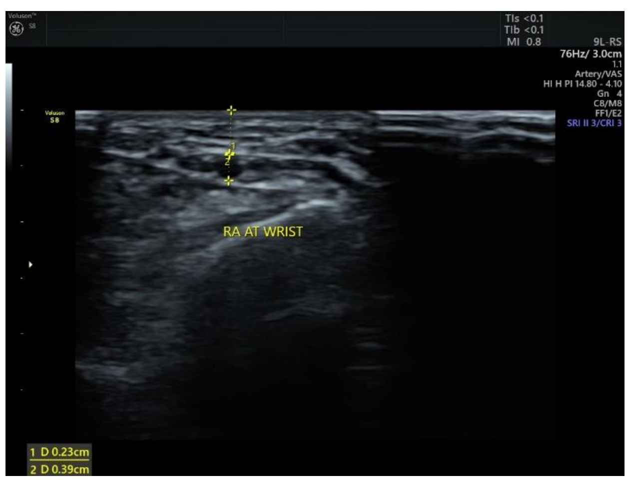


Fig: Showing diameter of radial artery at wrist with anechoic lumen and distance from skin.

Fig: Normal flow in radial artery.

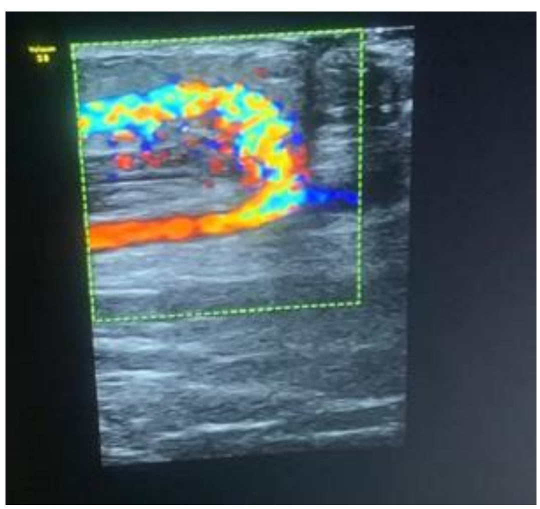


Fig: Normal flow in arterio-venous fistula (saggital view)

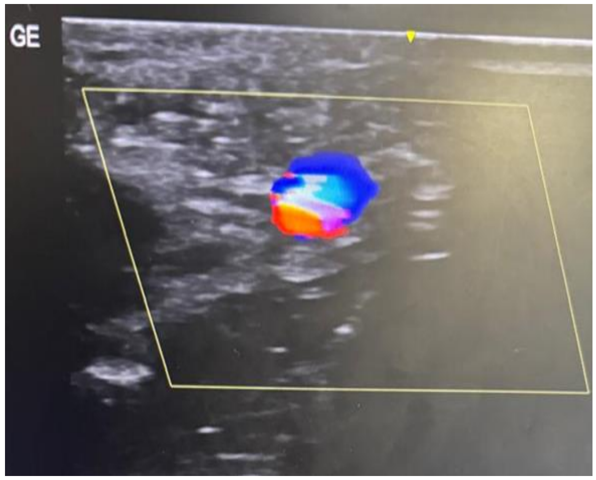


Fig: Normal flow in arterio-venous fistula (axial view)

Abnormal findings:

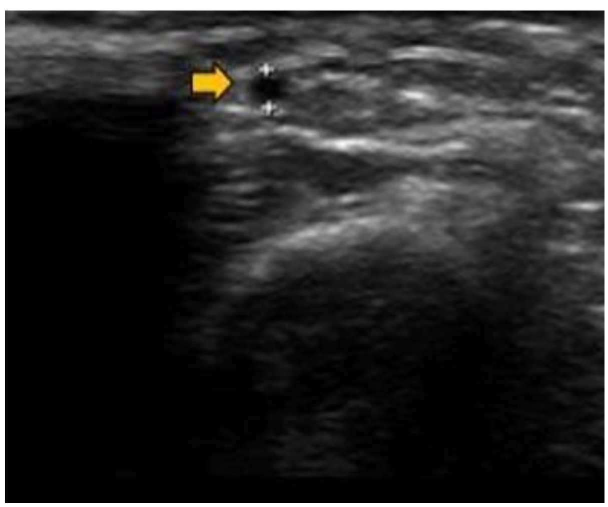


Fig : Narrowed calibre of cephalic vein at wrist (1.5 mm)

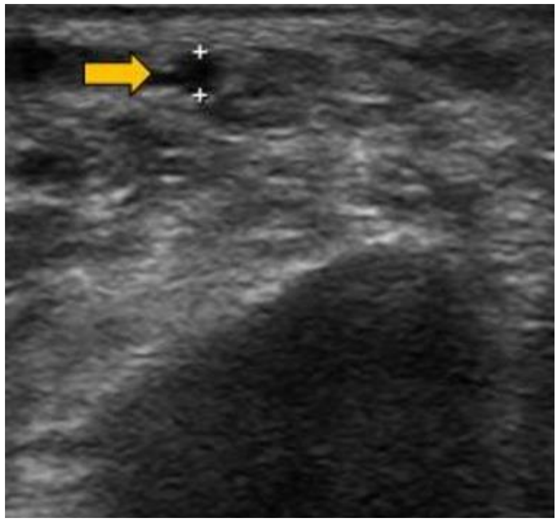


Fig : showing narrowed calibre of Radial artery. (1.6mm)

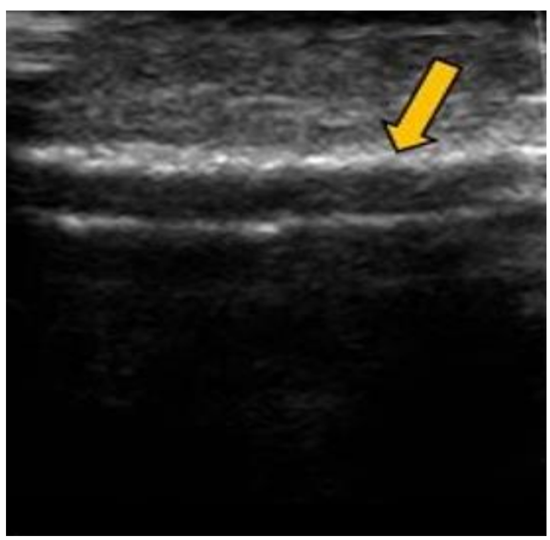


Fig : longitudinal sections showing atheromatous changes in the form of wall calcifications in Radial artery.

DISCUSSION

“Chronic kidney disease (CKD) represents a significant global health burden, with the number of patients requiring renal replacement therapy increasing exponentially. Hemodialysis remains the cornerstone of renal replacement therapy for patients with end-stage renal disease (ESRD). The success of hemodialysis depends critically on establishing and maintaining a functional vascular access, with arteriovenous fistula (AVF) being the preferred access method due to its superior patency rates, fewer complications, and lower mortality compared to central venous catheters or arteriovenous grafts. However, despite being the gold standard, AVFs are associated with significant primary failure rates and maturation issues. Doppler ultrasound has emerged as an essential non-invasive tool for the preoperative evaluation, postoperative monitoring, and surveillance of AVF. This study was undertaken to evaluate the role of Doppler ultrasound in assessing AVF maturation and predicting complications in hemodialysis patients.”

Demographic and Clinical Characteristics

Our study included 109 patients who underwent AVF creation for hemodialysis access. The demographic profile revealed a predominance of males (57.8%) over females (42.2%), which is consistent with the findings of Siddiqui et al., who reported a male predominance of 63% in their cohort of ESRD patients requiring hemodialysis.[75] The age distribution in our study showed that the majority of patients (56.9%) were between 41-60 years, followed by those above 60 years (33.9%), with a minimal representation of younger patients (9.17%) in the 20-40 year age group. This age distribution aligns with the epidemiology of CKD, which predominantly affects middle-aged and elderly populations due to the cumulative effect of risk factors over time. Siddiqui et al. reported a mean age of 57 years in their study population, which is comparable to our findings.[75]

The comorbidity profile of our study population revealed that diabetes mellitus (54.1%)

and hypertension (52.3%) were the most prevalent conditions, with 24.8% of patients having both comorbidities. These findings are consistent with global trends where diabetes and hypertension remain the leading causes of ESRD. Mendes et al. reported similar comorbidity profiles in their study, with diabetes present in 45.8% and hypertension in 62.5% of patients.[76] These comorbidities are significant as they not only contribute to the progression of CKD but also impact the vascular health and subsequently influence AVF outcomes.

The mean hemoglobin level in our study population was 10.5±1.2 g/dL, indicating anemia, which is a common finding in ESRD patients due to reduced erythropoietin production. The mean serum creatinine level was 8.6±2.03 mg/dL, reflecting advanced renal impairment. These biochemical parameters are important as they can influence AVF maturation and function. Anemia can affect flow dynamics within the AVF, while uremia-associated platelet dysfunction can influence thrombotic complications.

Vascular Parameters and Maturation

The preoperative mean cephalic vein diameter in our study was 1.98±0.58 mm, which increased to 7.45±0.68 mm by day 7 post-operation and further to 9.07±0.75 mm at 4 weeks. This progressive increase in vein diameter is a key indicator of AVF maturation. Robbin et al. reported that a vein diameter of ≥4 mm is associated with successful cannulation and AVF maturation.[77] Our findings demonstrate that substantial vein dilatation occurs within the first week post-creation, with continued expansion over the subsequent weeks. This temporal pattern of vein dilatation is crucial for understanding the maturation process and for determining the optimal timing for initial cannulation.

Preoperative radial artery diameter was 1.98±0.63 mm with a flow volume of 42.2±15.8 ml/min. When stratified according to risk of failure, 32.1% of patients had normal flow, 58.7% had intermediate flow, and 9.2% had high-risk flow characteristics. These preoperative parameters are critical determinants of AVF success. Jemcov et al. demonstrated that a preoperative radial artery diameter of <1.5 mm was associated with a higher risk of AVF failure.[78] Similarly, Bashar et al. reported that an arterial flow volume of <40 ml/min was predictive of poor maturation outcomes.[79] Our findings reinforce the importance of preoperative vascular assessment in predicting AVF outcomes.

Post-operative fistula flow rates showed a progressive increase from 261.1±106.3 ml/min on day 1 to 391.06±124.3 ml/min on day 7, and further to 689.7±138.09 ml/min at 4 weeks. This pattern of increasing flow is indicative of successful AVF maturation. According to the National Kidney Foundation's Kidney Disease Outcomes Quality Initiative (KDOQI) guidelines, a flow rate of >600 ml/min is considered adequate for hemodialysis.[80] Our study demonstrates that by 4 weeks, the mean flow rate exceeded this threshold, suggesting successful maturation in the majority of cases. However, individual variations in flow rates were observed, highlighting the need for personalized monitoring and management.

Maturation Status and Outcomes

At 4 weeks post-creation, 51.4% of AVFs in our study had achieved adequate maturation, while 48.6% remained inadequate. This maturation rate is comparable to that reported by Robbin et al., who found a maturation rate of 60% at 3 months.[77] The mean time to maturation in our cohort was 38.03±6.8 days, with the first successful cannulation occurring at a mean of 50.4±8.1 days post-creation. Lok et al. reported a median time to maturation of 46 days in their prospective study, which is slightly longer than our findings.[81] The difference could be attributed to variations in the definition of maturation and the criteria used for initiating cannulation.

Primary failure, defined as failure of the AVF to mature adequately for hemodialysis use, occurred in 24.8% of cases in our study. This failure rate is consistent with literature reports, which suggest primary failure rates ranging from 20% to 50%.[82] Understanding the factors associated with primary failure is crucial for improving AVF outcomes.

Factors Associated with Primary Failure

Our analysis revealed several factors significantly associated with primary failure of AVF. Comorbidities, particularly diabetes mellitus (p=0.05), hypertension (p=0.002), and the combination of both (p<0.001), were strongly associated with primary failure. This finding is consistent with the study by Bashar et al., who reported that diabetes and hypertension negatively impact AVF maturation by contributing to vascular calcification, endothelial dysfunction, and reduced vascular compliance.[79]

Preoperative vein diameter was significantly lower in patients who experienced primary failure (1.5±0.27 mm) compared to those with successful AVFs (2.5±0.29 mm), with a p-value of <0.001. Similarly, preoperative radial artery diameter was smaller in the primary failure group (1.45±0.29 mm vs. 2.58±0.27 mm, p<0.001). These findings underscore the critical importance of vascular dimensions in predicting AVF outcomes. Monroy-Cuadros et al. demonstrated that a vein diameter of <2 mm and an artery diameter of <1.6 mm were independent predictors of AVF failure.[83] Our results are in agreement with these findings and emphasize the value of preoperative Doppler ultrasound in identifying patients at risk of primary failure.

Interestingly, while the fistula flow rates on day 1 and day 7 did not differ significantly between the successful and failed AVF groups, a marked difference was observed at 4 weeks (774.06±100.1 ml/min vs. 615.6±124.04 ml/min, p<0.001). This suggests that early flow rates may not be predictive of ultimate AVF success, but the flow rate at 4 weeks is a reliable indicator of maturation status. Itoga et al. reported similar findings, noting that flow rates measured at 4-6 weeks post-creation were strongly predictive of long-term AVF patency.[84]

The time to maturation was significantly prolonged in the primary failure group (42.7±1.4 days vs. 32.6±6.4 days, p<0.001), as was the time to first successful cannulation (56.5±2.5 days vs.

43.4±6.6 days, p<0.001). This temporal difference in maturation trajectories between successful and failed AVFs highlights the importance of early identification of at-risk AVFs for timely intervention.

Complications

The most common complications observed in our study were thrombosis (9.17%), infection (5.5%), and stenosis (1.83%). “No cases of steal syndrome were reported. Thrombosis was significantly more prevalent in the primary failure group (25.9% vs. 3.6%, p<0.001), as were stenosis (7.4% vs. 0%, p=0.01) and infection (14.8% vs. 2.4%, p=0.01). These findings align with those of Lee et al.,” who identified thrombosis as the leading cause of AVF failure in their study.[85]

The association between complications and primary failure underscores the need for proactive surveillance to detect and address these issues early. Doppler ultrasound is particularly valuable in this context, as it can detect stenosis and thrombosis before clinical symptoms appear. Aragoncillo et al. demonstrated that ultrasound-based surveillance led to a 62% reduction in thrombotic events compared to clinical monitoring alone.[86]

Role of Doppler Ultrasound in AVF Assessment

Our study validates the utility of Doppler ultrasound as a comprehensive tool for AVF assessment. Preoperatively, it aids in the selection of suitable vessels by providing accurate measurements of vein and artery diameters and flow characteristics. Postoperatively, it enables the monitoring of maturation progress and early detection of complications.

The ability of Doppler ultrasound to predict primary failure based on preoperative vascular parameters is particularly valuable. Our findings demonstrate that patients with smaller vein and artery diameters are at higher risk of primary failure, allowing for more informed decision-making regarding the type and location of vascular access. Ferring et al. reported that preoperative ultrasound mapping increased the proportion of patients receiving an AVF (vs. graft or catheter) and improved primary patency rates.[87]

Furthermore, the longitudinal assessment of flow parameters provides insights into the maturation process and helps identify AVFs at risk of failure. The significant difference in flow rates at 4 weeks between successful and failed AVFs in our study suggests that this time point is critical for evaluating maturation status and predicting long-term outcomes.

Comparison with Previous Studies

Our findings on the predictive value of preoperative vascular dimensions align with those of Lauvao et al., who reported that a vein diameter of ≥2.5 mm and an artery diameter of ≥2 mm were associated with successful AVF maturation.[88] Similarly, Wong et al. found that a vein diameter of <1.6 mm increased the risk of primary failure by threefold[89]

Regarding flow parameters, our observation that flow rates at 4 weeks are predictive of AVF outcomes is consistent with the findings of Robbin et al., who reported that a flow rate of >500 ml/min at 4 weeks was associated with successful AVF maturation.[90] However, unlike some studies that suggest early flow rates (day 1 or day 7) are predictive of outcomes, we found no significant difference in these early measurements between successful and failed AVFs. This discrepancy might be due to variations in measurement techniques or patient characteristics.

The overall maturation rate of 51.4% at 4 weeks in our study is lower than the 60-70% reported in some studies.[91] This difference could be attributed to the higher prevalence of diabetes and hypertension in our cohort, which are known risk factors for poor maturation. Additionally, our stringent criteria for defining adequate maturation might have contributed to the lower rate.

The complications profile in our study is comparable to that reported by Al-Jaishi et al., who found thrombosis rates of 12.3% and infection rates of 4.5% in their systematic review of AVF outcomes.[92] The higher prevalence of complications in the primary failure group in our study emphasizes the interrelationship between complications and maturation failure.

Clinical Implications

The findings of our study have several important clinical implications for the management of patients requiring hemodialysis access:

1. **Preoperative Vascular Assessment**: The strong association between preoperative vascular dimensions and AVF outcomes underscores the importance of routine Doppler ultrasound evaluation before AVF creation. This assessment can guide the selection of optimal vessels and predict the likelihood of successful maturation.
2. **Risk Stratification**: Patients with diabetes, hypertension, and smaller vessel diameters can be identified as high-risk for primary failure. These patients might benefit from alternative vascular access strategies or more intensive monitoring.
3. **Surveillance Protocol**: The progressive increase in vein diameter and flow rate over time suggests that a structured surveillance protocol, with assessments at predefined intervals (e.g., day 1, day 7, and 4 weeks), can provide valuable insights into the maturation process. The significant difference in flow rates at 4 weeks between successful and failed AVFs highlights the importance of this time point for prognostic assessment.
4. **Early Intervention**: The early identification of AVFs at risk of failure allows for timely intervention. Techniques such as balloon angioplasty for stenosis or surgical revision for suboptimal flow can potentially salvage failing AVFs if implemented early. Ravani et al. demonstrated that early intervention based on ultrasound findings reduced the need for central venous catheters and improved overall patency rates.[93]
5. **Patient Education**: The predictable timeline of maturation observed in our study can inform patient education regarding the expected course after AVF creation and the importance of protecting the access site.

Limitations and Future Directions

Our study has several limitations that warrant consideration. First, it was conducted at a single center, which might limit the generalizability of the findings. Second, the follow-up period was limited to 4 weeks, precluding the assessment of long-term outcomes. Third, the definition of adequate maturation was based on standardized criteria, which might not account for individual variations in vascular anatomy and physiology.

Future research should focus on several areas to address these limitations and advance our understanding of AVF dynamics:

1. **Long-term Follow-up**: Extended follow-up studies are needed to correlate early Doppler findings with long-term AVF patency and functionality.
2. **Interventional Studies**: Prospective trials evaluating the impact of early interventions based on Doppler findings on AVF outcomes would provide valuable evidence for clinical practice.
3. **Biomarkers**: The integration of biochemical markers with ultrasound parameters might enhance the predictive accuracy for AVF outcomes. Markers of endothelial function, inflammation, and vascular calcification could provide additional insights into the maturation process.
4. **Novel Ultrasound Techniques**: Advanced ultrasound modalities, such as contrast-enhanced ultrasound or elastography, might offer more detailed assessment of vascular health and function.
5. **Predictive Models**: The development of predictive models incorporating clinical, biochemical, and ultrasound parameters could facilitate personalized risk assessment and management strategies.

Conclusion

In conclusion, our study reaffirms the pivotal role of Doppler ultrasound in the comprehensive assessment of arteriovenous fistulas for hemodialysis. The preoperative evaluation of vascular dimensions and flow characteristics provides valuable prognostic information, while the postoperative monitoring enables the tracking of maturation progress and early detection of complications. The significant associations between specific Doppler parameters and AVF outcomes underscore the utility of this non-invasive modality in guiding clinical decision-making. As the global burden of end-stage renal disease continues to rise, optimizing vascular access outcomes becomes increasingly important. Doppler ultrasound represents a valuable tool in this endeavor, offering detailed insights into the complex vascular adaptations that underlie successful AVF maturation. Future research should focus on refining our understanding of these adaptations and developing tailored interventions to improve AVF outcomes, ultimately enhancing the quality of life for patients requiring hemodialysis.

CONCLUSION

This study provides compelling evidence for the critical role of Doppler ultrasound in the evaluation, monitoring, and management of arteriovenous fistulas for hemodialysis access. Our findings demonstrate that preoperative vascular parameters, particularly cephalic vein and radial artery diameters, are significant predictors of AVF maturation and primary failure. Patients with smaller vessel diameters, diabetes mellitus, and hypertension were at substantially higher risk for primary failure, emphasizing the importance of comprehensive preoperative assessment.

The longitudinal evaluation of post-operative flow dynamics revealed a characteristic pattern of increasing vein diameter and flow rates over time, with the 4-week measurements being particularly informative regarding maturation status. The significant difference in flow rates at 4 weeks between successful and failed AVFs underscores the value of this time point for prognostic assessment and clinical decision-making.

The observed primary failure rate of 24.8% aligns with reported literature values and highlights the persistent challenge of achieving reliable vascular access for hemodialysis. Complications, particularly thrombosis, were significantly more common in the primary failure group, emphasizing the interrelationship between complications and maturation failure.

Doppler ultrasound emerges as an indispensable tool throughout the AVF lifecycle—from preoperative mapping to guide site selection, through postoperative monitoring to track maturation, to surveillance for early detection of complications. The non-invasive nature of ultrasound, coupled with its ability to provide detailed anatomical and functional information, makes it an ideal modality for the comprehensive assessment of AVFs.

The insights gained from this study have important clinical implications for vascular access planning and management. Risk stratification based on preoperative ultrasound findings can guide the selection of appropriate access strategies for individual patients. For those identified as high-risk for primary failure, alternative approaches or more intensive monitoring may be warranted. Furthermore, the established timeline of maturation can inform expectations regarding the functional readiness of AVFs for hemodialysis use.

In conclusion, Doppler ultrasound plays a pivotal role in optimizing AVF outcomes for hemodialysis patients. By enabling precise preoperative assessment, tracking maturation progress, and facilitating early detection of complications, ultrasound contributes significantly to the successful establishment and maintenance of vascular access. As the population of patients requiring hemodialysis continues to grow, the integration of ultrasound into standard clinical practice represents a valuable strategy for improving the quality of care and quality of life for this vulnerable patient group.

SUMMARY

INTRODUCTION

Arteriovenous fistula (AVF) is the preferred vascular access for hemodialysis due to its superior long-term patency and lower complication rates. However, primary failure and delayed maturation remain significant challenges. Doppler ultrasound offers a non-invasive method for evaluating vascular anatomy and hemodynamics, potentially improving AVF outcomes. This study aimed to assess the utility of Doppler ultrasound in evaluating AVF maturation and predicting complications in hemodialysis patients.

AIMS AND OBJECTIVES

Objectives:

2. To provide the possible applications of DUS during the creation and postoperative follow-up of AVFs, with particular emphasis on the following aspects:
   d) Preoperative vascular mapping.
   e) Maturation of the AVF.
   f) Monitoring/surveillance of AVF (follow-up and early detection of complications).

MATERIAL AND METHODS

This prospective study included 109 patients undergoing AVF creation for hemodialysis access. Preoperative Doppler ultrasound was performed to assess cephalic vein and radial artery diameters and flow parameters. Postoperative evaluations were conducted on day 1, day 7, and at 4 weeks to monitor vein diameter, flow rates, and complications. Patients were followed until successful cannulation or determination of primary failure.

RESULTS

- This study provides compelling evidence for the critical role of Doppler ultrasound in the evaluation, monitoring, and management of arteriovenous fistulas for hemodialysis access. Our findings demonstrate that preoperative vascular parameters, particularly cephalic vein and radial artery diameters, are significant predictors of AVF maturation and primary failure. Patients with smaller vessel diameters, diabetes mellitus, and hypertension were at substantially higher risk for primary failure, emphasizing the importance of comprehensive preoperative assessment.
- The longitudinal evaluation of post-operative flow dynamics revealed a characteristic pattern of increasing vein diameter and flow rates over time, with the 4-week measurements being particularly informative regarding maturation status. The significant difference in flow rates at 4 weeks between successful and failed AVFs underscores the value of this time point for prognostic assessment and clinical decision-making.
- The observed primary failure rate of 24.8% aligns with reported literature values and highlights the persistent challenge of achieving reliable vascular access for hemodialysis. Complications, particularly thrombosis, were significantly more common in the primary failure group, emphasizing the interrelationship between complications and maturation failure.
- Doppler ultrasound emerges as an indispensable tool throughout the AVF lifecycle—from preoperative mapping to guide site selection, through postoperative monitoring to track maturation, to surveillance for early detection of complications. The non-invasive nature of ultrasound, coupled with its ability to provide detailed anatomical and

functional information, makes it an ideal modality for the comprehensive assessment of AVFs.

- The insights gained from this study have important clinical implications for vascular access planning and management. Risk stratification based on preoperative ultrasound findings can guide the selection of appropriate access strategies for individual patients. For those identified as high-risk for primary failure, alternative approaches or more intensive monitoring may be warranted. Furthermore, the established timeline of maturation can inform expectations regarding the functional readiness of AVFs for hemodialysis use.
- In conclusion, Doppler ultrasound plays a pivotal role in optimizing AVF outcomes for hemodialysis patients. By enabling precise preoperative assessment, tracking maturation progress, and facilitating early detection of complications, ultrasound contributes significantly to the successful establishment and maintenance of vascular access. As the population of patients requiring hemodialysis continues to grow, the integration of ultrasound into standard clinical practice represents a valuable strategy for improving the quality of care and quality of life for this vulnerable patient group.

CONCLUSION:

Doppler ultrasound parameters, particularly preoperative vessel diameters and 4-week flow rates, are significant predictors of AVF maturation and primary failure. Routine ultrasound evaluation facilitates optimal vascular access planning, timely detection of complications, and improved AVF outcomes in hemodialysis patients.

PROFORMA

PATIENT NAME	
AGE/SEX	
DATE	
REFERRED BY	

AT THE LEVEL OF WRIST:

	RIGHT	LEFT
RADIAL ARTERY DIAMETER		
ULNAR ARTERY DIAMETER		
RADIAL ARTERY DIST FROM SKIN		
ULNAR ARTERY DIST FROM SKIN		

FOREARM:

	RIGHT	LEFT
RADIAL ARTERY DIAMETER		
ULNAR ARTERY DIAMETER		
CEPHALIC V DIAMETER		

BASILIC V DIAMETER		
RADIOCEPHALIC DIST		
ULNOBASILIC DIST		
CEPHALIC V DIST FROM SKIN		
BASILIC V DIST FROM SKIN		

ELBOW:

	RIGHT	LEFT
BRACHIAL ARTERY DIAMETER		
BRACHIAL ARTERY DIST FROM SKIN		

ARM:

	RIGHT	LEFT
CEPHALIC V DIAMETER		
BASILIC V DIAMETER		
CEPHALIC V DIST FROM SKIN		
BASILIC V DIST FROM SKIN		

VELOCITY PARAMETERS:

- **RADIAL ARTERY VELOCITY :**
- **ULNAR ARTERY VELOCITY:**
- **BRACHIAL ARTERY VELOCITY:**

CONSENT FORM

GUIDE : DR. SATISH D. PATIL

P.G. STUDENT : DR. PRAMA POLAVARAPU

PURPOSE OF RESEARCH:

I have been informed that the purpose of this study is to evaluate the role of doppler ultrasound in pre operative mapping of the vessels and post-op maturation and early detection of complications.

PROCEDURE:

I understand that I will undergo history, clinical examination, ultrasound.

RISKS AND DISCOMFORTS:

I understand that there is no risk involved in the above study.

BENEFITS:

I understand that my participation in this study will help in correct mapping of the vessels and assess the maturity and early detection of post op complications.

CONFIDENTIALITY:

I understand that the medical information produced by the study will become a part of the hospital record and will be subjected to confidentiality and privacy regulations of the hospital. If the data is used for publications, the identity of the patient will not be revealed.

REQUEST FOR MORE INFORMATION:

I understand that I may ask for more information about the study at any time.

REFUSAL OR WITHDRAWAL OF PARTICIPATION:

I understand that my participation is voluntary and, I may refuse to participate or withdraw from the study at any time

INJURY STATEMENT:

I understand in the unlikely event of injury to me during the study, I will get medical treatment but no further compensation. I will not hold the hospital and its staff responsible for any untoward incident during the course of the study.

Date:

DR.PRAMA POLAVARAPU **DR. SATISH D. PATIL**

(Investigator) (Guide)

STUDY SUBJECT CONSENT STATEMENT:

I/my ward confirm that DR.PRAMA has explained to me the purpose of this research, the study procedure that I will undergo and the possible discomforts and benefits that I may experience in my own language.

I/my ward have been explained all the above in detail in my own language, and I understand the same. Therefore I agree to give my consent to participate as a subject in this project.

______________________________ _________________

(Participant/ Guardian) Date

______________________________ _________________

(Witness to above signature) Date

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Declared as Deemed to be University u/s 3 of UGC Act, 1956

Accredited with 'A' Grade by NAAC (Cycle-2)

The Constituent College

SHRI B. M. PATIL MEDICAL COLLEGE, HOSPITAL & RESEARCH CENTRE, VIJAYAPURA

BLDE (DU)/IEC/ 942/2023-24 10/4/2023

INSTITUTIONAL ETHICAL CLEARANCE CERTIFICATE

The Ethical Committee of this University met on **Saturday, 18th March, 2023 at 11.30 a.m. in the CAL Laboratory, Dept. of Pharmacology,** scrutinized the Synopsis/ Research Projects of Post Graduate Student / Under Graduate Student /Faculty members of this University /Ph.D. Student College from ethical clearance point of view. After scrutiny, the following original/ corrected and revised version synopsis of the thesis/ research projects has been accorded ethical clearance.

TITLE: "ROLE OF DOPPLER ULTRSOUND IN EVALUATION OF ARTERIOVENOUS HEMODIALYSIS FISTULA, MATURATION AND COMPLICATIONS OF HEMODIALYSIS VASCULAR ACCESS".

NAME OF THE STUDENT/PRINCIPAL INVESTIGATOR: DR.PRAMA POLAVARAPU

NAME OF THE GUIDE: DR.SATISH D.. PATIL, ASSOCIATE PROFESSOR, DEPT. OF RADIODIAGNOSIS.

Dr. Santoshkumar Jeevangi
Chairperson
IEC, BLDE (DU),
VIJAYAPURA

Chairman,
Institutional Ethical Committee,
BLDE (Deemed to be University)
Vijayapura

Dr.Akram A. Naikwadi
Member Secretary
IEC, BLDE (DU),
VIJAYAPURA

MEMBER SECRETARY
Institutional Ethics Committee
BLDE (Deemed to be University)

Following documents were placed before Ethical Committee for Scrutinization.

- Copy of Synopsis/Research Projects
- Copy of inform consent form
- Any other relevant document

Smt. Bangaramma Sajjan Campus, B. M. Patil Road (Sholapur Road), Vijayapura - 586103, Karnataka, India
BLDE (DU): Phone: +918352-262770, Fax: +918352-263303, Website: www.bldedu.ac.in, E-mail:office@bldedu.ac.in
College: Phone: +918352-262770, Fax: +918352-263019, E-mail: bmpmc.principal@bldedu.ac.in