Optimising Hemodialysis Access: The Predictive Value of Radial Artery Doppler

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ABSTRACT

BACKGROUND: Managing end-stage renal disease with chronic hemodialysis requires reliable vascular access for high flow rates. Autogenous arteriovenous fistulas (AVF) are the preferred option, redirecting arterial blood into the venous system to enhance blood flow. AVF maturation depends on patient-specific factors (age, comorbidities, and cardiac output) and vessel conditions (topology, diameter, elasticity). Colour Doppler ultrasound is effective for evaluating hemodialysis access. Pre-operative ultrasound mapping shows the relationship between vessel characteristics and fistula maturation. This study evaluates duplex sonography's role in assessing arteries before AVF formation and the relationship between radial artery peak systolic velocity, flow volume, and early AVF success and failure rates.

AIMS AND OBJECTIVES: This study aims to evaluate the predictive value of radial artery Doppler ultrasound parameters, specifically peak systolic velocity and flow volume, in determining the success of arteriovenous fistula maturation in patients undergoing hemodialysis.

MATERIALS AND METHODS: All the patients diagnosed with end-stage renal disease, who were referred to the Department of radio-diagnosis for Doppler evaluation of upper limb vessels in view of AVF creation and satisfying the inclusion criteria were included in the study. The patients underwent Doppler evaluation of radial artery and cephalic vein during the pre-operative, immediate post-operative (post-op day 0 -14) and at late post-op period of 4-6 weeks to assess the maturity of AVF created.

RESULTS: The study found significant differences in radial artery flow volume between patent and failed fistulas. Preoperative flow volume was 94.72 ± 19.33 ml/min in patent fistulas and 71.11 ± 25.35 ml/min in failed ones. Postoperative day 0-14 flow volume was 557.76 ± 200.43 ml/min in patent fistulas and 232.42 ± 116.52 ml/min in failed ones, with a cut-off of 333 ml/min predicting failure (sensitivity 88.89%, specificity 85.37%). Postoperative day 6 weeks flow volume was 636.30 ± 169.25 ml/min in patent fistulas and 296.06 ± 140.63 ml/min in failed ones.

CONCLUSION: The study found that successful maturation of arteriovenous fistulas occurred in 82% of patients at six weeks. Radial artery peak systolic velocity and flow volume, cephalic vein diameter were key predictors of success. Early postoperative Doppler ultrasound measurements effectively predicted outcomes, underscoring the need for further research in this area.

KEYWORDS: Arteriovenous fistula, radial artery, Flow volume, Peak systolic velocity, Fistula maturation, Hemodialysis, End-stage renal disease, Colour Doppler.

BLINDED MANUSCRIPT

BACKGROUND / INTRODUCTION:

End-stage renal disease is a life threatening condition requiring chronic hemodialysis for patient survival. Effective hemodialysis requires reliable vascular access, with arteriovenous fistulas being the preferred method. [(1)] An arteriovenous fistula is surgically created by anastomosing a peripheral artery to a vein which increases blood flow and vascular remodelling. This process is essential for the fistula to mature and provide high flow rates required for hemodialysis.[(2)] However 20 to 50% of the fistulas created fail to mature in the long run. (3) The maturation of fistulas is dependent on various factors such as age, comorbidties, cardiac output and certain vessel characteristics. (2) The non-invasive and cost effective colour Doppler allows detailed evaluation of blood vessel characteristics, offering valuable insights to predict the outcome of artetiovenous fistula. (4) Pre-operative and post-operative colour Doppler vessel assessment which includes peak systolic velocity and flow volume have been shown to correlate with fistula maturation. (5) This study aims to evaluate the role of duplex sonography, particularly radial artery PSV and flow volume, in predicting early AVF failure, with the goal of improving clinical outcomes for patients undergoing hemodialysis.

MATERIALS AND METHODS:

This is a prospective follow-up study conducted in the department of Radio-diagnosis at Sri Manakula Vinayagar Medical College and Hospital, Puducherry, India over 18 months. Institutional ethics committee approval (EC/87/2022) was obtained and the study was conducted according to the Good practice guidelines and the Declaration of Helsinki. The sample size was 70 with a drop-out rate of 10% which was calculated using nMASTER software version 2.0 with 95% confidence interval and absolute precision 6 with sensitivity and specificity of 91.7% and 95.6% respectively as described by Pratama et al. (6) Due to the loss to follow-up of patients and reduction in inflow cases, the sample size was reduced to 50. The study included patients diagnosed with end-stage renal disease (ESRD) who required the creation of an arteriovenous fistula (AVF) for hemodialysis. Patients were excluded if AVF creation was not indicated, if their vascular anatomy did not permit the construction of a native AVF, or if they were on medications such as antiplatelet, anticoagulants, or hormonal contraceptives. Doppler evaluation was performed using PHILIPS70 G affiniti machine with 5-12 Mhz linear transducer after obtaining informed consent.

Ultrasound evaluations were performed using a PHILIPS 70 G Affiniti machine with a 5-12 MHz linear transducer. Radial artery and cephalic vein were assessed preoperatively and at 0-14 days and 6 weeks post-operatively. Continuous variables included Doppler parameters such as radial artery peak systolic velocity, flow volume, cephalic vein diameter and depth of fistula site from the skin. Qualitative variable includes fistula patency. (Figure 1.)

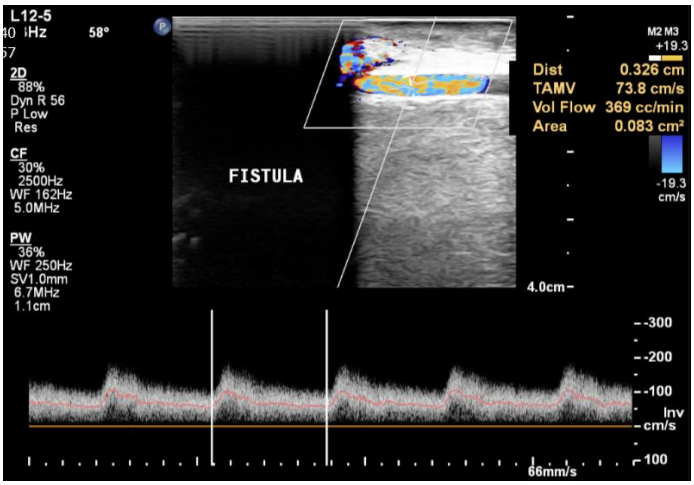

Fig.1. 63 year old male with history of diabetes mellitus. Flow volume measurement in radial artery was done during the immediate post-operative period using colour Doppler, giving a value of 369 ml/min.

Data obtained was entered in the software Epi info version 7.2.1.0 and analyzed using SPSS software version 24.0. Association between the study variables were done using unpaired T-test. P value <0.05 were considered statistically significant. Pearson's correlation coefficient was used to find correlation coefficient. Inter-observer agreement was assessed using the kappa statistic. Graphical representation of data were done with the help of MS word and MS excel were used to obtain various type of graphs such as bar and pie diagram. Statistical software: SPSS version 24 was used for data analysis.

RESULTS:

This study included 50 participants with end-stage renal disease planned for undergoing AVF creation with a mean age group of 25.5 + 12.57 years. Males in the study are 43 (83%) and females are 7 (7%).

Table 1. Doppler Parameters in patent and failed fistulas during the pre-operative and post-operative periods (0 – 14 days and at 6 weeks)

Parameters	Mean ± SD	Patent fistula	Failed fistula	Independent t test value	P value
Radial artery PSV (cm/s)					
Preoperative	66.67± 20.41	69.94 ± 19.92	51.77 ± 16.21	2.55	**0.01***
Post-operative (0 – 14 days)	245.10±120.14	269.20 ± 116.57	135.33 ± 62.73	3.32	**0.002***
Post- operative (6 weeks)	281.50±135.01	312.71 ± 126.92	139.33 ± 58.04	3.98	**0.001***
Radial artery flow volume (ml/min)					
Preoperative	90.47 ± 22.23	94.72 ± 19.33	71.11 ± 25.35	3..13	**0.003***
Post-operative (0 – 14 days)	499.20±225.73	557.76 ± 200.43	232.42 ± 116.52	4.67	**0.001***
Post- operative (6 weeks)	575.06±214.82	636.30 ± 169.25	296.06 ± 140.63	5.39	**0.001***
Cephalic vein diameter					
Pre-operative	2.48 ± 0.48	2.53 ± 0.50	2.23 ± 0.20	2.74	**0.04***
Post-operative (0 – 14 days)	3.84 ± 0.58	3.94 ± 0.55	3.34 ± 0.46	3.01	**0.004***
Post- operative (6 weeks)	3.99 ± 0.56	4.07 ± 0.53	3.60 ± 0.52	2.41	**0.019***

The mean radial artery PSV preoperatively was 66.67 ± 20.41cm/s, post-operative day 0 to 14 days was 245.10 ± 120.14 cm/s and post-operative day 6 weeks was 281.50 ± 135.01 cm/s. Highly significant relation was between fistula outcome and pre-operative radial artery PSV (P value = 0.01), post-operative radial artery PSV both during days 0 – 14 (P value = 0.002) and at 6 weeks (P value = 0.001). **(Figure 2)**

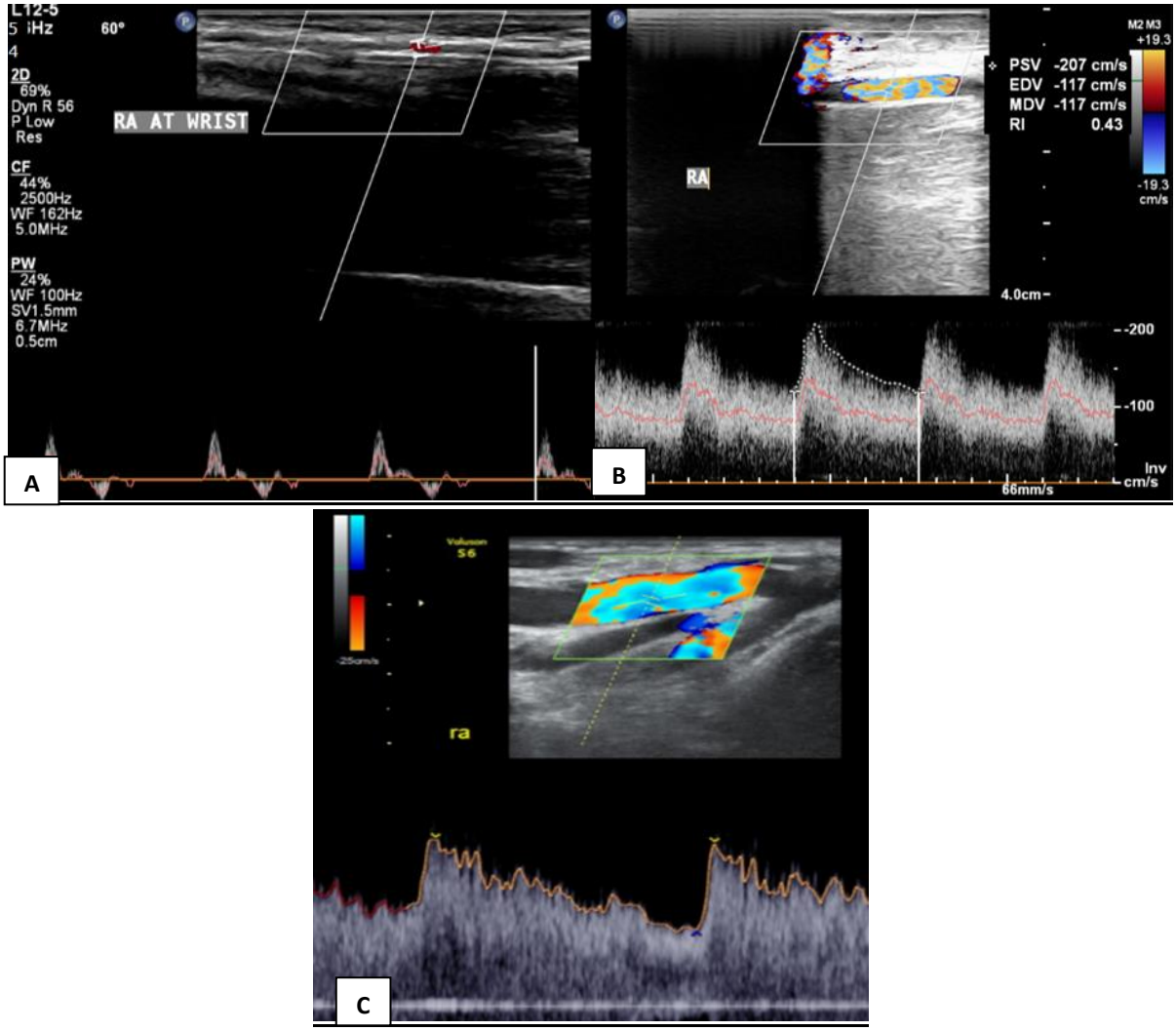

Figure 2. A 43 year old male with history of diabetic nephropathy. (A) Colour Doppler US of radial artery pre-operatively shows radial artery PSV of 57 cm/s. (B) Colour Doppler US of radial artery during the immediate post-operative period (0-14 days) show a PSV of 207 cm/s. (C) Similarly PSV at 6 weeks is 323 cm/s.

In the pre-operative period the mean flow volume in radial artery was 90.47 ± 22.23 ml/min. The mean flow volume during the post-operative period at 0-14 days was 499.20±225.73 ml/min and at 6 weeks was 575.06±214.82 ml/min. Highly significant relation was between fistula outcome and pre-operative radial artery flow volume (P value = 0.003), post-operative radial artery flow volume both during days 0 – 14 (P value = 0.001) and at 6 weeks (P value = 0.001).

Table 2. Sensitivity and specificity of vessel parameters measured by sonography in pre and postoperative period in detection of arteriovenous fistula failure among studied group

Variable	Cut off	Area under the curve (AUC)	Younden index	Sensitivity	Specificity	Positive LR	Negative LR

Preoperative Radial artery flow volume (ml/min)	< 66.3 (60.2 to 116.5)	0.785 (0.645 to 0.888)	0.617	66.7% (29.9 to 92.5%)	95.12% (83.5 to 99.4%)	13.67	0.35
Post-operative Radial artery flow volume (ml/min) POD 0 to 14	< 333 (240 to 454)	0.943 (0.839 to 0.989)	0.742	88.89% (51.8 to 99.7%)	85.37% (70.8 to 94.4%)	6.07	0.13
Preoperative Radial artery PSV (cm/s)	< 46 (42 to 80)	0.753 (0.611 to 0.864)	0.506	55.6% (21.2 to 86.3%)	95.12% (83.5 to 99.4%)	11.39	0.47
Post-operative Radial artery PSV (cm/s) POD 0 to 14	< 145 (125 to 270)	0.881 (0.758 to 0.955)	0.655	77.8% (40.0 to 97.2%)	87.8% (73.8 to 95.9%)	5.47	0.38

ROC curve analysis in our study evaluated the predictive accuracy of radial artery peak systolic velocity and flow volume for AVF maturation. Pre-operative radial artery peak systolic velocity demonstrated significant predictive value, with a cut-off of 46 cm/s(sensitivity – 55.6%, specificity – 95.1%). Similarly immediate post-operative radial artery PSV showed significant correlation, with a cut off of 146 cm/s(sensitivity – 77.8%, specificity – 87.8%). Regarding flow volume of radial artery, immediate post-operative value showed strong predictive value, with a cut off of 333 ml/min (sensitivity - 88.89%, specificity - 85.37%). **(Figure 3)**

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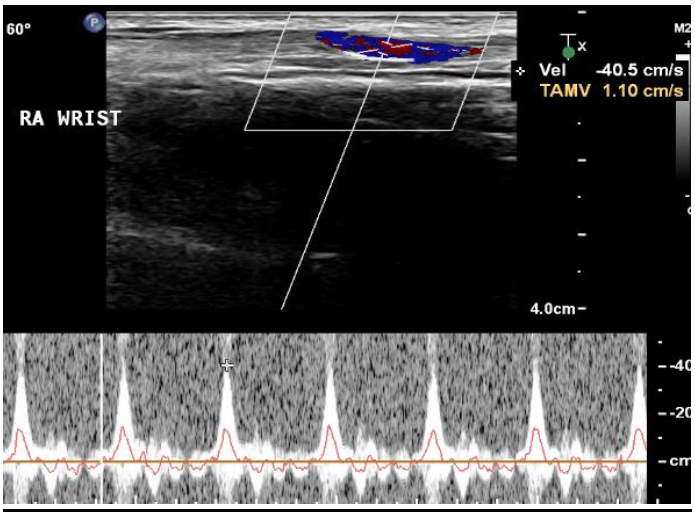

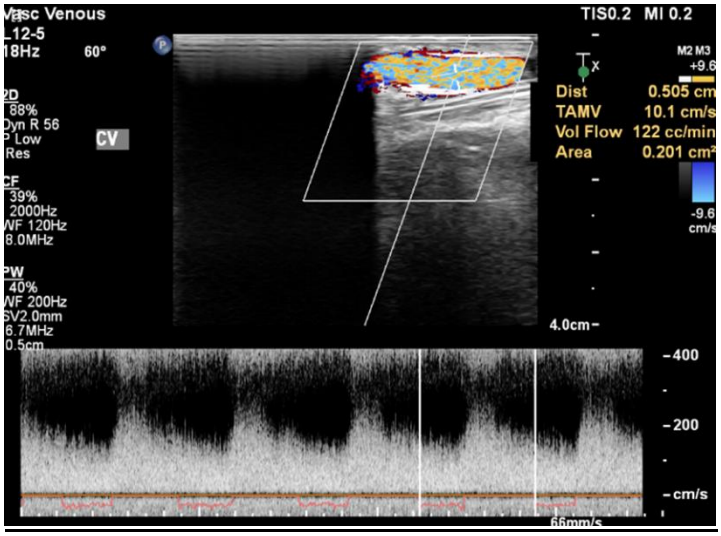

Figure 3. 60 years old female diagnosed with end-stage renal disease. (A) Radial artery PSV and flow volume were evaluated pre-operatively and were found to be 40 cm/s and 60.3 ml/min respectively. (B) On evaluating the patient during the immediate post-operative period, which showed a flow volume of 122 ml/min. 82% (n=41) participants had patent fistula and 18% (n=9) participants had failure of fistula when assessed at 6 weeks post-operatively.

DISCUSSION:

Arteriovenous fistulas are the preferred method for dialysis access in patients with end-stage renal disease, as recommended by hemodialysis vascular access guidelines. Dysfunction of AVFs is a significant cause of morbidity and hospitalization among hemodialysis patients. (7) Timely intervention to address early fistula failure is crucial. Clinically, confirming an immature fistula can take 3–4 months. Therefore, establishing well-defined criteria for identifying potentially failing fistulas early in the postoperative period would be highly beneficial. (8)

In this study we measured the peak systolic velocity (PSV), flow volume of radial artery and cephalic vein diameter both during the pre-operative, immediate post-operative (0-14 days) and at late post-operative period of 6 weeks to assess the fistula outcome. This study indicated that pre-operative and immediate post-operative measurements of radial artery peaks systolic velocity and flow volume were significant predictors of AVF maturation.

Our study demonstrated that pre-operative radial artery peak systolic velocity greater than 46 cm/s and flow volume greater than 66.3 ml/min were associated with high likelihood of AVF maturation. These findings were in correlation with studies conducted by Pratama et al and Lockhart et al. (6,9). Hence these parameters can be used to predict the maturity of AVF.

Failure group shows significant decrease in flow volume of radial artery when during the early post-operative period (0 – 14 days) and was a highly significant variable in predicting fistula maturation. Our study revealed a cut-off value of 333 ml/min to discriminate between a mature and failed fistula, which was in correlation with a study conducted by Ladenheim et al, who gave a cut off of 200.5 ml/min. (10) In our study, mean cephalic vein diameter preoperatively was 2.53 ± 0.50 mm in patent fistulas and 2.23 ± 0.20 mm in failed fistulas ($p < 0.04$) when compared to a study by Brimble et al which was 2.52 and 2.33 mm.(11) And the study by Dasari et al gave a value of 2.17 mm and 1.90 mm in patent and failed radio-cephalic AVFs. (12) During the follow-up period, 82 % of fistulas matured while 18 % failed to mature.

Early failure occurs majorly when a vascular access is unable to provide adequate blood supply. This occurs when the draining vein does not dilate adequately or the arterial flow is inadequate, which are assessed in our study.(13)

The study calls for further research with larger sample sizes and in diverse clinical settings to

validate the identified thresholds and improve clinical guidelines for AVF monitoring and management

The study's sample size is relatively small, which can limit the generalizability of the findings. Larger sample sizes are necessary to validate and enhance the reliability of the results.

The research was conducted in a single center, which might introduce bias and limit the applicability of the results to other settings or populations.

The follow-up period was limited to six weeks post-surgery. Longer follow-up periods are needed to assess the long-term success and functionality of arteriovenous fistulas (AVFs).

Operator-dependent errors can occur during duplex scan measurements, potentially affecting the accuracy of the preoperative and postoperative assessments.

The study calls for further research with larger sample sizes and in diverse clinical settings to validate the identified thresholds and improve clinical guidelines for AVF monitoring and management

CONCLUSION

Flow volume and peak systolic velocity of radial artery measured during the pre-operative and immediate post-operative period (0 – 14 days) were found to be effective in predicting arteriovenous fistula outcome. Radial artery blood flow of less than 333 ml/min during the post-operative period (0-14 days) may accurately predict fistula outcome as is the case in our study.

List of Abbreviations

1. AUC – Area under curve
2. AVF – Arteriovenous Fistula
3. ESRD – End-stage renal disease
4. LR – Likelihood ratio
5. PSV – Peak Systolic Velocity
6. ROC – Receiver Operating Characteristic

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