

Reliability of preoperative venous mapping ultrasonography in predicting for autogenous arteriovenous fistula maturation

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ABSTRACT

Background: Autogenous arteriovenous fistula creation is the preferred route for vascular access for hemodialysis. Although preoperative venous mapping ultrasonography has been advocated as an operative planning adjunct and recently incorporated into the Society for Vascular Surgery clinical guidelines, controversy remains regarding its usefulness for predicting access success. The purpose of the present retrospective clinical study was to test the hypothesis that vein size measured on routine preoperative venous mapping is a poor predictor of primary fistula maturation.

Methods: Consecutive upper extremity autogenous arteriovenous fistulas created by three dedicated vascular surgeons were retrospectively reviewed. The demographic characteristics, preoperative venous mapping, functional maturation, and patency were analyzed. The clinically relevant variables were tested for predictive significance using a logistic regression model.

Results: A total of 199 upper extremity autogenous arteriovenous fistulas had been created during a 5-year period. Patients were aged 70 ± 16 years (range, 20-96 years), and 62% were men. Most had already been undergoing dialysis before fistula creation (83%), usually via a tunneled central venous catheter (62%). Radial-cephalic, brachial-cephalic, and brachial-basilic arteriovenous fistulas had been created in 82 patients (41%), 76 patients (38%), and 10 patients (5%), respectively. Fistula maturation, defined as a palpable thrill and/or successful cannulation of the fistula with the ability to deliver a flow rate of 400 mL/min, was achieved in 67% of the patients. A higher body mass index was associated with nonmaturation on both univariate and multivariate analyses (success, 28.6 ± 7.7 kg/m²; vs failed, 31.6 ± 9.4 kg/m²; $P = .029$; odds ratio [OR], 1.06; 95% confidence interval [CI], 1.02-1.10; $P < .01$). On univariate analysis, the maximum target vein diameter assessed by preoperative venous mapping was slightly larger in the group achieving successful maturation (2.9 ± 1.1 mm vs 2.6 ± 0.9 mm; $P = .014$). However, neither the maximum target vein diameter nor a target vein size >3 mm was significantly predictive of maturation on multivariate analysis (maximum vein diameter: OR, 0.65; 95% CI, 0.35-1.22; $P = .176$; vein size >3 mm: OR, 0.91; 95% CI, 0.32-2.60; $P = .857$). After a median follow-up of 15 months (interquartile range, 26 months), the primary functional patency, primary-assisted patency, and secondary patency rates were $39.1\% \pm 0.6\%$, $94.5\% \pm 0.6\%$, and $97.9\% \pm 0.5\%$. No association of vein diameter with long-term patency was found.

Conclusions: Despite the national fistula-first initiatives, most patients still undergo access via catheter at the initiation of hemodialysis. The use of routine preoperative venous mapping does not predict successful primary maturation. Also, no clinically useful predictor of fistula maturation was identified in the present study. (*J Vasc Surg* 2021;73:1787-93.)

Keywords: Arteriovenous fistula; Maturation; Patency; Venous mapping

Life-extending renal replacement therapy has reached a global scale. Worldwide, it has been estimated that >1.5 million persons require dialysis to survive.¹ In the United States, $>700,000$ patients are maintained by dialysis, with a total annual expenditure in excess of \$30 billion, representing $>5\%$ of the entire budget of the Centers for Medicare and Medicaid Services.²

Approximately 70% of patients requiring hemodialysis have access to their vascular system maintained via a surgically created peripheral arteriovenous fistula (AVF) or arteriovenous graft.³ These vascular reconstructive operations create high blood-flow conduits that can be repeatedly accessed percutaneously, allowing patients' blood to rapidly contact the dialysate. Although fairly easy to

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create, these conduits have proved notoriously difficult to maintain. Only ~60% of AVFs will mature to functionality,⁴ and only ~50% of AVFs and 30% of arteriovenous grafts will maintain primary patency for ≥ 6 months.⁵⁻⁹ Complications, including venous outflow stenosis, frank thrombosis, pseudoaneurysm, infection, and arterial steal, are common. On average, patients will require at least one procedure every 2 years to keep blood reliably flowing through the access conduit.⁵

Despite its being axiomatic, the utility of ultrasound vein mapping before arteriovenous fistula creation has often been difficult to demonstrate.¹⁰ Although the findings from many reports have been convincing,¹¹⁻¹⁶ the results from several notable, randomized studies have proved disappointing. The frustrating failure rate of AVF maintenance has naturally led to a search for improved strategies. One popular approach is the routine use of preoperative ultrasonography to measure and map the superficial veins of the upper extremities to select the optimal conduit for anastomosis. This practice has been extensively studied, endorsed by many surgeons,^{11-13,17-23} and included in the Society for Vascular Surgery practice guidelines for the surgical placement and maintenance of arteriovenous hemodialysis access.²⁴ Other practitioners, including us, have noted a surprisingly poor correlation between the preoperative venous mapping and intraoperative findings and have been concerned that usable veins might be overlooked if using solely the ultrasound findings. The purpose of the present clinical study, therefore, was to test the hypothesis that the vein size measured on routine preoperative venous mapping is actually a poor predictor of primary AVF maturation.

METHODS

The present study was a retrospective review of consecutive patients who had undergone upper extremity autogenous hemodialysis access creation performed at a single institution by three vascular surgeons during a 5-year period. All patients had undergone preoperative upper extremity ultrasound vein mapping using 5-, 6-, or 12-MHz scanning probes by registered vascular technologists in a dedicated vascular laboratory accredited by the Intersocietal Accreditation Commission. The vein assessments included the diameter, compressibility, depth, and continuity. Vein sizes were recorded at the wrist, distal forearm, mid-forearm, proximal forearm, antecubital fossa, distal upper arm, mid-upper arm, and proximal upper arm. Assessments of central vein continuity and arterial sufficiency were also performed. For these measurements, the arm was placed in a dependent position, and tourniquets were not routinely used. Patients already receiving dialysis via an alternate route had undergone ultrasound vein mapping on a nondialysis day.

AVFs were created with the patient under local or general anesthesia. After no-touch dissection, the target veins were gently dilated with insufflation of heparinized

ARTICLE HIGHLIGHTS

- **Type of Research:** A single-center, retrospective cohort study
- **Key Findings:** Fistula maturation was achieved in 67% of patients who had undergone autogenous arteriovenous access creation. Vein size >3 mm on preoperative mapping ultrasound scans was not significantly associated with fistula maturation. Few predictors of fistula maturation were encountered. After a median follow-up of 15 months, primary functional patency did not significantly differ in patients with a vein <3 vs >3 mm in diameter (26.4% vs 18.3%; $P = .94$).
- **Take Home Message:** Vein size on preoperative venous mapping ultrasound scans is a poor predictor of success in autogenous access creation.

saline on a blunt needle. Anastomoses were created with running 7-0 polypropylene sutures.

The baseline patient characteristics, end-stage renal disease status, perioperative details, and complications were tabulated and analyzed. A scripted telephone interview was conducted with the patients to reassess the AVF outcomes.

The patency and functionality endpoints were defined in accordance with the Society for Vascular Surgery reporting standards.²⁵ Similarly, a vein size cutoff of 3 mm corresponding to the highest grade indicated in the 2002 guidelines was selected. Fistula maturation, a binary outcome variable, was defined as a palpable thrill and/or successful and repeated cannulation of the fistula with the ability to deliver a flow rate of 400 mL/min. Non-maturation (maturation failure) was defined as the absence of thrill at follow-up examination or failed initial cannulation. Patients with a palpable thrill who had not yet required dialysis were censored as having a primary functionally mature AVF. Patients with a palpable thrill in a AVF that could not be successfully accessed were censored as having a primary functional failed AVF. AVFs that required assistance to become functional were classified as failure of functional maturation. For time-based variables, the primary functional patency signified uninterrupted AVF flow and usage after creation. AVFs that required endovascular or surgical intervention to maintain patency were designated as patent with assistance. AVFs that required endovascular or surgical intervention to restore patency were designated as secondarily patent.

Univariate comparisons were performed using the χ^2 test for categorical variables and the independent Student t test for continuous variables. Results are presented as percentages and the mean \pm standard deviation. Logistic regression was performed to analyze the independent predictors of primary functional maturation, with

Table I. Univariate comparison of patients with maturation of autogenous arteriovenous fistulas vs nonmaturation

Variable	AVF maturation		P value
	Yes (n = 133)	No (n = 66)	
Demographic characteristics			
Age, years	69 ± 27	71 ± 14	.54
Male sex	83 (62.4)	40 (60.6)	.86
White race	96 (72.2)	54 (81.8)	.14
BMI, kg/m ²	28.6 ± 7.7	31.6 ± 9.4	.029
Hypertension	122 (91.7)	65 (98.5)	.11
Diabetes mellitus	79 (59.4)	44 (66.7)	.34
CVA	19 (14.3)	14 (21.2)	.37
COPD	17 (12.8)	7 (10.6)	.31
CAD	60 (45.1)	29 (43.9)	.52
Smoker	34 (25.6)	19 (28.8)	.90
Antiplatelet agent	48 (36.1)	27 (40.9)	.63
Anticoagulation therapy	23 (17.3)	10 (15.2)	.92
Dialysis status			
Hemodialysis	110 (82.7)	55 (83.3)	.27
Previous ipsilateral hemodialysis access	55 (41.4)	24 (36.4)	.42
Previous tunneled catheter	89 (66.9)	35 (53)	.057
Perioperative findings			
General anesthesia	12 (9.0)	6 (9.1)	.58
Dominant side access	41 (33.3)	18 (28.1)	.47
AVF type			.23
Radial-cephalic	47 (35.3)	35 (53)	
Brachial-cephalic	53 (39.3)	23 (34.8)	
Brachial-basilic	8 (6)	2 (3)	
Basilic vein transposition	24 (18)	6 (9.1)	
OR time, minutes	106 ± 33	97 ± 28	.050
Venous mapping results			
Maximum target vein diameter, mm	2.9 ± 1.1	2.6 ± 0.9	.014
Vein diameter ≥3 mm	56 (42.1)	20 (30.3)	.11
Maximum vein diameter 1 level proximal to fistula, mm	3.8 ± 1.5	3.5 ± 1.2	.072
Postoperative complication and outcomes			
Steal phenomenon	13 (9.8)	9 (13.6)	.41
Steal syndrome	2 (1.5)	5 (7.6)	.029
Venous hypertension	0 (0)	0 (0)	1.00
Neuropathy	0 (0)	2 (3)	.11
Surgical site infection	0 (0)	1 (1.5)	.33
Bleeding	6 (4.5)	2 (3.0)	.62
Fluid collection	5 (3.8)	1 (1.5)	.38
Anastomotic complication	1 (0.8)	1 (1.5)	.61

AVF, Arteriovenous fistula; BMI, body mass index; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; OR, operating room.

Data presented as mean ± standard deviation (continuous variables) or number (%); χ^2 and independent Student's *t* test for categorical and continuous variables, respectively. Boldface *P* values represent statistical significance.

Table II. Predictors of functional maturation using multinomial logistic regression, including statistically significant variables on univariate analysis ($P < .10$)

Variable	OR (95% CI)	<i>P</i> value
BMI	1.06 (1.02-1.10)	.005
Previous tunneled dialysis catheter	0.58 (0.31-1.09)	.090
Operating room time	0.99 (0.98-1.01)	.38
Maximum vein diameter one level proximal to fistula	0.90 (0.64-1.27)	.55
Target vein diameter ≥ 3 mm	0.91 (0.32-2.60)	.86

BMI, Body mass index; *CI*, confidence interval; *OR*, odds ratio.
Boldface *P* values represent statistical significance.

$P < .10$ on univariate analysis as the inclusion criterion. Separate models were created for co-linear variables such as the maximum target vein diameter and vein diameter of ≥ 3 mm. Calibration was assessed using a goodness-of-fit test. Life-tables were created to study primary functional maturation and patency results. A Kaplan-Meier survival analysis with a log-rank test was used to compare primary patency in patients with veins measuring < 3 mm or ≥ 3 mm on preoperative mapping ultrasound scans. Analyses were performed using SPSS Statistics for Windows, version 24.0 (IBM Corp, Armonk, NY). The Advocate Health Care Network institutional review board approved the present study.

RESULTS

The outcomes of 199 consecutive patients were reviewed and analyzed. Most of the cohort had already been undergoing dialysis before autogenous AVF creation (165 of 199; 83%). Hemodialysis access was maintained via tunneled central venous catheters for 124 patients. A few patients had had failing AVFs or arteriovenous grafts. Radial-cephalic, brachial-cephalic, and brachial-basilic AVFs were created in 82 (41%), 76 (38%), and 10 (5%) patients, respectively. Basilic vein transposition was performed in 30 patients (15%).

Maturation was achieved in 133 autogenous AVFs (67%). On univariate analysis, patients whose fistulas had failed to mature were more likely to be obese (body mass index, 31.6 ± 9.4 vs 28.6 ± 7.7 kg/m²; $P = .029$) and to have slightly smaller target veins found on preoperative ultrasonography (2.6 ± 0.9 mm vs 2.9 ± 1.1 ; $P = .014$; Table I). Neither preoperative dialysis status ($P = .27$) nor AVF type ($P = .23$) significantly affected fistula maturation. No significant difference was found in primary functional maturation between the radial-cephalic and brachial-cephalic AVFs (47 of 82 [57%] vs 53 of 76 [69%]; $P = .11$).

Logistic regression analysis was performed to analyze the independent predictors of AVF maturation using a P value of $< .10$ on univariate analysis as the inclusion criterion. Two models were created: one with a target vein diameter of ≥ 3 mm as a discrete variable and one with a maximum target vein diameter as a continuous variable. The odds ratios (ORs) with the variable target vein

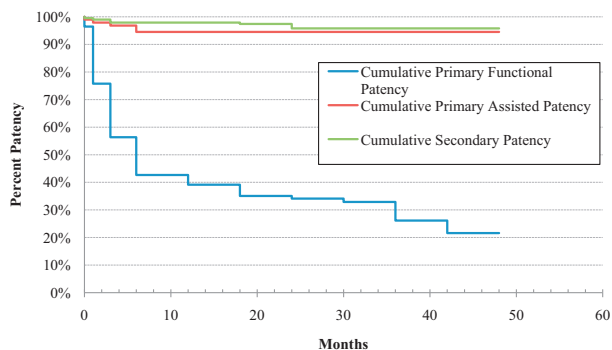
diameter of ≥ 3 mm are reported in Table II. No significant factors were encountered using the maximum target vein diameter instead of a target vein diameter of ≥ 3 mm in an alternate model. The only factor predictive of fistula maturation was the body mass index (OR, 1.06; 95% confidence interval [CI], 1.02-1.10; $P < .01$; Table II). Although AVFs that did not mature exhibited a significantly smaller vein size on univariate analysis, no reasonable construct of the preoperative ultrasound findings was predictive of maturation, including the maximum target vein diameter ($P = .18$), target vein diameter of ≥ 3 mm ($P = .86$), or maximum diameter of the vein one level proximal to the fistula ($P = .55$).

After a median follow-up of 15 months (interquartile range, 26 months), the 1-year primary functional patency, primary-assisted patency, and secondary patency rates were $39.1\% \pm 0.6\%$, $94.5\% \pm 0.6\%$, and $97.9\% \pm 0.5\%$, respectively (Fig 1). The primary functional patency rate of AVFs created from target veins > 3 mm was not different from the rate for AVFs created from smaller veins when analyzed using the Kaplan-Meier method and log-rank comparison ($P = .94$; Fig 2).

DISCUSSION

The filtering capacity of the kidneys is essential for human life; without it, death will ensue in ~ 1 week. Kidney failure was uniformly fatal until 1941 when Willem J. Kolff invented the first hemodialysis machine, a filtering device that could temporarily assume the function of the kidneys by passing the patient's blood through a cellophane sack designed to draw out urea and other toxins.²⁶ Today, this treatment is commonplace; worldwide, it has been estimated that renal replacement therapy maintains > 1.5 million human lives.¹

Hemodialysis requires continuous, large-bore, high-flow access to the bloodstream. This can be most reliably established through the creation of a peripheral AVF using an autogenous vein. The operation is technically straightforward and well-tolerated and almost always generates a continually patent arteriovenous anastomosis with increased flow through the target vein. However, the reliability of the resultant access conduit has been remarkably poor. Only $\sim 60\%$ of autogenous



time (mos)	0	6	12	18	24	30	36	42	48	54	60
# at risk (primary patency)	199	189	144	94	65	52	39	33	22	13	8

Fig 1. Cumulative primary functional, primary-assisted and secondary patency rates of 199 arteriovenous fistulas (AVFs).

fistulas will mature sufficiently for effective dialysis, and, even after maturation, the repeated trauma of percutaneous access and the vexing issue of outflow stenosis will necessitate reintervention in the vast majority.⁴⁻⁶

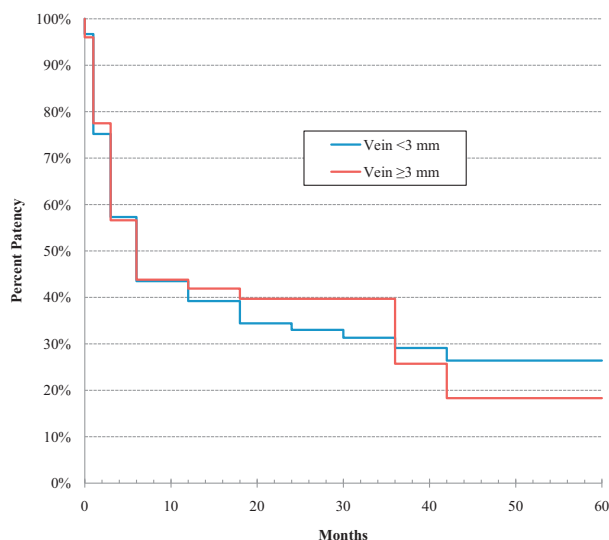
The frustration of AVF maintenance has naturally led to a search for optimization of the initial operation. The seemingly most obvious factor for a successful outcome is the size and quality of the target vein. Thus, the 2008 Society for Vascular Surgery clinical practice guidelines for the surgical placement and maintenance of arteriovenous hemodialysis access advised that, “ultrasound venous mapping is of critical importance in these patients, not only for identifying preferred autogenous access sites but also for evaluating the depth of venous structures.”²⁴ This would seem self-evident, given the known importance of fully developed blood flow and the strong dependence of the success of peripheral vein grafting on conduit diameter.²⁷

Despite its being axiomatic, the utility of ultrasound vein mapping before AVF creation has often been difficult to demonstrate.¹⁰ Although the findings from many reports have been convincing,¹¹⁻¹⁶ the findings from several notable, randomized studies have proved disappointing. A randomized trial comparing preoperative ultrasound vein mapping and physical examination in 218 patients by Ferring et al²⁸ showed no difference in primary patency (65% vs 56%; $P = .081$), although secondary patency was improved (80% vs 65%; $P = .012$). Nursal et al²⁹ randomized 70 patients to either physical examination alone or preoperative duplex ultrasound vein mapping and documented identical primary patency in the two groups (66%). Kim et al³⁰ created AVFs in 469 patients using physical examination alone and found that their patency was superior to that of patients selected for additional duplex ultrasonography because of worrisome physical findings.

Finally, Smith et al³¹ had randomized 94 patients to selective vs routine preoperative imaging examinations and found no difference in primary failure rate (36% vs 21%; $P = .14$). They concluded that, “if clinical evaluation detects anatomy suitable for AVF formation, duplex imaging may not be needed.”³¹ Even when routine preoperative ultrasound screening has been recommended, little consensus has been reached regarding its technique, interpretation, or the criteria for acceptable minimum diameters.^{11,16,17,21} The conflicting results from previous studies investigating the utility of routine preoperative vein mapping before AVF creation have led the National Kidney Foundation to temper their enthusiasm for the practice. In their 2019 clinical practice guidelines for vascular access, they admitted that, “the belief that vessel mapping with duplex ultrasonography is better than clinical examination remains contentious,” and has generally been “recommended in the past based solely on expert opinion.”³² The vein size threshold has remained a great point of controversy. Although Sidawy et al²⁵ classified veins of <3 mm as “grade 3,” the National Kidney Foundation guidelines have recommended a minimal threshold of 2 mm.

The results from the present study support this circum-spection. Preoperative ultrasound vein mapping was performed for 199 consecutive patients undergoing primary autogenous AVF creation by three surgeons at a busy teaching hospital. A variety of radial-cephalic, brachial-cephalic, and brachial-basilic techniques were used; the 67% rate of primary fistula maturation was similar or greater than the reported rates.^{4-8,13,33,34} Although the target vein diameter as measured using preoperative ultrasonography was significantly different on univariate analysis, it was not a significant predictor of maturation on multivariate analysis. Furthermore, receiver operating characteristic analysis of the maximum vein diameter of successful maturation yielded a low accuracy index (area under the curve, 0.6). Finally and, most importantly, dividing the cohort into patients with veins >3 or <3 mm showed no differences in maturation or long-term patency (Fig 2). The only predictor of success of the operation was a nonobese body habitus; a variable that cannot readily be modified in the short interval between consultation and surgery.

This disappointing finding, which has also been confirmed by many other investigators, is difficult to reconcile with the known tenets of vascular biology, rheology, and surgery. Thus, the question of why the diameter of the target vein was not a determinant of a successful fistula operation. The possibilities are many and include the somewhat poor reliability and reproducibility of ultrasound venous diameter measurements, the inconsistent states of hydration and sympathetic tone present at the assessment, variations in venous health, thickness and valvular function, and the severity of



time (mos)	0	6	12	18	24	30	36	42	48	54	60
# at risk (vein <3 mm)	123	59	43	34	27	23	15	12	9	6	5
# at risk (vein ≥3 mm)	76	38	25	21	15	13	10	4	2	0	0

Fig 2. Cumulative primary functional patency of arteriovenous fistulas (AVFs) created using veins assessed to be >3 mm or strictly <3 mm in diameter on preoperative ultrasound mapping.

antecedent phlebotomy trauma perpetrated on the target vein.^{1,35} The inherent ability of the target vein to remodel in response to the quantum, nonphysiologic increase in blood flow afforded by fistulization is critically important, immeasurable at present, and probably varies widely within our species.^{1,36} In their evaluation of AVF diameters measured on serial postoperative ultrasound scans, Robbin et al³⁷ found that these were moderately predictive of access maturation. Finally, a strong and continual dependence exists for AVF maintenance on percutaneous access technique that is independent of conduit quality.

The limitations of the present study included its retrospective nature without a formal, prospective randomization. The study was conducted in a single center, potentially limiting its wider applicability. Although the operative technique was based on standard practice, different results might have been obtained with alternative techniques such as routine tourniquet use or access creation under a regional anesthetic block.^{38,39} Also, patients were not randomized to preoperative evaluation with vs without vein mapping ultrasound examination. Neither intraoperative nor postoperative ultrasound vein measurements were the subject of the present analysis. Finally, no significant demographic or anatomic predictors of fistula maturation were revealed in the present small homogeneous cohort.

CONCLUSIONS

AVF creation and maintenance has continued to be attended by unacceptably high and frustrating rates of nonmaturation and failure. Routine preoperative venous mapping did not predict for successful fistula maturation. No clinically useful predictor of maturation or long-term patency was identified in the present study. Peripheral vascular access for hemodialysis has continued to be an area of medicine with high unmet clinical needs and considerable room for improvement.

AUTHOR CONTRIBUTIONS

Conception and design: RE, AR, FD, CJ, JW, LS

Analysis and interpretation: RE, AR, NP, FD, IK, SL, TO, CJ, JW, LS

Data collection: RE, AR, NP, LS

Writing the article: RE, LS

Critical revision of the article: RE, AR, NP, FD, IK, SL, TO, CJ, JW, LS

Final approval of the article: RE, AR, NP, FD, IK, SL, TO, CJ, JW, LS

Statistical analysis: RE, FD, LS

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Overall responsibility: LS

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