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Vein diameter after intraoperative dilatation with vessel probes as a predictor of success of hemodialysis arteriovenous fistulas

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Manuscript Preparation E
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Background: Vascular access is “the life line” for patients on chronic hemodialysis. The autogenous arteriovenous fistula provides the best access to the circulation because of low complication rate, long-term use, and lower cost, compared to arteriovenous graft and central venous catheter. The primary objective of this prospective study was to investigate the predictive value of vein diameter after intraoperative dilatation with vessel probes on hemodialysis fistula maturation.





Material/Methods: Ninety-three fistulas were performed by a single surgeon from February 1, 2006 to January 31, 2009. Intraoperative vein dilatation with vessel probes was attempted in all fistulas. Measurements of the feeding artery diameter, vein diameter and the increased vein diameter after intraoperative dilatation were performed and immediate failure, early patency, early failure, primary patency, and fistula survival outcomes were recorded during 48-month follow-up.

Results: Early failure occurred in 20% of fistulas and 70% matured sufficiently for cannulation. Variables with significant impact on the failure to mature by univariate analysis were: body-mass index (P=0.041), artery diameter (P<0.001), vein diameter (P=0.004), and vein diameter after dilatation (P=0.002). However, multivariate analysis showed that only body-mass index (P=0.038), artery diameter (P=0.001), and the diameter of the vein after dilatation (P=0.018) significantly affected maturation. In a group of 56 (60%) patients with vein diameter before dilatation ≤ 2 mm, among vessel characteristics found by multivariate analysis, only vein diameter after dilatation (P=0.004) significantly affected function.

Conclusions: Artery diameter and vein diameter after intraoperative dilatation with vessel probes were the main predictors of fistula function.

MeSH Keywords: **Vascular Probe • Intraoperative Vein Dilatation • Arteriovenous Fistula**

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Background

Vascular access is “the life line” for patients on chronic hemodialysis (HD). Numerous studies have shown the superiority of well-matured upper extremity autogenous arteriovenous fistula (AVF) compared to the arteriovenous graft (AVG) or central venous catheter (CVC). Those results have been incorporated into the well-known guideline [1–3]. Many preoperative, intraoperative, and postoperative parameters influence the success of AVFs. Some of them are well-known, but there are also unknown factors that could influence AVFs outcomes.

The main preconditions to perform patent AVF are good inflow and outflow. The impact of the vessel diameter was researched in numerous studies. Artery and vein diameters below 2 mm were predictors of high incidence of early thrombosis or failure to mature in some studies, and some authors recommended cut-off size of the artery and the vein [4,5]. The most widely mentioned recommendation is: artery diameter (AD) ≥ 2 mm and vein diameter (VD) ≥ 2.5 mm [6,7] or VD ≥ 3 mm [8].

Increasing the artery and the vein diameter is necessary for maturation [9,10]. There is no simple and reliable test to determine vascular compliance preoperatively. The predictive value of arterial resistance index (RI) is uncertain [2]. It has been reported that preoperative RI >0.7 in the feeding artery indicates that arterial blood flow will not increase sufficiently, reducing the chance of successful creation of an AVF [11]. Two other studies found no difference in fistula outcome for hyperemic response [7,12].

Preoperative venous size and, especially, vein distensibility are also difficult to measure. Planken et al. revealed daily variations in forearm venous diameters, which should be taken into account when defining cut-off diameters prior to vascular access surgery [13]. Lockhart et al. recommended using a venous tourniquet in preoperative duplex ultrasonography (DUS) because its use increases the number of patients eligible for forearm fistulas without decreasing the adequacy rate [14].

Use of vessel probes is well-known in angioaccess surgery. Some surgeons use intravascular or coronary probes to measure the diameter of the vessels intraoperatively [9,15]. Some authors used vessel probes to assess the venous anatomy and, if they had succeeded in introducing the 3-mm probe into the vein, the vein was used [16].

The aim of our study was to evaluate the influence of clinical and morphological variables and to estimate the predictive value of VD after intraoperative dilatation using vessel probes on AVF surgery success and AVF function.

Material and Methods

Data was prospectively gathered for 93 AVFs in a Caucasian population. We enrolled 118 patients with end-stage renal disease who were scheduled to undergo fistula surgery from February 1, 2006 to January 31, 2009 in the General Hospital Bjelovar. Informed consent of all patients was obtained and the local Medical Ethics Committee approved the study. The inclusion criteria were: patent radial artery and the nearest vein regardless of the size and the vessel quality, except for the very small vessels (diameter <1 mm and/or the impossibility of comfortable introduction of at least a 1.5-mm probe into the vein). The exclusion criteria were: brachial artery AVFs (n=9), patients lost to follow-up (n=5), patients who died prior to the first cannulation (n=5), AVF never used (n=3), and fistula with arterialized vein (n=3).

AVFs in all patients were constructed as distally as possible on the upper extremity. The preoperative examination, based on recommendations described elsewhere [2,17,18], was done by the same surgeon who performed all of the AVFs. Preoperative, intraoperative, and follow-up parameters were recorded prospectively. Valid preoperative DUS was not possible to obtain during the study period in our district hospital. Recommended standards for reports dealing with arteriovenous HD accesses by Sidawy et al. were used to determine comorbid conditions of patients, early failure, patency rates, functionality, and complications of AVFs [18].

A fistula was defined as functional if it was able to deliver a pump flow rate of at least 320 mL/min (a commonly used pump flow rate in our HD unit) and sufficient HD was done in at least 1 treatment. A nonfunctioning (failed) fistula was defined as an AVF that thrombosed before the first cannulation or did not reach functional status (patent or not) [18]. Primary patency was defined as the interval from AVF creation to abandonment (thrombosis or low flow inadequate for sufficient HD), or the time of patency measurement [18]. An immediate failure was defined as failed AVF function in the first 24 hours. Early patency or failure was defined according to a thrill and/or bruit 4 weeks after the surgery. The follow-up end-point was 48 months after the construction of the fistula.

Surgical procedure

All procedures were performed under local anesthesia. AVF was recorded as distal radial arteriovenous fistula (DRAVF) when the location of the anastomosis was at the distal part, and as proximal radial arteriovenous fistula (PRAVF) when anastomosis was at the proximal part of the forearm radial artery.

The surgical procedure was fairly similar to that proposed by Konner [19]. The artery and the vein were exposed through a longitudinal incision and mobilized with caution with the minimal touch technique. Usually the vessels were mobilized to

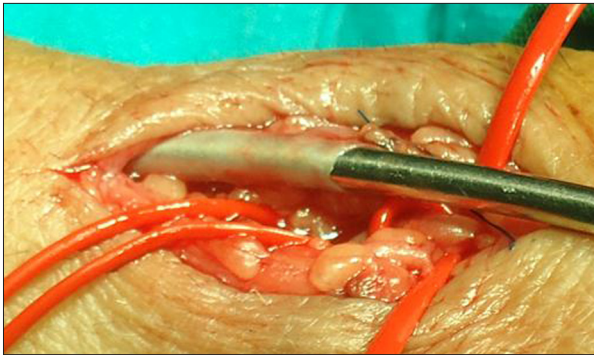


Figure 1. Intraoperative vein dilatation with vessel probe.

the parallel position and encircled with a 3-mm-wide nylon tape to stop the blood flow. Vascular clamps were used only in calcified arteries (never for a vein). Arteriotomy and venotomy were made in the lateral aspects of the circumference of the vessel. In the DRAVFs, the length was 8–10 mm, and 6–8 mm in the PRAVFs. The arterial and vein diameters were measured with vessel probes and micrometer at the anastomotic site. Dilatation of the vein (about 10–15 cm proximally) was usually done through the venotomy distal to the anastomosis (Figure 1). Before use, dilators were moistened and warmed in warm heparinized saline. It is crucial that the introduction of dilators should not be crude because of possible intimal injury. A series of dilators (from the small one of 1.5 mm) were passed into the vein to explore vein patency and its ability to dilate. The dilatation was gradual and was stopped if the patient signalled the pain or the dilator could not be comfortably introduced (without forcing). Before and after the dilatation, the vein was rinsed out with warm heparinized saline. The diameter of the biggest dilator used was recorded as the maximum target VD after intraoperative dilatation. A side-to-side anastomosis was constructed using a continuous 6.0 or 7.0 polypropylene suture and the distal limb of the vein was ligated.

Follow-up

The first control was performed 24 hours postoperatively. After 4 weeks, early patency or failure was recorded. The further follow-up was made by nephrologists (independent observer), as well as the estimation of fistula's adequacy for HD. The dialysis staff recorded the date of the first cannulation, the pump flow rate, and possible problems.

Statistical analysis

For univariate analysis of collected data by sex, and by AVF functional status, chi-square test was used for categorical data, and Mann-Whitney test for numerical data. Multivariate analysis of AVF functional status was performed by multivariate logistic regression. We analyzed the data using SAS software ver. 9.3 (SAS Institute Inc., Cary, NC, USA).

Table 1. Baseline data (n=93).

Characteristic	Mean	SD
Age (years)	64.1	12.8
BMI (kg/m ²)	25.3	3.7
Vessels characteristics		
Vein diameter (mm)	2.11	0.4
Vein diameter after dilatation (mm)	3.38	0.7
Artery diameter (mm)	2.20	0.5
	N	%
Gender		
Female	42	45
Male	51	55
Comorbidities		
Diabetes mellitus	37	40
Hypertension	80	86
Temporary CVC	42	45
First AVF	54	58
Second AVF	26	28
Third AVF	10	11
Fourth AVF	3	3
Location of access		
DRAVF	62	67
PRAVF	31	33

BMI – body mass index; CVC – central venous catheter; AVF – arteriovenous fistula; DRAVF – distal radial AVF; PRAVF – proximal radial AVF.

Results

Patient data, including demographic characteristics, comorbid conditions, presence of temporary CVC, and vessel characteristics are shown in Table 1.

According to the anastomosis site, DRAVFs were made in 62 (67%) patients and PRAVFs in 31 (33%) patients. The non-dominant arm was used in 70 (75%) patients. During the study period, immediate failure occurred in 15 (16%) patients. Early patency was recorded in 75 (81%) AVFs, and 65 (70%) AVFs became functional. Twenty-three (25%) patients died during the follow-up, and 11 (12%) patients received a permanent CVC. Among the patients with temporary CVC (n=42), 35 were placed on the contralateral side to the fistula site. The vein was not visible or palpable in 28 (30%) patients on physical examination, but was

Table 2. Univariate analysis of predictive factors associated with successful fistula maturation (n=93).

Characteristic	Fistula groups				P
	Functional		Failed		
	Median	IQR	Median	IQR	
Age (years)	68	16	68	18	0.645
BMI (kg/m ²)	24.5	5.5	26.2	4.9	0.041
Vessel characteristics					
Vein diameter (mm)	2.00	0.4	2.00	0.4	0.004
Vein diameter after dilatation (mm)	3.50	2.0	3.00	1.0	0.002
Artery diameter (mm)	2.10	0.6	1.80	0.6	<0.001
	N	%	N	%	
Female	28	67	14	33	
Male	37	73	14	27	0.538
Comorbidities					
Diabetes mellitus	24	65	13	35	0.390
Hypertension	59	74	21	26	0.056
Temporary CVC	29	69	13	31	0.872
First AVF	39	72	15	28	n/a
Location of access					
DRAVF	41	66	21	34	
PRAVF	24	77	7	23	0.263

BMI – body mass index; CVC – central venous catheter; AVF – arteriovenous fistula; DRAVF – distal radial AVF; PRAVF – proximal radial AVF; n/a – not available.

found during the exploration. There were 18 unsuccessful explorations (14 at the distal site and 4 at the proximal site). The vein was the reason for abandoned site in 15 cases (the vein was impossible to find or VD was less than 1 mm in 6 patients, while in 9 explored veins it was impossible to introduce a dilator of at least 1.5 mm). In another 3 patients the AD was too small (<1 mm).

Univariate statistical analyses showed significant differences in VD (p=.004, Mann-Whitney test), VD after dilatation (p=0.002, Mann-Whitney test), AD (p<0.001, Mann-Whitney test), and BMI (p=0.041, Mann-Whitney test) between functional and failed AVFs, while no significant differences were found for other characteristics: age, sex, diabetes, hypertension, temporary CVC, first attempt of access, and location of access (Table 2). Multivariate analysis taking into consideration interactions of all clinical and morphological variables shown to affect AVF function by univariate analysis, found that only BMI, VD after dilatation, and AD were significant for prediction of fistula surgery success. VD was not significant in multivariate analysis, in contrast to univariate analysis. The characteristics and multivariate

logistic regression analysis results are shown in Table 3. The multivariate logistic model was significant, with –2 log likelihood =53.085, p<0.001, and the prediction accuracy was 78.7%.

After exclusion of all non-significant predictors from the multivariate logistic model, BMI remained a significant predictor (p=0.038, with OR 0.808 and 95% CI for OR ranging from 0.660 to 0.998), as well as VD after dilatation, (p=0.018, with OR=4.667, and 95% CI for OR ranging from 1.301 to 16.743), and AD, (p=0.001, with OR=17.047, and 95% CI for OR ranging from 2.995 to 97.037). The model was significant, with –2 log likelihood=57.862, p<0.001, and prediction accuracy of 78.7%.

The relationship between VD after dilatation in functional and failed fistulas is presented in Figure 2, and the relationship between artery diameters in functional and failed fistulas is presented in Figure 3.

In the group of patients with VD ≤2 mm (n=56), 34 (60.7%) became functional. Results of multivariate analysis of vessel characteristics in this group of patients are presented in Table 4.

Table 3. Results of a multivariate logistic regression analysis of predictive factors associated with fistula success (n=93).

Characteristic	OR	95% CI		P
		Lower	Upper	
Age (years)	1.012	0.958	1.069	0.666
BMI (kg/m ²)	0.808	0.660	0.988	0.038
Sex	1.037	0.286	3.759	0.956
Diabetes	0.534	0.109	2.615	0.439
Hypertension	0.401	0.074	2.160	0.287
Temporary CVC	1.622	0.424	6.207	0.480
First AVF	n/a	n/a	n/a	0.317
Location of access	0.275	0.044	1.703	0.165
Vein diameter (mm)	2.905	0.351	24.045	0.323
Vein diameter after dilatation (mm)	4.667	1.301	16.743	0.018
Artery diameter (mm)	17.047	2.995	97.037	0.001

BMI – body mass index; CVC – central venous catheter; AVF – arteriovenous fistula; DRAVF – distal radial AVF; PRAVF – proximal radial AVF.

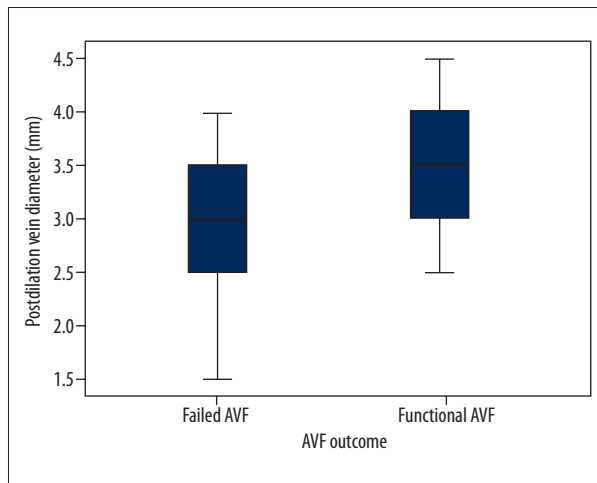


Figure 2. Relationship between vein diameter after dilatation in functional and failed fistulas.

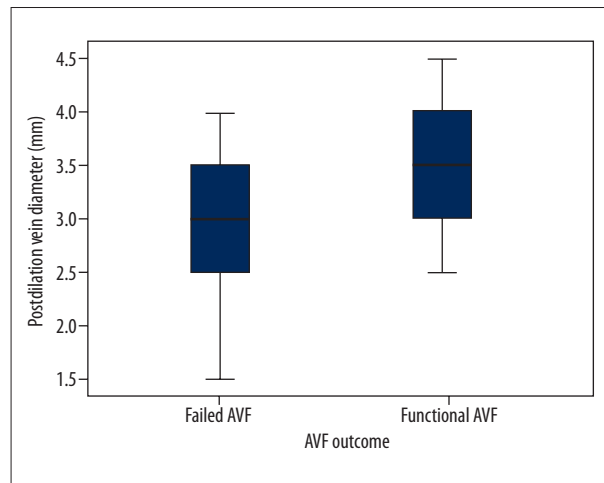


Figure 3. Relationship between artery diameter in functional and failed fistulas.

Table 4. Multivariate analysis of vessel characteristics in the group of patients with vein diameter ≤2 mm (n=56).

Characteristic	Fistula groups				P
	Functional		Failed		
	Median	IQR	Median	IQR	
Vein diameter (mm)	2.00	0.2	1.85	0.4	0.176
Vein diameter after dilatation (mm)	3.50	0.6	2.75	1.1	0.004
Artery diameter (mm)	2.00	0.1	1.90	0.5	0.055

By life table analysis of 93 AVFs, primary patency at 12, 24, 36, and 48 months was 63.2%, 50.8%, 44.6%, and 41.6%, respectively (Figure 4, Table 5).

There were 2 wound inflammations grade 1 according to Sidawy et al. [18], which were resolved within 14 days upon antimicrobial therapy. Wound hematoma occurred in 19 patients, and in

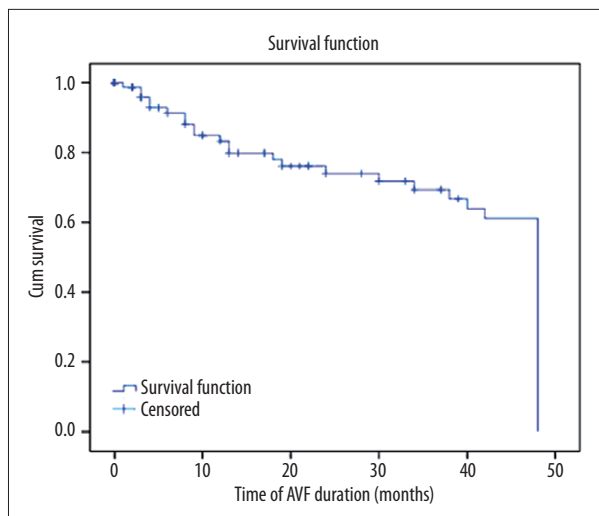


Figure 4. Kaplan-Meier arteriovenous fistula survival analysis (n=93).

1 case resulted in partial wound disruption. There was no vein rupture during dilatation. According to Tordoir et al. [20], 2 cases of steal syndrome appeared after DRAVF grade 1 and 2 and

were treated conservatively. No steal syndrome was recorded after PRAVF.

Discussion

Vascular access surgeons are faced with the same challenge all over the world: choosing the best vascular access type for chronic HD. Results of different studies are sometimes confounding and contradictory. Size and quality of the vessels seem to be the most important factors known [6,7,10]. Our findings support this statement, because vessel characteristics were found to be the most significant, both by univariate and multivariate analysis. BMI showed borderline statistical significance in prediction of AVF function. The strongest predictor of functional maturation in our study was the AD. The importance of AD has also been noted in other studies [4,5]. Korten et al. stated that the highest primary patency at 1 year was observed in the group with radial artery diameters ≥ 2.1 mm and ≤ 2.5 mm. In that study, no correlation between vein diameters (using pneumatic cuff occlusion) was found, even though 29% of veins had diameter value of < 2

Table 5. Life table analysis of cumulative primary patency rates for 93 fistulas.

Interval (mo)	No. at risk at beginning of interval	No. failed during interval	Withdrawn during interval	Interval failure rate	Cumulative patency rate	Standard error (%)
0–1	93	17	1	0.184	81.6	3.63
2–3	75	9	2	0.122	71.7	4.40
4–6	64	3	3	0.048	68.3	4.81
7–9	58	1	4	0.018	67.0	5.05
10–12	53	3	1	0.057	63.2	5.27
13–15	49	2	2	0.042	60.6	5.43
16–18	45	2	1	0.045	57.8	5.60
19–21	42	3	1	0.072	53.7	5.64
22–24	38	2	2	0.054	50.8	5.78
25–27	34	0	0	0.000	50.8	6.11
28–30	34	2	1	0.050	47.7	5.92
31–33	31	1	0	0.032	46.2	6.09
34–36	30	1	1	0.034	44.6	6.06
37–39	28	2	1	0.073	41.4	5.96
40–42	25	0	2	0.000	41.4	6.34
43–45	23	0	0	0.000	41.4	6.60
46–48	23	0	1	0.000	41.4	6.60

mm [21]. In contrast, some studies have not shown a correlation between artery size and fistula success. Tordoir et al. have shown correlation only with the diameter of the vein, not the artery, but there were small variations of the arterial diameters [15]. Using multivariate logistic regression analysis, Lauvao et al. found that the VD was the sole independent predictor of fistula maturation [17]. Kheda et al. found no impact of diameter of the artery and the vein on fistula failure, but the diameters were above the recommended minimum values [9].

In our study, the vein diameter after dilatation, which could indicate venous potential distensibility, has shown significant correlation with functional maturation, especially in the group of patients with $VD \leq 2$ mm (Table 4). These results concur with Malovrh's finding that the vein's potential distensibility is more important than the diameter [11]. Van der Linden et al. also found that the vein distensibility, measured preoperatively by plethysmography, is a better predictive factor than the vein size [22].

There is currently no simple and reliable test for preoperative estimation of vascular compliance; thus, intraoperative exploration still remains crucial. Saucy et al. stated that intraoperative surgical assessment of the vessels provides the last chance to choose the right strategy [6]. According to Kheda et al., an ideal test would be rapid, inexpensive, and require little training [9]. The careful intraoperative exploration of the vein patency and dilatation of the vein with probes in vascular access surgery meets these criteria. This procedure gives surgeons the information about both vein patency and distensibility. It is simple and takes a few minutes. Only a comfortable, forceless introduction of the dilator into the vein is allowed.

Other procedures to check intraoperative vein patency and distensibility are possible, as suggested by Konner et al. [19]. Veroux et al. showed that mechanical intraoperative dilatation of small (≤ 2 mm) cephalic veins with a standard 4×150 mm angioplasty balloon during the creation of a distal AVF for hemodialysis is a safe and feasible procedure. This technique

assures excellent primary patency, maturation time, and dramatically decreases reintervention rate compared to hydrostatic vein dilatation [23]. In our study, the 16% immediate failure rate and the 30% non-maturation rate could be due to technical errors in surgery or use of vessels that were too small.

This study has a number of limitations. The effects of intraoperative vein exploration and dilatation with steel vessel probes are not clearly visible, because there is no valid control group. Intraoperative measurement of the vessel size could underestimate the diameter of the artery and, especially, of the vein, because of the vessel spasm. This study presents a single-center experience. There are many questions and only a few answers. Other, preferably multicenter, studies should be done to reveal potentially positive or negative effects of intraoperative vein exploration and dilatation with vessel probes on vascular access outcomes.

Conclusions

This study shows AD as the strongest predictor of functional fistula. Increasing of VD after intraoperative dilatation with vessel probes was a better predictor of successful AVF maturation than VD itself. Careful intraoperative exploration and dilatation of the vein with vessel probes could be a useful adjunct procedure, which helps the surgeon to estimate vein patency and distensibility. This information could be crucial in the decision of using an explored vein, especially of borderline size, or lack of valid preoperative DUS. Other studies should be done to estimate the impact of that procedure on angioaccess surgery outcomes.

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Conflict of interest

None.

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