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UTILITY OF ULTRASOUND AND DOPPLER MEASUREMENTS IN HEMODIALYSIS ARTERIOVENOUS FISTULA MATURITY ASSESSMENT

Radiodiagnosis

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ABSTRACT

A substantial proportion (28%–53%) of Arteriovenous Fistula never matures adequately. However, if there is any doubt about maturation, the fistula should be evaluated by ultrasound. With US showing evidence of stenosis or multiple draining venous branches and thrombosis, will help to undergo early intervention. Ultrasound minimum venous diameter and blood flow volume measured at 1-2 months with cut-off of flow volume of 500-600 ml/min, calibre up to 4-5mm, can be used to accurately assess the likelihood of maturation. If findings indicate the fistula is unlikely to mature, a new permanent access can be placed, thus reducing the waiting time.

KEYWORDS

Hemodialysis, Arteriovenous Fistula, Maturity, Ultra-sound, Doppler.

INTRODUCTION

Arteriovenous Fistula, as compared with arteriovenous grafts, is the preferred haemodialysis vascular access because they have greater longevity and less frequent infections [1]. The 1997 DOQI goal is to use an aggressive approach to AVF placement, with, eventually, 40% of all patients undergoing dialysis doing so with a fistula. A substantial proportion (28%–53%) of AVFs never matures adequately to be usable for dialysis [2-4]. Whereas a graft can be used for dialysis 2 weeks after placement, the typical AVF is not used until 3 months after placement [3]. An AVF is typically not evaluated for maturity until 2–3 months after placement, and nephrologists often wait up to 6 months before declaring the fistula a failure [5,3]. Patients typically spend this time undergoing dialysis three times a week by means of a catheter. These patients have a potentially decreased ability to undergo dialysis effectively because of suboptimal dialysis blood flow. If the AVF never matures, this is time wasted. In addition, there is increased risk of catheter infection as many as two episodes per year with the attendant morbidity and cost [6]. Thus, the ability to predict whether an AVF is going to mature eventually is important. Early recognition that the fistula is unlikely to mature can lead to fistula evaluation and possible revision or placement of a new vascular access [5]. AVF maturation is usually assessed subjectively by means of physical examination. A mature fistula will typically have an easily palpable superficial vein of adequate diameter that facilitates easy cannulation. It will have a uniform thrill to auscultation and palpation that indicates adequate blood flow without stenosis. The accessible draining vein needs to be more than 10 cm long to allow for rotation of needle sites and adequate distance between the cannulating needles. If the draining vein is too tortuous or too deeply located in the subcutaneous tissues, it will be difficult to cannulate. In this study we aim to compare various objective Ultrasonographic criteria for native arteriovenous fistula maturation with subsequent fistula outcomes and clinical evaluation.

Literature Survey

Thomas Graham of Glasgow first presented the principles of solute transport across a semipermeable membrane in 1854 [7]. The first haemodialysis in a human being was by Hass [8] , and the artificial kidney was developed into a clinically useful apparatus by Kolff in 1943 – 1945. Later in 1966 Brescia and Cimino invented the Brescia-Cimino fistula [9]. In 1997 KDOQI first Vascular Access guidelines were publicized, followed by revisions in 2001 and 2006. Which focused on, concerted measures to increase fistula placement and maturation. Earlier guidelines strongly promoted surveillance for graft stenosis; latest version is more equivocal about its value [10]. Duplex ultrasound detection of AV fistula stenosis is theoretically attractive technique. The studies are noninvasive, can be repeated serially, and are accurate in the localization of fistula stenosis. Since AV fistulae and access grafts are subcutaneous, the inflow artery, the proximal anastomosis, the entire AV graft, the distal anastomosis, and the outflow vein can all be easily examined. Several interesting techniques have been described for evaluating fistula dysfunction [11, 12]. The simplest technique is examination of the inflow arterial waveform (13). It is important to remember that the diastolic component of an arterial waveform reflects the resistance of the vascular bed being perfused. in circulatory beds with low resistance, there will be significant forward flow in diastole. Similar flow patterns are exhibited by AV fistulae because they perfuse low-resistance venous outflow beds and therefore display significant forward flow in diastole.

Harkrider and Comeaux (13) have devised a unique technique for monitoring arteriovenous fistulae by examining the native arterial waveform proximal to the fistula. A normally functioning AV fistula has significant diastolic flow , and the ratio of the Doppler derived velocity in peak diastole divided by the velocity in peak systole makes it possible to determine a flow ratio (Vd/Vs). With measurements made at a Doppler angle of 60 degrees, Harkrider and Comeaux (13) determined that a normally functioning fistula without significant outflow problems has a Vd/Vs ratio _0.4. With significant stenosis in the fistula or outflow tract, the diastolic flow component decreases, resulting in a Vd/Vs ratio _0.3. This becomes a very easy, indirect method to detect problems with the access site by interrogation of the proximal arterial waveform in the feeding artery. Tordoir et al. (14) developed specific criteria for the determination of fistula stenosis as outlined in. For Brescia-Cimino or forearm autogenous fistula a peak systolic frequency of greater than 12 kHz is indicative of greater than 50% stenosis. flow Volume has been used by some investigators to evaluate fistula function. According to Rittgers et al.[15], the average 6 mm PTFE fistula has a volume flow of 750 ±383 mL/min. All grafts in which a volume flow ±450 mL/min was measured by duplex scanning occluded within 2 weeks. Similar findings were reported by Shackleton et al. [16], who achieved a sensitivity of 83% and specificity of 75% for predicting interval thrombosis when a flow rate of 450 mL/min was selected as a low-flow threshold. To perform duplex surveillance, the entire fistula or graft should be examined, including the inflow artery, the proximal anastomosis, the graft/fistula itself, the distal anastomosis, and the outflow vein. Color-flow Doppler can assist in identifying anatomic areas of stenosis for further interrogation with velocity or frequency measurements. A. Alamdaran MD in 2008 [17] Found that There is a high level of abnormalities, especially high flow volume, in well functioning mature AVFs. Color Doppler ultrasonography makes early detection of the patients with a higher risk possible and it can also guide the surgeon to select the surgical procedure. Martin R. Back, et al in 2008[18] showed that Duplex-derived hemodynamic parameters characterized early dialysis access conduit function, prognosticate access patency, guided necessary remedial interventions, and facilitated favourable access longevity. Koseoglu, Kutsi et al in 2008[19] study shows that Doppler ultrasound examination of AVF feeding artery using resistive index

(RI) in the feeding artery may provide useful data on morphologic and functional characteristics of AVF. Martin Ferring in 2008[20] showed most haemodialysis patients nowadays are older and have diabetes or cardiovascular disease. These vascular risk factors are associated with increased arterial disease and an increased risk of AVF failure. Pre-existing arterial disease can be assessed by ultrasound assessment that is particularly important for the radial artery. Singh et al in 2007[21] findings show that that most immature fistulas have one or more remediable anatomic problems that are demonstrable at postoperative US. Moreover, salvage procedures to correct these defects can substantially increase the proportion of fistulas that are usable for dialysis. Postoperative fistula US may be useful in triaging the subsequent treatment of the immature fistula to the appropriate surgical or interventional service. These preliminary findings need to be validated in future multicenter prospective studies.

MATERIAL AND METHOD:

This prospective Study was done at the “SRI VENKATESWARA INSTITUTE OF MEDICAL SCIENCES” TIRUPATI, on patients with haemodialysis AVF in situ referred to the department of Radio-diagnosis for maturity assessment over a period of two years with a 3 month follow up. Ethical committee clearance was obtained; patients were explained about the procedure in their own language. Cases where clinical assessment was not done or follow up not available were excluded from study; finally the data of 33 patients was used for analysis. AVF US was done serially at 1st post op day after 1st month and after 3rd month. A provisional diagnosis was suggested after the ultrasound examination and these findings were correlated with clinical assessment.

Overview of US Technique

US examination of the AVF was performed with the patient in an upright seated position. The arm positioned at 45° from the body and comfortably supported by towels on a couch. An initial overview of the AVF feeding artery, draining vein, and anastomotic region was obtained. Gray scale examination of the vessel diameter was performed in both the transverse and longitudinal planes using a linear probe. The diameter of the draining vein was measured in the anteroposterior dimension in the transverse plane by using gentle transducer pressure. Draining venous diameter similarly measured at the caudal, middle, and cranial portion of the draining vein. These standard measurements gave an overall assessment of the AVF draining venous diameter. The depth of draining vein from the skin surface was recorded. Presence of tributaries joining the draining vein there caliber and distance from fistula site of each tributary was noted. The anastomotic site, and related proximal veins of upper limb, the feeding artery were evaluated in grey scale sonography to look for calibre. Focal stenotic or narrowed portions of the draining vein that may be flow limiting or presence of any intraluminal echogenic contents were recorded. The number and length of the thorombosed segment and its distance from the fistula site were noted. Any presence of abnormal dilatation of vessels suggestive of varix or aneurysm formation was screened for. Three to five blood flow measurements were obtained in the draining vein. To decrease the possibility of encountering turbulent flow, these measurements were obtained in the middle of the forearm for a forearm AVF or the middle of the upper arm for an upper arm AVF. Blood flow was evaluated in a straight non-tapering venous segment. Because blood flow rate acquisition was made with the assumption that laminar flow are present, areas with turbulent flow, such as areas with stenosis, are avoided. If an area of turbulence was noted in the usual acquisition site, flow volume was measured as far as reasonably possible away from the site, but still in the forearm for a forearm AVF and the upper arm for an upper arm AVF. The Doppler range gate was set to encompass the entire lumen, and the diameter was measured perpendicular to the vessel walls. The angle of flow relative to the fistula was held constant at 60° to limit one potential aspect of measurement variability. The pulse repetition frequency and gain was individually optimized to avoid aliasing. Three to four cardiac cycles were used for automatic machine determination of the time-averaged velocity across the venous lumen. Flow was determined by equipment software using the formula (38) FLOW VOLUME (ml/min) = $TAV \times \pi r^2 \times 60$. The blood flow measurements WERE averaged. All AVF US examinations were performed on single ultrasound machine TOSHIBA XARIO I STYLE using linear array probe of 3 to 14 mhz frequency.

Qualitative Clinical Evaluation: The AVFs were clinically evaluated by one of the experienced clinician in dialysis units. Subjective criteria include an easily palpable superficial vein of adequate diameter and a uniform thrill to palpation. The accessible draining vein needs to be relatively straight and more than 10 cm long. On the basis of these criteria, the clinicians were asked to predict whether the fistula would eventually mature, and their evaluations were recorded on a worksheet. The available whole medical record of the patient was studied. The results were analysed and recorded as follows at 1st day, 1st month and 3rd month. The information was noted in the Data Collection Sheet. All data were presented as mean ± SEM. Multiple comparisons were performed using Student's t- test .Nominal variables were compared by chi square test. A p-value of < 0.05 was taken into consideration in determining significance. All statistical procedures were computed by using SPSS 20(Inc) software and Microsoft excel sheet.

RESULTS AND DISCUSSION

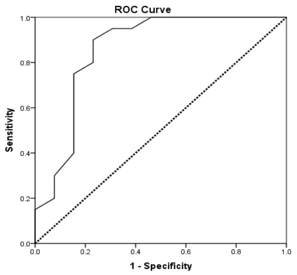
The patients in our study belonged to age group from 12 years to 72 years with a mean age of 48.8± 11.7 years. Of the 33 patients 43.9% were females and 56.1% were male, we did not find any significant difference between fistulas attaining maturity and gender. Most common type of fistula was left forearm radio cephalic (60%) fistula followed by left arm brachiocephalic fistula (18%).Of the 33 fistulas assessed 20 were successful with corresponding postoperative ultrasound measurements at 1st and 3rd months, and of the 13 fistulas which were labelled inadequate for haemodialysis by clinical assessment 10 were correctly assessed as inadequate by postoperative ultrasound measurement and three were wrongly assessed as adequate in terms of flow volume measurement.

MINIMUM VENOUS DIAMETER

An adequate fistula diameter is important, as a 15-gauge haemodialysis needle is placed into the vein by means of palpation and visual inspection. The optimal criterion for minimum venous diameter is a trade-off between sensitivity and specificity. Our initial hypothesis based on clinical experience was that a minimum venous size of 4 mm is needed for easy cannulation. The mean venous diameter measured in our study was 5.89 ± 1.7 mm. The mean venous caliber of mature fistulas at 3rd month was 5.62±1.49 mm and of immature fistulas was 3.42±1.56mm (Table 1). In our study the mean venous caliber of mature radio cephalic fistula at 2- 3 months was 5.267 mm ± 0.948 mm of which left radio-cephalic were 13 and right radio-cephalic were 2. This was in correlation with findings of Wong et al [22] who found a mean diameter of 0.58 cm ±0.12 in the successful radio cephalic fistula at 6 weeks. In our study we found that mean minimum venous caliber was higher in females as compared to males but overall women are less likely to achieve a minimum venous diameter of 5mm a finding consistent with prior observations of inferior fistula outcomes among women [23, 24]. This may be in part due to smaller vessels in women [25]. In contrast patient age, diabetes status, and fistula location did not correlate with maturity. The overall sensitivity of diameter criterion in our study is optimal (90%–95%) when the minimum venous diameter cutoff is 0.4– 0.5 cm (Graph 1).

Table 1; Minimum venous calibre 3rd month in mature and immature fistula.

MATURE	Mean		5.6200
	95% Confidence Interval for Mean	Lower Bound	4.9222
		Upper Bound	6.3178
	Median	5.0500	
	Variance	2.223	
	Std. Deviation	1.49088	
	Minimum	4.00	
	Maximum	9.50	
IMMATURE	Mean		3.4231
	95% Confidence Interval for Mean	Lower Bound	2.4807
		Upper Bound	4.3655
	Median		3.8000
	Variance		2.432
	Std. Deviation		1.55946
	Minimum		1.00
	Maximum		6.00
	Range		5.00



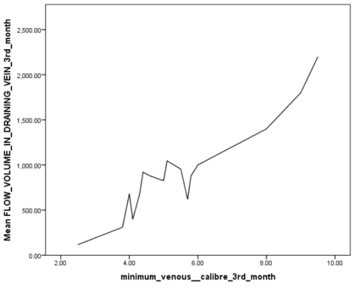
Graph 1: R.O.C curve showing the sensitivity of use of venous calibre at third month in predicting fistula maturity.

FISTULA BLOOD FLOW RATE

Haemodialysis is typically performed at a dialysis blood flow rate of 350–450 mL/min, for 3.5–4 hours three times per week. The blood flow rate through the fistula must exceed the minimum acceptable dialysis blood flow rate of 350 mL/min by at least 100 mL/min to ensure successful use of the fistula for dialysis, or the vein could collapse during haemodialysis. Blood flow rate has been measured to be at least 350–500 mL/min in normally functioning AVFs [26]. Lin et al (27) found a mean blood flow rate greater than 634 mL/min in the 2nd postoperative week in 152 patients with successful radiocephalic fistulas. Mean blood flow rate in successful AVFs was reported by Wong et al [22] to be approximately 650 mL/min at 12 weeks. Average blood flow rate in adequately functioning AVFs in our study was 1037mL/min ± 382, which is similar to those found by Lin et al (37) and Wong et al [22]. The relatively higher mean flow rate in our study may be attributed to the inclusion of proximal i.e. arm fistulas which are known to have higher flow volume as documented by Alamdaran et al [17] who in their study showed a mean flow volume of 1665±554 mL/min They found a linear correlation between the size of draining vein and the mean flow volume which was reflected in our study. The mean flow volume among fistulas which attained caliber more than 5mm was 1020ml, this value being lesser than the mean for all that mature fistulas shows that a vein which just attains adequate caliber may not be adequate for dialysis as the flow volume in it may be low due to either presence of tributaries or development of thrombosis later. The overall accuracy of the blood flow criteria in our study is optimal (90%–95%) for values of 500–600 mL/min. Factors such as depth from the skin also determine whether a fistula is successful (Table 2 , Graph 2). For this reason, not every fistula that meets the blood flow criteria is usable for dialysis. No differences in blood flow rate in mature fistulas were found between the various patient subsets of age, diabetes status, and fistula location.

Table 2: Table showing the mean Flow volume (ml/min) at 3rd month in mature and immature fistulas

	Maturity	N	Mean	Std. Deviation	Std. Error Mean
Flow volume at 3rd month	Mature	20	1037.00	382.307	85.48653
	Immature	13	223.84	199.312	55.27946



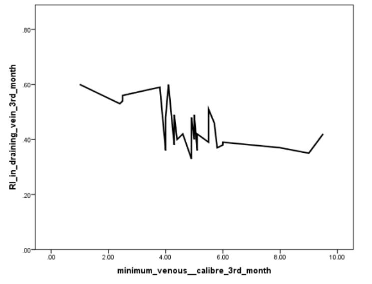
Graph 2: Line graph showing the variation of flow volume (ml/min) with venous calibre at 3rd month (mm)

RESISTIVE INDEX (RI) IN DRAINING VEIN

In a study conducted by Toni Misevic et al [28] they found the RI in draining veins of adequately functioning fistulas was 0.4. In our study the mean RI in draining veins of fistulas considered mature at 3rd month was 0.4± 0.04; higher mean RI was noted among immature fistulas i.e. 0.52±0.06 as shown in Table 3 and in Graph 3. Mean RI in draining vein in a study by Radoslaw Piteura et al was 0.5±0.12 (15), which in our study was 0.46±0.059. In their study the mean RI among mature fistulas and the percentage of fistulas which were functioning was not mentioned. Relatively higher RI value was noted in veins of lower caliber in our study which was not reported earlier.

Table 3: Table showing the mean RI in draining vein at 3rd month in mature and immature fistulas

Fistula Maturity At 3 Months		Mature	Immature
RI in draining Vein 3rd month	Mean	.40	.52
	Standard Deviation	.04	.06
	Standard Error of Mean	.01	.02
	Valid N	20	11



Graph 3: Line graph showing the relation of minimum venous calibre and RI in draining vein at 3rd month fistulas

SINGLE VERSUS MULTIPLE ASSESSMENTS

Paired Samples Statistics (Table 4a)

	Mean	N	Std. Deviation	Std. Error Mean
Flow volume at 3rd month	716.6667	33	514.27538	89.52385
Flow volume at 1st month	664.5455	33	456.03653	79.38577

Paired Samples Test (Table 4b)

Pair	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Flow volume at 3rd month- Flow volume at 1st month	52.122	173.23679	30.156	-9.3058	113.54831	1.728	32	.094

A potential problem with a single measurement of fistula diameter and blood flow rate is that both the diameter and the flow may increase with time. Thus, more than one measurement may be needed to accurately predict maturation potential. However, in the group of 38 patients in the study by Wong et al [22], individual fistula blood flow rate did not increase substantially in 2–12 weeks. We obtained multiple measurements in the same fistulas over time; we found no significant difference in the flow volumes of AVFs measured after 1 month and 3 months, as shown in the paired sample t test in (table 4a 4b) which depicts that there is no significant difference in the means of flow volume measured at after 1st and 3rd month. Thus, an initial US assessment at 1 month after surgery should help predict subsequent fistula maturity with a high degree of accuracy. Multiple draining venous branches close to the anastomosis may be surgically ligated to increase the chance of maturation [29] which was found in our study and those cases showed adequate flow after ligation. If little chance for AVF maturation is present on the basis of the developed criteria, an alternate permanent access can be surgically placed in a timely fashion.

Table 4a, 4b: Independent sample T test showing the significance of values of flow volume in draining vein at 3rd month in predicting the fistula maturity

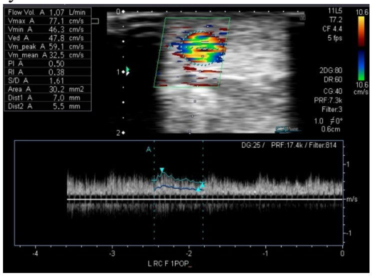


Fig 1 showing ultrasound measurement of flow volume in draining vein.

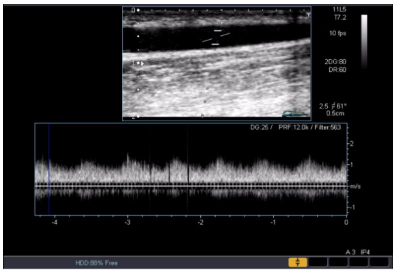


Fig 2 Normal high velocity flow pattern in draining vein with high forward flow in diastole .

LIMITATIONS OF OUR STUDY

Limitations of this study include modest referral bias. Although all patients with AVF were supposed to be referred for postoperative US evaluation, some patients were not scheduled for US or did not keep their appointment. Although roughly equivalent numbers of forearm and upper arm AVFs were placed, there were more patients with forearm fistulas in this study. This situation demonstrates a bias toward sending patients with AVFs that were difficult to evaluate, and patients in whom fistula maturation was questionable. Another limitation of this study was the potential for marked variability in flow volume measurement both in the same patient and between sonographers. No attempt was made to control all possible sources of variability; interobserver variability was not specifically studied in this patient population. Careful attention to technique is crucial to achieving reproducible fistula blood flow measurements and has a definite learning curve. The issue of interobserver variability must be actively investigated.

CONCLUSION

In summary, a single US fistula evaluation of minimum venous diameter and blood flow rate at 1-2 months can be used to accurately assess the likelihood of AVF maturation. If the AVF appears unequivocally mature at physical examination after 1 month, US may be superfluous. However, if there is any doubt about fistula maturation, the fistula should be evaluated at US. This early evaluation allows the patient with US evidence of stenosis or multiple draining venous branches and thrombosis, stenosis, to undergo early surgical or radiological treatment. If US findings indicate the fistula is unlikely to ever mature using the cut off criteria like flow volume of 500-600ml/min or caliber of up to 4-5 mm minimum, a new permanent access can be placed expeditiously. Thus reducing the waiting time is routinely advised.

FUTURE SCOPE

With further validation of above data on larger sample size Doppler can be used as a useful tool to predict fistula failure at a earlier date and reduce the morbidity due to long waiting time involved in clinical assessment. US evaluation for adequacy should be performed. Objective US assessment is also useful when an experienced examiner is not available, which is a common experience in many haemodialysis units.

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