Original Article

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Radiology Section

Value of Preoperative Sonographic Vascular Evaluation of Haemodialysis Access in Upperlimb

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ABSTRACT

Objective: To know the value of preoperative Dopplerul-trasonography vascular mapping of upper limb for hemodialysis access placement.

Materials and Methods: Prospective ultrasonographic assessment of upper extremity vessels was performed in 60 patients prior to hemodialysis access placement and potential access sites were selected (based on the standard criteria). The findings were correlated with the operative findings. Discrepancies found between ultrasonographic and operative findings were analysed.

Results: All the 60 patients who underwent vascular mapping had vascular access placed. 80% of them had native arteriovenous fistulae (AVF) placed. In 95% of patients, at the selected sites, the vascular parameters as determined by ultrasonography matched with the operative findings. In 5% of patients there were discrepancies between the ultrasonography findings and operative findings. There was no negative surgical exploration. There was strong correlation between the diameters measured by ultrasonography and surgery.

Conclusion: Preoperative ultrasonography vascular mapping prior to hemodialysis access placement has facilitated definite selection of potential sites in difficult patient population in whom evaluation by physical examination was inconclusive. It also helped in maximizing the native AVFs and decreasing the negative surgical exploration rates.

Keywords: Arterio-venous fistula, Hemodialysis access placement, Upper limb vascular mapping

INTRODUCTION

Hemodialysis (HD) is one of the discoveries of last century, which revolutionized the management of patients with renal failure. The vascular access (VA) is the end-stage renal disease (ESRD) patient's 'life line', providing the route for HD therapy. Arterio-venous fistulae (AVF) are the preferred access for HD. With continuously increasing number of patients on HD, complications following the procedure have been increasing as major causes of morbidity with subsequent hospitalization and increased cost to HD patients. The number of potential VA sites for HD per subject is limited. Therefore, measures to improve the longevity of VA are needed. AVF failures have been attributed to inadequate vessels used for surgery. Preoperative evaluation with Doppler ultrasonography (USG) is an excellent choice and may facilitate selection of suitable vessels and reduces AVF failures.

With the advance of high-resolution USG scanners the increased anatomical knowledge obtained with US mapping may change surgical management with an increase in the number of AVFs versus graft placed. It avoids the risk of phlebitis or contrast reaction from conventional venography and shows more vascular details than physical examination (PE). It is especially valuable in patients with poorly visualized veins as in bulky individuals, diabetics, elderly and patients with history of prior access.

OBJECTIVE

This study is intended to know the value of preoperative Doppler ultrasonographic vascular mapping on planning access placement with the subsequent decrease in negative surgical exploration.

MATERIALS AND METHODS

This was a hospital based prospective study of 60 patients done between November 2008 to June 2010. The patients planned for VA placement referred from the vascular Surgery department are included in this study. Patients with previously failed AV Grafts, deformed or scarred upper limb, upper limb arterial disorder like Raynaud's, heart valve disease or prosthesis, previous arm, neck or chest surgery/trauma were excluded. In all the 60 patients, evaluation by physical examination was inconclusive. More than half the patients (68%) were in the age group of 50 to 70 y.

a. Ultrasonographic evaluation of upper limb vessels

- This study was done using Voluson 730 Pro and GE Logiq 500 pro ultrasound scanners using Linear array probes with a frequency of 7 MHZ or higher for B-mode, and 5MHZ or higher for Doppler.
- The examination is performed with the patient lying supine on the couch. Depending on the planned access site, the operator sits on a stool facing the patient. The limb under examination is exposed, extended and placed in a relaxed position on a support. Tourniquet is applied to the proximal part of the limb under examination.

b. General protocol [1-4]

- The anatomy under examination is checked in both transverse and longitudinal planes.
- The transverse plane is used to identify vessels (artery and vein) and evaluate their diameter and wall thickness. Internal diameters are measured at different levels:caudal,mid and cranial forearm; at the antecubital fossa(ACF);and at the caudal, mid and cranial upper arm, as applicable.
- Arteries should be assessed for wall morphology. Document any arterial calcifications and stenosis.
- Veins should be assessed for compressibility and adequate drainage to deep venous system. Thrombosed, phlebitic and sclerotic segments of the vein should be noted.
- The depth of the CV from the skin surface is measured, if the depth is more than 0.5cms, the surgeon will need to consider for transposition.
- For a suitable anastomosis with brachial artery in ACF, the length of CV should extend 2cms below and that of basilic vein 4cms above the ACF.
- The nondominant arm is usually evaluated first. The forearm veins and arteries are assessed to determine whether the patient is a candidate for a forearm AVF, the most desirable initial type of VA. If

Vessel	Minimum Diameter(cms)
AVF vein	0.25
Graft vein	0.40
Artery(Graft or AVF)	0.20

[Table/Fig-1]: List of minimum diameter criteria for AVF and Graft creation

Order of Access Placement	Type of placement
One	Non-dominant forearm cv fistula
Two	Dominant forearm cv fistula
Three	Non dominant or dominant upper arm cephalic vein fistula
Four	Non dominant or dominant upper arm basilic vein transposition fistula
Five	Forearm loop graft
Six	Upper arm straight graft
Seven	Upper arm loop graft(axillary artery to axillary vein)

[Table/Fig-2]: List of the preferred order of vascular access placement

Access	Access site	Access Side		Total
		Left	Right	
Fistula	Brachiobasilic	2	5	7
	Brachiocephalic	15	11	26
	Brachio-Cubital	2	2	4
	Radiocephalic	8	3	11
	Total	27	21	48
Graft	Arteriovenous	6	6	12

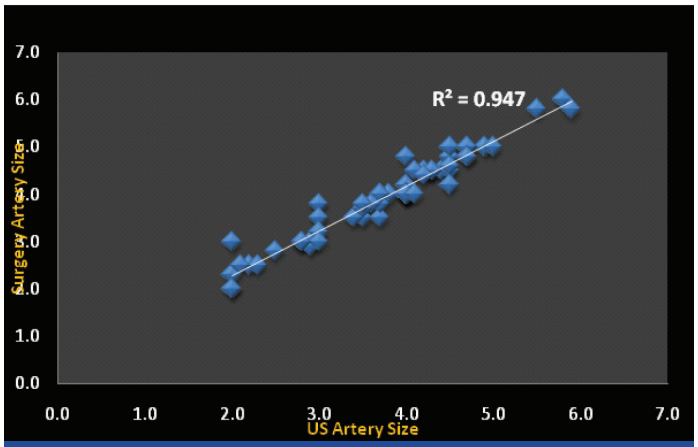
[Table/Fig-3]: Types of vascular accesses performed during surgery

vascular anatomy suitable for fistula creation is not found, the upper arm vessels should be mapped. Although a dominant forearm AVF is generally preferred over a nondominant upper arm AVF. If not suitable for AVF, the vessels should meet the size criteria for graft.

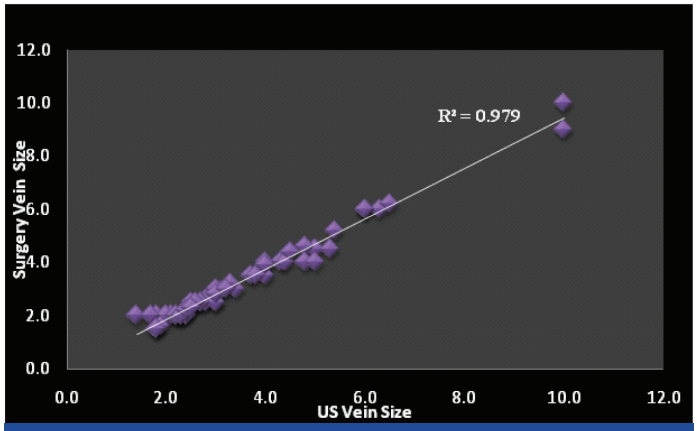
- Detailed anatomy of branches is not essential; If branches are large, to their completion to avoid missing variant anatomy. Presence of large vein branches in the first 10cms of the draining vein should be noted. However, identification of the particular variants at the median ACF is mandatory. Determine the anatomy of the median ante-cubital vein and note other anatomical variants. Most common: predominant forearm cephalic and upper arm basilic vein, double cephalic systems, 'Y' shaped connection between cephalic and basilic veins and other less common variants. The forearm CV may drain preferentially via a large ante-cubital vein into basilic or brachial veins if the upper arm CV is too small or thrombosed. In this case, placement of forearm fistula is still possible as long as diameter thresholds are maintained.
- An artery in the ACF that is smaller than expected, or the presence of two arteries at this site, is a clue that there is high bifurcation of the brachial artery and should be confirmed.
- Colour and Spectral Doppler waveforms are obtained in longitudinal plane of vessels selected for potential vascular access. Bilateral internal jugular and subclavian veins should be examined for symmetric respiratory phasicity and transmitted cardiac pulsatility, as well as to exclude outflow stenosis. Unilateral or bilateral monophasic waveforms or low velocity venous waveforms are abnormal [5,6].They should prompt further evaluation.
- Marking of skin surface for mapping of the potential vascular system is done accordingly.

Veins (Ultrasound)	(Veins) Surgery					Total
	Axillary	Antecubital	Basilic	Cephalic	Thrombosed	
Axillary	12	0	0	0	0	12
Antecubital	0	3	0	0	0	3
Basilic	0	0	6	0	0	6
Cephalic	0	0	0	36	1	37
Missed	0	2	0	0	0	2
Total	12	5	6	36	1	60

[Table/Fig-4]: Comparison of veins used between US and surgery



[Table/Fig-5]: Correlation between US and Surgery artery size



[Table/Fig-6]: Correlation between US and Surgery vein size

An important aspect of planning for AVF and graft creation is vessel size and preferential order of placement as given in [Table/Fig-1,2] [2,7].

c. Surgical correlation

- The USG result was then correlated with per-operative size of the vessel used in surgical procedure and outcome. The surgical outcomes were recorded. Correlation was performed to determine the selection of access site. The discrepancies found between the US and operative findings were also evaluated. Sizes of the vessel used for fistula formation was noted and measured. The circumference of the vessel selected was measured with the help of a thread which was then measured with a help of a scale to obtain the diameter of the vessel.

RESULTS

In the current study 60 patients were enrolled for evaluation of upper limb vascularity for VA. In the present study, the highest number of cases was in the age group of 50-59y followed by the age group of 60-69y. The mean age was 52y. Out of 60 patients 33 were males & 27 were females. Among 60 cases of CKD, majority (68.3%) of them were diabetics and hypertensives. 20 % of patients were

Arteries	N	Mean artery size by ultrasound	Surgically measured mean artery size
Brachial fistula	37	4.005 mm	4.176 mm
Radial	11	2.418 mm	2.691 mm
Axillary	2	5.150 mm	5.500 mm
Brachial graft	10	4.230 mm	4.370 mm

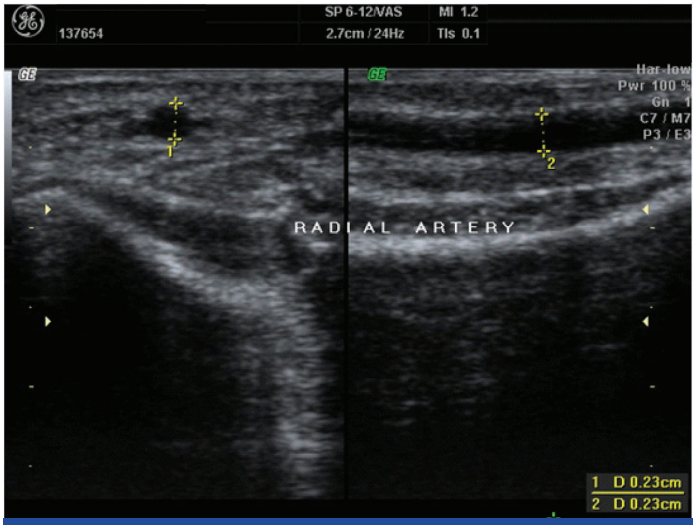
[Table/Fig-7]: US & surgical measurements of arteries

Arteries	N	Mean vein size by ultrasound	Surgically measured mean vein size
Axillary	12	5.725	5.400
Antecubital	3	5.433	4.500
Basilic	6	2.450	2.367
Cephalic vein (wrist)	11	2.191	2.020
Cephalic vein (elbow)	26	3.192	2.876

[Table/Fig-8]: US & surgical measurements of veins

Author/ Study	PE (%)	PE + DUSG (%)
Silva et al.,	34%	64%
Allon et al., [3]	14%	63%
Malvroh etal., [4]	0%(n=62)	77%
Wells et al.,	73%(n=145)	86.5%
Present study	0%	80%

[Table/Fig-9]: Comparison of present study with other studies for increase in AVF creation when physical examination was combined with US for pre-operative vascular mapping

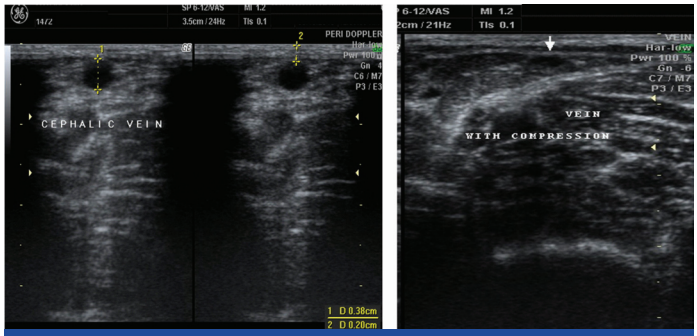


[Table/Fig-10]: Transverse & longitudinal US scan of left radial artery at wrist demonstrating adequate diameter (>2 mm)

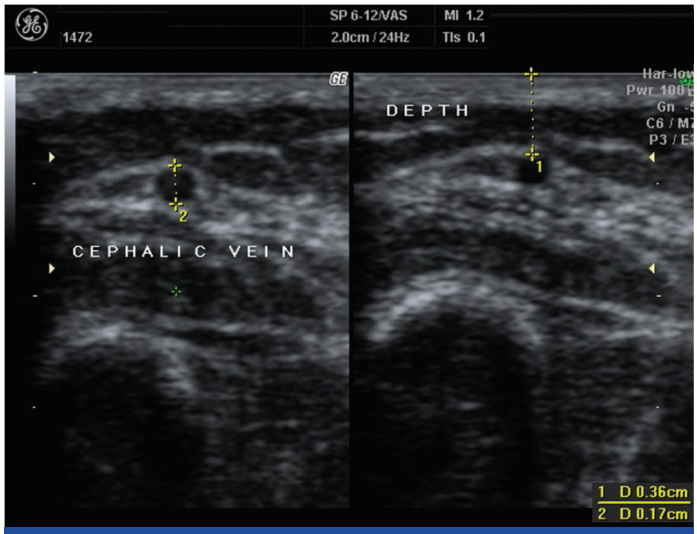
suffering from Diabetes Mellitus (DM) alone, 23 % of patients were suffering from hypertension (HTN) alone & 25 % of patients had both DM & HTN. Remaining patients were free from DM & HTN.

Majority of VA were grafts for the patients suffering from DM alone & in patients with DM & HTN. In patients suffering from HTN alone majority VA was fistula. Out of 60 patients, 48 underwent native AVF & remaining 12 patients had grafts [Table/Fig-3].

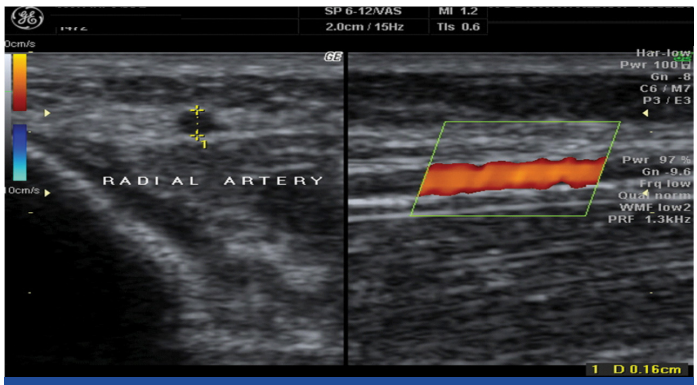
Left upper limb was selected for VA in 54 % of patients & right upper limb in reaming 46 %. Current study had four types of native AVFs; they are brachio-cephalic, brachio-basilic, brachio-cubital & radio-cephalic. Among these AVFs, brachio-cephalic was most common type of VA utilized, in 26 patients. Greater number of both sexes went for AVF as VA, 75.7% in males & 85.1% in females. Amid of grafts male sex predominated, eight male patients & four female patients underwent for grafts.



[Table/Fig-11] : Transverse gray scale sonograms of normal cephalic vein at wrist demonstrating: (a) Adequate diameter (> 2mm), (b) Depth from the skin surface and (c) Patency by compression of the vein



[Table/Fig-12] : Transverse gray-scale image showing small caliber cephalic vein measuring 1.7mm (inadequate for AVF placement)



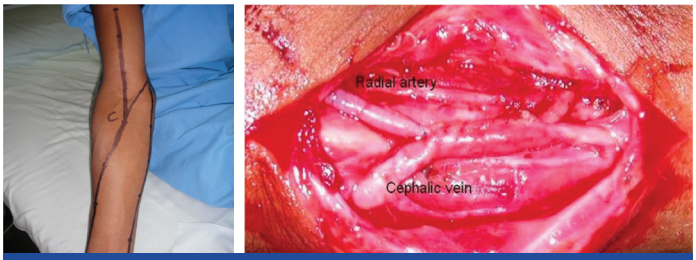
[Table/Fig-13]: (a) Transverse US scan of left radial artery at wrist showing small calibre artery measuring 1.6mm (inadequate for AVF placement). (b). Longitudinal US scan showing normal colour flow. However, it is not taken for AVF placement because of inadequate diameter

There was 100% correlation between the side of access selected and type of access selected by USG and surgery. Similarly there was 100% correlation between the arteries selected by the USG& arteries utilized during surgery for VA.

In the current study 95% correlation found between veins selected by the USG and veins utilized during surgery for VA [Table/Fig-4]. Because of greater number of anatomical variations at the cubital region 05% of mismatch was noted. Significant correlation was found between the diameters of arteries & veins measured by the USG & during the surgery [Table/Fig-5,6]. Hence, accuracy of selecting the type of VA in chronic renal failure patients by USG is 95%.

DISCUSSION

Chronic kidney disease (CKD) is one of the major public health problems with significant morbidity, mortality & causes immense deterioration of quality of life. Approximate incidence of patients



[Table/Fig-14]: Preoperative ultrasonographic vascular mapping for vascular access
[Table/Fig-15]: Intra-operative photograph showing radio-cephalic fistula

suffering from stage 5 CKD in developing countries is 150 per million populations [8]. 100 to 220 per million is the incidence of stage 5 CKD in India, amidst of them only 10 % receive renal replacement therapy. In a population based study from Bhopal in Central India, Modi et al., have reported the average crude and age adjusted incidence rates of stage 5 CKD (ESRD) as 151 and 232 per million population [9].

Hemodialysis (HD) is the most popular method of renal replacement therapy worldwide. HD is conducted by two methods, through a central venous dialysis catheter and other by permanent surgical access. Native AVF & synthetic AV graft are two types of permanent surgically created HD access. A native AVF is a surgically created, direct anastomosis between an artery and a vein, placed in either the forearm or upper arm. Connecting the artery to the vein causes more blood to flow into the vein. As a result, the vein grows larger and stronger, because of the greater flow of the arterialized blood through them, making repeated needle insertions for HD treatments easier [9,10]. If a primary AV fistula cannot be established, a synthetic AV graft is the next preferred type of VA. It is an artificial graft tunneled in the superficial soft tissues of the forearm, upper arm, or upper thigh with arterial and venous anastomosis [1]. Grafts may be placed in straight, looped, or curved configurations.

Fistulae and grafts differ according to failure rates, determination of access maturity, patency, complications, and peri-operative morbidity. Fistulas are preferred to graft cause of higher long-term patency rates, and lower rate of complications [10,11]. In the prevailing study out of 60 patients 80% were opted for native AVF & remaining 20% for vascular grafts. Similar observations were obtained in the study conducted by Allon M et al., who demonstrated 77 % of patients went for native AVF & 23% for vascular grafts [2].

Type of the VA depends on various factors like age, sex, race, presence of previous VA, underlying co-morbid conditions & body mass index. In our study patients suffering from DM alone or with HTN were opted for vascular grafts where as patients without DM were opted for native AVF. Allon M et al., in his study did not show any significant difference in the type of VA utilized on the basis of co-morbid conditions like DM [2].

According to the various researches including Allon M et al., the native AVF as VA predominated in the male patients than in the female sex [2]. Contrary the prevailing study demonstrated 85% of the female patients were opted for native AVF compared to 75% of male patients.

In simple terms, vascular mapping is a way of evaluating arteries and veins for fistula creation. In general, three means are available to perform mapping: physical examination (PE), USG examination and angiographic evaluation [11,12]. PE, a simple bedside assessment is performed to evaluate the patency of the arterial and the venous systems. Although an upper-extremity PE can be valuable, when used alone, it may be inadequate to identify suitable vasculature, particularly in obese patients or those with a history of prior VA, and is often supplemented with additional techniques, such as USG [13].

Duplex USG provide qualitative and quantitative data of arterial and venous systems before AVF creation. This technique using Doppler USG can identify veins otherwise missed by clinical examination. This approach is particularly helpful in patients with DM and in the elderly due to arterial narrowing and calcification which are relatively common in patients with CKD. It is for these reasons that arterial evaluation should be seriously carried out to know the patency, wall morphology, diameter and anatomical course while veins are seen for patency, diameter, length of a segment and depth [12,13].

The internal diameter of the artery is measured in longitudinal or transverse sections. In the longitudinal section, the probe is aligned to show the intimal layers at the near and far walls to measure the distance from intima to intima perpendicular to the arterial wall. In the transverse section, the probe needs to be perpendicular to the skin surface and the long axis of the artery parallel to the skin surface to avoid diameter overestimation [14]. Researchers like Malovrhet al., [15], Parmar et al., [16] & Wong et al., [17] showed immediate and early AVF failures when very small caliber arteries below 1.7 mm are used to prepare AVF. A minimum diameter of 2 mm was first suggested by Silva et al., who reported good AVF outcomes (8% early failure, 83% functional primary patency at 1 y) [7].

In the present study smallest mean arterial diameter measured by US was 2.418 mm for radial artery & largest mean arterial diameter is 5.150 mm for axillary artery. There was significant correlation between the diameters of arteries measured by US & by surgeons intra operatively [Table/Fig-7]. In a study by Malvroh et al., [18], mean radial artery diameter measured by US and surgery was 2.3 + 0.66 (range: 1.4 – 3.2) and 2.1+ 0.58 (range: 2.1-2.8) respectively. In this study, diameter of the radial artery measured by US and surgery was 2.4 ±0.5 (range: 2.0 – 3.8) and 2.6 ± 0.5 (range: 2.0 – 4.0) respectively.

Arterial wall morphology is also important in the success of VA. Arterial wall calcifications, diffuse intimo-medial thickening & atherosclerotic plaques play important role in the longevity of VA, which are better picked up by the B- mode USG. Ku et al., found a significant correlation between IMT and AVF failure due to thrombosis or dialysis inadequacy at 1 y ($r = 0.358$, $p= 0.027$) [19]. In the current study, the arteries with abnormal morphological changes were not selected for VA.

A peak systolic velocity (PSV) of at least 50 cm/sec was found to be necessary for a successful fistula in a study by Sedlacek M et al., [20]. In another study by Lockhart et al., arteries measuring < 2mm in diameter were excluded, there was no difference in pre-operative PSV between adequate and inadequate fistulae & no increased failure rate with a PSV of < 50 cm/sec. Therefore, above an arterial diameter of 2 mm, arterial flow and PSV may be unimportant in determining fistula outcome [21]. Since the mean smallest arterial diameter chosen for VA in our study was more than 2 mm, we did not give importance to PSV.

After the arterial assessment, venous assessment is important for successful VA. A normal vein has a thin and smooth wall, an anechoic lumen, and is fully compressible [22]. The vein mapped to receive arterial anastomosis should be measured after it is dilated. This size will more closely approximate the size of arterialized vein following fistula formation. The vein is generally dilated by use of sequential tourniquet placement or an inflated blood pressure cuff on the arm [23].

Venous diameter is an important criterion in the preoperative mapping sonogram. A minimum diameter of 2.5 mm with tourniquet was first suggested by Silva who reported good AVF outcomes (8% early failure, 83% functional primary patency at 1 y) [18]. Criteria for upper arm veins are not established but a diameter of at least 3 mm has been recommended [24]. Vein diameters have a considerable day-to-day variation and depend on the examination conditions (ambient temperature and patient position). Therefore, veins should be evaluated under optimal conditions [25,26]. Minimum mean diameter of vein for VA measured by US is 2.191 mm for CV& maximum diameter of 5.725 mm for axillary veins. There is notable correlation found between the diameters of veins measured by US & by surgeons intraoperatively [Table/Fig-8].

Duplex US have been shown to yield sufficient anatomical data that correlates with angiographic studies [27]. In the present study three anatomical variations were detected which helped in planning for

surgery. Two were high brachial artery bifurcation and another one was cephalic vein duplication.

We have come across various determinants determined by US of arteries and veins in the upper limbs, which helps in selecting the site for successful VA. Vascular mapping with PE alone is insufficient and it has to be supplemented by the US vascular mapping. Preoperative venous and arterial mapping with US has led to remarkable increase in AVF placements when compared with PE alone, particularly in patients with inadequate PE due to obesity, absent pulses, or those with a history of previous vascular access. Various studies show that there is consequential increase in the incidence of successful VA after US vascular mapping than with physical mapping alone [Table/Fig-9] [28]. The prevailing study shows accuracy of 95% for selecting the type of VA in CRF patients.

There is substantial decrease in negative surgical exploration rates with pre-operative vascular US. Malvroh et al.,[18], documented 0% negative surgical exploration rate. Another study by Allon et al.,[29], showed 11% (28 0f 256) negative surgical exploration rate. In the present study there was 0 % negative surgical exploration rate. 5% of the US selected veins did not match the operative findings. But however, this did not yield to negative surgical exploration as other suitable vessels were found at the same site. These discrepancies were seen in the veins of cubital region and were attributed to the confusing venous variations of the cubital region. Hence, thorough knowledge of anatomical variations can reduce discrepancies and aid the surgeons for better surgical management [Table/Fig-10-15].

Hence, pre-operative US vascular mapping and evaluation of various parameters (anatomy, vessel diameter and patency) was valuable in selecting potential site for successful VA construction.

CONCLUSION

Using various parameters like vessel diameters, anatomical variations, patency and wall morphology, pre-operative Doppler ultrasonographic vascular mapping is valuable in selecting potential sites for vascular access there by helping in maximizing the native AVFs and decreasing the negative surgical exploration rates.

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