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Value of Preoperative Sonographic Vascular Evaluation of Haemodialysis Access by Arterio-Venous Fistula in Upper Limb

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ABSTRACT

This study was done to know the value of preoperative sonographic vascular mapping of for haemaccess placement by arterio-venous fistula in upper limb. Pre-operative sonographic assessment of upper limb vessels was performed in 60 patients prior to vascular access placement and potential sites were selected (based on the standard criteria). The findings obtained were correlated with the operative findings and discrepancies found between sonographic and operative findings were analysed. All the 50 patients who underwent vascular mapping had VA placed. In 96% of patients, at the selected sites, the vascular parameters as determined by sonography matched with the operative findings. In 4% of patients there were discrepancies between the sonographic findings and operative findings. There was no negative surgical exploration. There was strong correlation between the diameters measured by US and surgery. Preoperative sonographic vascular mapping prior to Haemodialysis 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 maximising the successful AVFs and decreasing the negative surgical exploration rates.

INTRODUCTION

Haemodialysis (HD) has been a groundbreaking advancement in managing patients with renal failure, providing a lifesaving option for those with end-stage renal disease (ESRD)[1]. In HD, a reliable vascular access (VA) serves as the "lifeline" through which blood can be cleansed, making it a fundamental component for the patient's survival and quality of life[2]. Among the types of vascular access available, arteriovenous fistulae (AVF) are preferred due to their longevity, effectiveness and lower risk of complications[3]. However, the growing population of ESRD patients has led to a rise in the number of VA placements required. This increased demand for access procedures has also brought a surge in associated complications, heightening morbidity, healthcare costs and challenges for patients undergoing HD.

Due to the limited number of accessible VA sites in a patient, it is crucial to adopt methods that maximize the durability and functionality of each access point. One of the primary causes of AVF failure lies in the inadequate quality or size of the vessels used in surgery[4]. Consequently, careful preoperative (PO) planning is essential to select suitable vessels and avoid premature AVF failure. In this context, preoperative vascular mapping using ultrasound (US) has emerged as an indispensable tool[5]. Ultrasound is a non-invasive, radiation-free and cost-effective modality that enables precise visualization of blood vessels, facilitating the selection of the most appropriate vessels for AVF creation. This approach not only improves the chances of a successful initial surgery but also significantly reduces the risk of requiring subsequent corrective procedures[6].

The advancement of high-resolution ultrasound technology has enhanced the ability to obtain both qualitative and quantitative data about vascular structures before surgery, which greatly assists in planning. Sonographic mapping offers surgeons detailed anatomical information that can lead to better outcomes by increasing the likelihood of successful AVF placements[7]. Unlike traditional methods such as venography, ultrasound avoids the risk of phlebitis or contrast reactions and provides more comprehensive vascular details than a physical examination alone. This detailed visualization is particularly beneficial for patients in whom veins are less visible or accessible, such as those who are obese, diabetic, elderly, or have a history of prior access surgeries. With sonographic mapping, the surgical team gains a clear understanding of the vascular landscape, reducing the likelihood of negative surgical explorations and improving the overall efficiency and safety of vascular access procedures[8].

This study aims to evaluate the effectiveness of preoperative sonographic mapping in planning vascular access placements for haemodialysis patients, with the goal of reducing negative surgical explorations and enhancing surgical outcomes. By assessing the efficacy of vascular sonographic mapping before access placement, the study seeks to establish a correlation between preoperative imaging findings and intraoperative results. This correlation could lead to better selection of vascular sites, improved surgical success rates, and overall positive outcomes for patients requiring haemodialysis access.

MATERIALS AND METHODS

This prospective study was conducted at Mamata Medical College, Khammam, from July 2014 to November 2015. Fifty patients referred from the Surgery Department, who were scheduled for arteriovenous fistula (AVF) placement, were included.

Data Collection and Ultrasonographic Assessment: Duplex ultrasonography was employed to evaluate each patient's vascular access suitability, specifically targeting vessel size, wall morphology, and patency, based on the requirements for AVF formation. This imaging technique helped determine the optimal site for access placement.

Inclusion and Exclusion Criteria:

- **Inclusion:** Patients requiring AVF construction in the upper limb for haemodialysis access.
- **Exclusion:** Patients requiring AV grafts., those with scarred or deformed upper limbs., upper limb arterial disorders like Raynaud's disease., candidates for imminent renal transplant from a living donor., individuals with heart valve disease or prostheses., patients with prior surgical or traumatic intervention to the arm, neck, or chest., and any patient for whom AVF placement is contraindicated or technically unfeasible.

Ultrasonography Equipment and Imaging Protocol: The study utilized Esoate My Lab 60 and Sonoscape ultrasound scanners with 7 MHz or higher frequency linear array probes for B-mode imaging. Each vessel was examined in transverse and longitudinal planes to gather the following information:

B-mode Observations:

- Vessel size.
- Vascular anatomical assessment.
- Wall thickness.
- Detection of cephalic vein branches that might require ligation to prevent fistula flow diversion.
- Vein compressibility.

Color Flow and Doppler:

- Vessel patency assessment.
- Identification of arterial and venous flow disturbances.

Criteria for Hemodialysis Access Selection: Ultrasound findings guided the AVF site selection in a prioritized manner:

Forearm AVF:

- Radial artery diameter of 2.0 mm or greater and a cephalic vein of at least 2.5 mm in diameter throughout its course into the subclavian vein were deemed suitable. The presence of a large forearm median cubital vein or brachial/basilic vein was also considered favorable.

Upper Arm AVF:

- If a suitable forearm vein-artery combination was unavailable, the upper arm cephalic or basilic vein (without stenosis or occlusion) was evaluated. The cephalic vein was preferred due to lower morbidity and preservation of the upper arm for future procedures.

Surgical Correlation and Measurement: Ultrasonographic assessments were compared with intraoperative findings to assess vessel size, surgical details, and outcomes. Discrepancies between ultrasound and surgical findings were documented, and vessel circumference was measured using a thread and then converted to diameter using a scale for consistency.

Statistical Analysis: Appropriate statistical tests were applied to determine any significant differences between ultrasonographic and surgical findings, analyzing the accuracy of ultrasonography for AVF access placement.

RESULTS AND DISCUSSIONS

The combined (table 1) provides an overview of the age and gender distribution within the study population of 50 patients. The age group with the highest representation is 50-59 years, comprising 19 individuals (38%), followed by those aged over 60, with 15 patients (30%). A smaller proportion of patients are found in the 40–49 age group, with 10 individuals (20%), while only 4 patients (8%) fall within the 30-39 age range. There are very few patients under 20 years old (2 patients, or 4%) and none within the 20-29 age range. The gender distribution across these age groups is relatively balanced, with 24 males (48%) and 26 females (52%) in the overall study population. This distribution indicates that the need for AVF placement in this study predominantly arises in older age groups, with a slight female majority.

(Table 2) illustrates the distribution of clinical histories among the study population and their corresponding fistula types. Among the 50 patients, the majority had either hypertension (30%) or both diabetes and hypertension (28%), with 22% having only diabetes and 20% classified under "Others." The most common fistula type used was radio-cephalic (48%), followed by brachio-cephalic (40%), while brachio-basilic and brachio-cubital fistulas were less frequently employed, with 8% and 4% respectively. The table highlights that patients with different clinical histories had varying distributions of fistula types, with radio-cephalic fistulas being the most common across all clinical categories.

(Table 3) combines the distribution of patients by the side of access chosen for haemodialysis and the type of fistula used. Of the 50 patients, the majority (60%) had their access on the left side, while 40% had it on the right side. Among fistula types, radio-cephalic was the most common, representing 48% of all accesses, with a relatively balanced distribution between the left (54.2%) and right (45.8%) sides. Brachio-cephalic fistulas were the next most common at 40%, predominantly on the left side (70%). Brachio-basilic and brachio-cubital fistulas were less frequent, with an equal split between the left and right sides for each type.

(Table 4) presents the study population by gender, side of access, and type of fistula.

- **Side of Access:** Of the 50 patients, 60% had their access on the left side and 40% on the right. Among males, 54.2% had left-sided access, and 45.8% had right-sided access. For females, 65.4% had left-sided access and 34.6% had right-sided access.
- **Type of Fistula:** The most common fistula type overall was radio-cephalic (48%), with a slightly higher frequency in males (54.2%) than in females (45.8%). Brachio-cephalic fistulas accounted for 40% of all cases, with a distribution of 45% in males and 55% in females. Brachio-basilic fistulas were evenly distributed between genders (8%), while brachio-cubital fistulas were present only in females (4%).

(Table 5) presents a comparison of artery sizes measured by ultrasound (US) and during surgery for the radial and brachial arteries. For the radial artery, the mean size was 2.418 mm on ultrasound and 2.691 mm during surgery, with a t-value of 0.5577 and a p-value of 0.689, indicating no statistically significant difference between the two measurements. Similarly, for the brachial artery, the mean size was 4.005 mm on ultrasound and 4.176 mm during surgery, with a t-value of 0.3019 and a p-value of 0.7638, also showing no statistically significant difference. This suggests that the ultrasound measurements of artery sizes closely correlate with the sizes observed during surgery, supporting the accuracy of ultrasound as a preoperative evaluation tool for arterial selection.

(Table 6) compares vein sizes measured by ultrasound (US) and during surgery for different veins used in vascular access. The antecubital vein had a mean size of 5.433 mm by ultrasound and 4.500 mm

Table1: Age and Gender Distribution of the Study Population

AGE GROUP (YEARS)	MALE	FEMALE	TOTAL (%)
< 20	1	1	2 (4%)
20-29	0	0	0 (0%)
30-39	2	2	4 (8%)
40- 49	5	5	10 (20%)
50-59	9	10	19 (38%)
>60	7	8	15 (30%)
Total	24 (48%)	26 (52%)	50 (100%)

Table 2: Clinical History and Fistula Type Distribution of Study Population

CLINICAL HISTORY	BRACHIO-BASILIC	BRACHIO-CEPHALIC	BRACHIO-CUBITAL	RADIO-CEPHALIC	TOTAL (%)
DIABETES (DM)	1 (25%)	4 (20%)	0 (0%)	6 (25%)	11 (22%)
HYPERTENSION (HTN)	1 (25%)	6 (30%)	1 (50%)	7 (29.2%)	15 (30%)
DIABETES + HYPERTENSION	1 (25%)	6 (30%)	0 (0%)	7 (29.2%)	14 (28%)
OTHERS	1 (25%)	4 (20%)	1 (50%)	4 (16.6%)	10 (20%)
Total (%)	4 (8%)	20 (40%)	2 (4%)	24 (48%)	50 (100%)

Table 3: Distribution of Patients Based on Side of Access and Fistula Type

FISTULA TYPE	LEFT	RIGHT	TOTAL (%)
Brachio-Basilic	2 (50%)	2 (50%)	4 (8%)
Brachio-Cephalic	14 (70%)	6 (30%)	20 (40%)
Brachio-Cubital	1 (50%)	1 (50%)	2 (4%)
Radio-Cephalic	13 (54.2%)	11 (45.8%)	24 (48%)
Total (%)	30 (60%)	20 (40%)	50 (100%)

Table 4: Gender Distribution by Side of Access and Type of Fistula

GENDER	SIDE OF ACCESS	TOTAL (%)		TYPE OF FISTULA	TOTAL (%)
	Left	Right		Brachio-Basilic	Brachio-Cephalic
Male	13 (54.2%)	11 (45.8%)	24 (48%)	2 (50%) 9 (45%)	
FEmale	17 (65.4%)	9 (34.6%)	26 (52%)	2 (50%) 11 (55%)	
Total	30 (60%)	20 (40%)	50 (100%)	4 (8%) 20 (40%)	

Table 5: Correlation of Artery Sizes Selected Between Ultrasound (US) and Surgery

ARTERY	N (US)	MEAN ARTERY SIZE (US) (mm)	N (SURGICAL)	MEAN ARTERY SIZE (SURGICAL) (mm)	T VALUE	P VALUE
Radial	20	2.418 ± 1.326	20	2.691 ± 1.742	0.5577	0.689
Brachial	30	4.005 ± 1.987	30	4.176 ± 2.382	0.3019	0.7638

Table 6: Correlation of Vein Sizes Selected Between Ultrasound (US) and Surgery

VEIN	N (US)	MEAN VEIN SIZE (US) (mm)	N (SURGICAL)	MEAN VEIN SIZE (SURGICAL) (mm)	T VALUE	P VALUE
Antecubital	2	5.43 ± 3.894	2	4.500 ± 3.243	0.2604	0.8189
Basilic	4	2.45 ± 1.512	4	2.367 ± 1.843	0.0696	0.9467
Cephalic vein (wrist)	20	2.19 ± 1.059	20	2.020 ± 1.654	0.3894	0.6992
Cephalic vein (elbow)	24	3.19 ± 2.682	24	2.876 ± 1.295	0.4913	0.6256

surgically, with a t-value of 0.2604 and a p-value of 0.8189, indicating no statistically significant difference. The basilic vein measurements showed a mean size of 2.450 mm on ultrasound and 2.367 mm surgically, with a t-value of 0.0696 and a p-value of 0.9467, also non-significant. The cephalic vein at the wrist had a mean size of 2.191 mm on ultrasound compared to 2.020 mm surgically, with a t-value of 0.3894 and a p-value of 0.6992, showing no significant difference. For the cephalic vein at the elbow, the mean size was 3.192 mm on ultrasound and 2.876 mm surgically, with a t-value of 0.4913 and a p-value of 0.6256, again showing no significant difference.

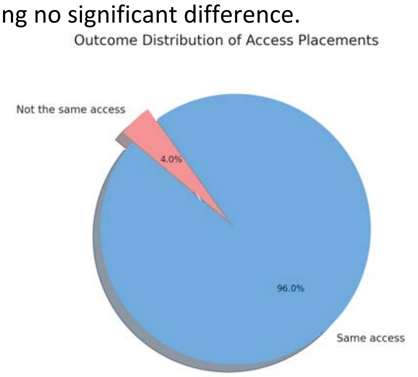

Fig. 1: Outcome Distribution of Access Placements in Study Population

The above graph shows the outcome distribution based on whether the planned access site (determined by ultrasound) matched the actual access site used during surgery. Among the 50 patients in the study, 48 (96%) had the same access site as initially planned by ultrasound, while 2 patients (4%) had a different access site than initially planned. This high percentage of cases with the same access site suggests that ultrasound planning is highly accurate and effective in determining appropriate vascular access for surgery.

Chronic kidney disease (CKD) is a significant public health issue with considerable morbidity, mortality, and a profound impact on quality of life. CKD affects approximately 17.2% of the population, with around 6% having CKD stage 3 or worse[9]. Hemodialysis (HD) is the most widely used renal replacement therapy, conducted either via a central venous dialysis catheter or through surgically created permanent access[10].

For Permanent HD Access, two Main Types Exist: the native arteriovenous fistula (AVF) and synthetic arteriovenous (AV) graft. A native AVF involves a surgically created direct connection between an artery and a vein, commonly in the forearm or upper arm[11]. This connection increases blood flow into the vein, causing it to enlarge and strengthen over time, which facilitates repeated needle insertions for HD treatments. AVFs generally demonstrate higher long-term patency and lower complication rates compared to synthetic grafts[12].

In the present study, 50 patients scheduled for AVF creation underwent preoperative vascular mapping, which included both males (24) and females (26). Physical examination alone proved inconclusive in all patients, necessitating further imaging. The patients had a variety of risk factors, with 38% between 50 to 59 years of age. Additionally, 11 patients were diabetic, 15 were hypertensive and 14 had both diabetes and hypertension, which are known risk factors for AVF failure due to their association with marginal vascular health. Thus, preoperative ultrasound (US) assessment was essential to optimize vessel selection and reduce failure rates.

All 50 patients in this study successfully underwent vascular access (VA) placement following preoperative ultrasonographic mapping, irrespective of their medical history. Interestingly, while some studies, like those by Allon[13] reported no significant impact of comorbidities on the type of VA used, this study found that 52% of female patients were selected for native AVFs, slightly more than male patients at 48%.

Vascular mapping enables assessment of arteries and veins for fistula creation, utilizing physical examination, ultrasound (US) evaluation and angiography. Duplex ultrasound provides qualitative and quantitative data on the vascular system prior to AVF creation, helping identify veins otherwise undetectable by clinical examination. This is especially beneficial in patients with CKD and diabetes or elderly patients, who may exhibit arterial narrowing and calcification.

Vessel diameter is crucial for successful AVF creation. Study by Malovrh[14] emphasize the importance of adequate vessel size, with a minimum arterial diameter of 2 mm associated with higher AVF patency and lower early failure rates. In this study, the mean ultrasonographic diameter for the radial artery was 2.418±1.326 mm, closely matching the surgical measurement of 2.691±1.742 mm, with no significant difference, indicating a good correlation between US and surgical findings.

The study also highlights the importance of arterial wall morphology in VA success. Arterial wall calcifications, intimo-medial thickening, and plaques can compromise AVF longevity and are better visualized with B-mode US. In line with Ku *et al.*'s findings, the present study avoided using arteries with abnormal wall morphology for VA construction.

In addition to arterial assessment, venous assessment plays a vital role in successful VA placement. Criteria for venous diameter include a minimum diameter of 2.5 mm for wrist veins and 3 mm for upper arm veins. In this study, the mean ultrasonographic measurement for the cephalic vein at the wrist was 2.191±1.059 mm, closely matching the surgical measurement of 2.020±1.654 mm. Similarly, the cephalic vein at the elbow showed mean measurements of 3.192±2.682 mm by US and 2.876±1.295 mm surgically, with no significant difference, underscoring the accuracy of US in venous diameter assessment.

Preoperative sonographic vascular mapping improves AVF placement success rates compared to physical examination alone, particularly in patients where physical examination is limited by obesity, absent pulses, or prior vascular access. This study demonstrated a 96% accuracy rate for selecting appropriate AVF sites with US vascular mapping, which significantly reduces negative surgical exploration rates. While previous studies, such as Allon *et al.*, reported up to 11% negative exploration rates, this study achieved a 0% rate, with only 4% of US-selected veins not aligning with operative findings. However, alternative suitable vessels were identified in these cases, preventing negative outcomes.

CONCLUSION

Preoperative sonographic vascular mapping is highly effective for selecting optimal vascular access sites in patients where physical examination alone is inconclusive. This approach has led to a 96% success rate in matching sonographic and surgical findings, with no negative surgical explorations in this study. The accuracy of US in assessing vessel diameter, anatomy, patency and wall morphology enhances AVF placement success and minimizes complications. Discrepancies were minimal (4%) and did not impact outcomes, as alternative vessels were identified at the same site.

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