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The Significance of Inflow Artery and Tourniquet Derived Cephalic Vein Diameters on Predicting Successful Use and Patency of Arteriovenous Fistulas for Haemodialysis

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WHAT THIS PAPER ADDS

In patients undergoing radiocephalic arteriovenous fistulas, a tourniquet derived cephalic vein diameter <4.3 mm (lower three quartiles) was the single independent predictor of inferior secondary and functional secondary patency. In patients undergoing brachiocephalic arteriovenous fistulas, functionality and patency rates were all inferior in the presence of a small brachial artery (≤4.1 mm, lowest quartile), indicating that an alternative access site might be preferrable.

Objective: To investigate the significance of inflow artery and cephalic vein diameters on predicting patency of radiocephalic and brachiocephalic arteriovenous fistulas (AVFs).
Design: Single centre study with retrospective analysis of prospectively collected data between November 2010 and July 2015.
Methods: A detailed history and physical examination was undertaken, including age, gender, history and duration of haemodialysis, cause of chronic kidney disease, and the presence of comorbidities/risk factors. Pre-operative arterial and venous upper extremity mapping was performed and inner vessel diameter was recorded, using a tourniquet for the veins. Outcome measures included AVF use (functionality), primary, primary assisted, secondary, and functional secondary patency.
Results: One hundred and thirty five AVFs (57 and 78 radiocephalic and brachiocephalic AVFs, respectively) were constructed and followed up for 5 years. A cephalic vein diameter <4.3 mm (lower three quartiles) was the single independent predictor of inferior secondary and also functional secondary patency of radiocephalic AVFs ($p = .02$, HR 11.2, 95% CI 1.44–90.9). A brachial artery diameter ≤4.1 mm (lowest quartile) was an independent predictor of AVF functionality (57% vs. 83% for larger arteries, $p = .017$), and inferior primary, primary assisted, secondary, and functional secondary patency of brachiocephalic AVFs (primary assisted patency 21.9% vs. 55.9% at 3 years, $p = .001$/log-rank test, HR 3.1, $p = .002$/Cox regression). The presence of lower extremity PAD or use of dual antithrombotics was also independently associated with an inferior secondary patency. The number of risk factors (brachial artery diameter ≤4.1 mm, PAD, and use of dual antithrombotics) demonstrated risk stratification capabilities for functional secondary patency.
Conclusions: Among patients undergoing radiocephalic AVFs, a tourniquet derived cephalic vein diameter <4.3 mm was the single independent predictor of inferior secondary and functional secondary patency. Among patients undergoing brachiocephalic AVFs, all patency rates were inferior in the presence of a brachial artery diameter ≤4.1 mm and secondary patency was inferior in the presence of multiple risk factors.

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INTRODUCTION

Arteriovenous fistulas (AVFs) are the first line option for haemodialysis according to recommendations[1,2]; however, it is increasingly recognised that attempts to create an AVF should not be made at all costs, particularly in patients already on haemodialysis.[3] Vein mapping has an established role in pre-operative assessment. Vein diameter is mostly used as a predictor of success, with a cephalic vein diameter >4 mm being a predictor of successful AVF function.[4,5]

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Additionally, brachiobasilic or brachiocephalic AVFs made with larger veins have better long-term patency rates, compared with those of smaller veins,[6] the latter being typically excluded if too small (e.g. <2.5 mm).

Nevertheless, the evidence for the importance of the radial or brachial inflow artery diameter for radiocephalic and brachiocephalic AVFs, respectively, is conflicting, limited, and not put into clinical context.[4,5,7–16] As a result, generally accepted minimum arterial diameters useful in clinical practice have not been provided and a possible effect of brachial artery diameters on long-term patency has not been investigated. For radiocephalic AVFs, several studies have demonstrated poor functionality rates with a radial artery smaller than 1.5–2.3 mm,[8,10,11,13] and a cephalic vein smaller than 1.6–2.7 mm,[7,10,11,13,16] but others have failed to confirm the above associations for arterial[7,9,16] and venous diameters.[7,9] One study showed an association between radial artery diameter and primary patency.[7] For brachiocephalic AVFs, two studies have demonstrated that pre-operative brachial artery diameters were significantly smaller for upper arm fistulas that failed to become functional, compared with those that became functional[5,14]; however, a third study failed to confirm these findings.[16] Additionally, a minimum suggested diameter useful in clinical practice was not provided and a possible effect of brachial artery diameter on long-term patency was not investigated. Vein diameter has been shown to be a predictor of success, with a cephalic vein diameter exceeding 4 mm being a predictor of functionality.[4,5]

Tourniquet use increases the number of patients eligible for forearm fistulas without decreasing the functionality rate, as veins that appear small in diameter because of possible spasm are not excluded if dilated with a tourniquet.[17] Because vein diameter is not universally measured with a tourniquet, there is a lack of information for the results of this improved technique.

The aim of the present study was to investigate the relative role of the diameter of the inflow artery and cephalic vein using a tourniquet, on AVF functionality and patency results, in an effort to better define minimum arterial and venous diameters used during pre-operative work-up and improve patient selection.

PATIENTS AND METHODS

Consecutive patients who attended a Vascular Access Outpatient Clinic and had a primary radiocephalic or brachiocephalic AVF performed between November 2010 and July 2015 were prospectively evaluated and retrospectively analysed. Patients undergoing redo AVF surgery, brachiobasilic AVFs, or brachiomedian antebrachial vein AVFs were excluded.

Pre-operative clinical assessment

A detailed history and physical examination was initially undertaken, including age, gender, history, duration of haemodialysis, cause of chronic kidney disease, and the presence of comorbidities/risk factors. The latter included diabetes mellitus (defined as use of insulin or oral hypoglycemic agents), hypertension (systolic blood pressure >140 mmHg, diastolic blood pressure >80 mmHg, or use of anti-hypertensives), and dyslipidaemia (defined as use of anti-lipidaemic agents, e.g. statins, ezetimibe, etc). Also included were coronary artery disease, defined as history of angina, myocardial infarction, or coronary intervention, including angioplasty and/or bypass grafting, and peripheral arterial disease (PAD), defined as history of intermittent claudication, critical limb ischaemia, or revascularisation of the lower limbs. These clinical characteristics were collected to be used as potential cofounders and to adjust the results of multivariate analysis.

Pre-operative vessel mapping

Pre-operative arterial and venous mapping was performed, as previously described.[18] Venous diameters were assessed with a phlebotomy tourniquet, that is a stretchable webbed 1 inch band with a buckle closure, sequentially applied to the proximal forearm, distal, and proximal arm.[17] Duplex ultrasound was performed with a Mylab50xvision scanner (Esaote S.p.A., Genova, Italy). Radial and brachial artery inner diameters were routinely assessed at the level of intended anastomosis construction, noting the presence of atherosclerotic plaques, arterial calcification, and high bifurcation of the brachial artery. Velocity and waveform spectral analysis was performed. The minimum inner diameter of the cephalic and basilic veins was determined along their course after a 1 min tourniquet application; the depth of the cephalic vein along its path was also noted, with emphasis on identifying a section of sufficient length to allow future AVF use. This information was taken into account when assessing the possibility of cephalic vein elevation as a subsequent procedure to improve functionality. The axillary arteries and veins were also interrogated. Ultrasound commenced on the non-dominant arm and the assessment was selectively repeated on the contralateral arm as required. The minimum vessel diameter used to construct an AVF was 2 mm for the radial artery and 3 mm for the cephalic vein at the wrist and elbow levels respectively, with no minimum diameter exclusion for the brachial artery. Additional exclusion criteria included sites with heavy arterial calcification or a high brachial artery bifurcation.

Surgical technique

All procedures were performed under local anaesthesia with lidocaine solution 1%, preferably on an outpatient setting and using magnifying glasses (loupes). Cephalic vein flushing with 2500 IU heparin provided anticoagulation and simultaneous gentle dilatation. Cephalic vein transposition and use of mid to distal forearm cephalic vein, as dictated by pre-operative vessel mapping, was performed selectively. Brachiocephalic AVFs were performed through a transverse antecubital fossa incision. Arteriotomy length was restricted to 7–8 mm for brachiocephalic AVFs, while this was liberally extended to 10–15 mm for radiocephalic AVFs. All anastomoses were made with 7–

0 polytetrafluoroethylene (PTFE, Gore-tex, Gore Medical, Flagstaff, AZ, USA).

Outcome measure definition

Reporting Standards for Arterio-Venous Accesses of the Society for Vascular Surgery and the American Association for Vascular Surgery were used to define access functionality and patency.[19] All AVFs were assessed clinically 6–8 weeks post-operatively for the presence of a strong thrill over a sufficiently dilated (e.g. 8–10 cm length and >5–6 mm diameter) vein with a superficial course; if not ultrasound was performed to assess vein diameter and depth to determine the need for an elevation procedure. Fistulas were considered functional if they were cannulated for dialysis on six occasions. Immediate post-operative thrombosis (a fistula that did not achieve or that had loss of bruit or thrill within 72 h of creation) was also reported.

Established AVF surveillance (pain during haemodialysis, prolonged bleeding time after haemodialysis, and abnormal findings on physical examination) and monitoring parameters (high venous pressures, suboptimal blood flow, or recirculation on haemodialysis) were used to determine failure of a previously functional AVF.[2]

Primary patency (PP) was defined as a fully functional AVF, with the first episode of failure or thrombosis being used to determine PP loss.

Primary assisted patency (PAP) was defined as the time to thrombosis of a patent AVF without thrombectomy, including those in which any intervention had been performed to prevent what was perceived to be impending AVF failure.

Secondary patency (SP) was defined as time to thrombosis an AVF that was patent (including those in which patency was restored after thrombectomy). AVFs ligated for steal were censored for the calculation of PP, PAP, and SP.

Functional secondary patency (FSP) was defined as a patent AVF (including AVFs with patency restored after thrombectomy) but also still in use; abandonment for any reason, including thrombosis, AVF ligation, and uncorrectable malfunction was used to determine functional secondary patency loss.

Initial failures were included in the calculation of patency rates.[19]

Statistics

All data were analysed with IBM SPSS Statistics 22 (IBM Corp., Armonk, NY, USA) or STATA/SE 12.0 (StataCorp LP, College Station, TX, USA). Demographics and results of pre-operative ultrasound vessel mapping of the two main study groups (radiocephalic and brachiocephalic AVFs) were compared. Categorical variables were analysed with the chi-square or Fisher exact tests, where appropriate. The Kolmogorov-Smirnov test did not show a normal distribution of continuous variables, prompting reporting of medians (interquartile range) and use of the non-parametric Mann-Whitney test to compare groups. The continuous variables of age, duration of haemodialysis (where applicable), and diameters of the radial or brachial artery and cephalic vein were grouped into quartiles, separately for the two groups. Patients were followed up for a minimum of 6 months and up to the point FSP was lost or the patient had died. All access patency rates were calculated by the Kaplan-Meier method and compared with the log-rank (Mantel-Cox) test. Hazard ratios for independent predictors of patency results were calculated with Cox proportional hazards models. To estimate patient survival, in patients who had two AVFs performed, survival was calculated from the first AVF. A p value $<.05$ was considered to be statistically significant.

RESULTS

A total of 127 patients (97 males/30 females) had 135 AVFs (57 and 78 radiocephalic and brachiocephalic AVFs respectively) constructed electively during the study period by four vascular surgeons. Eight patients had two AVFs performed, including two patients who had two brachiocephalic AVFs each, and six patients who had both a radiocephalic AVF and a brachiocephalic AVF, all on separate occasions. Demographics, pertinent history, and comorbidities/risk factors of the two study groups are shown in Table 1. The median age of the two study groups was comparable, but more males than females had a radiocephalic AVF.

The frequency of diabetes and coronary artery disease was higher in patients undergoing brachiocephalic AVFs; likewise antithrombotics, usually in the form of aspirin or clopidogrel, were used more often in patients undergoing brachiocephalic AVFs than in those undergoing radiocephalic AVFs.

Pre-operative cephalic vein and arterial diameters were larger in patients undergoing brachiocephalic AVFs than radiocephalic AVFs (Table 2).

Thirteen AVFs (3 radiocephalic and 10 brachiocephalic) underwent elevation to enhance functionality (Table 2).

AVF functionality results

Outcome measures of AVF functionality, including usage time, are shown in Table 2.

Radiocephalic AVF. One patient could not have his AVF function assessed (Table 2). The functionality rate for radiocephalic AVFs was 80.4%. There were no predictors of radiocephalic AVF functionality.

Brachiocephalic AVF. One 82 year old patient died a few days after a brachiocephalic AVF as a result of a cardiac arrest (30 day mortality 1.3%). Two additional patients could not have their AVF function assessed (Table 2). Two other patients had their AVF ligated because of steal syndrome at 3 weeks and 6 months respectively. The brachiocephalic AVF functionality rate was 76%. Brachiocephalic AVFs made with small arteries (lowest quartile brachial artery, diameter $\leq$4.1 mm) had inferior functionality rates (12/21, 57.1%) than those made with larger arteries (45/54, 83.3%,

Table 1. Demographics, pertinent history, and comorbidities/risk factors of the radiocephalic and brachiocephalic AVF study groups.

	AVF type Radiocephalic (n = 57)	Brachiocephalic (n = 78)	p value	All AVFs (n = 135)
Age, years, median (IQR)	62 (51.5–71.0)	67 (56–76)	.08	65 (55–76)
Gender, male/female	49/8	54/24	.02	103/32
Pre-dialysis (%)	22 (38.6%)	39 (50.0%)	.22	61 (45.2%)
Duration of dialysis, months, median (IQR) [a]	1.68 (0.99–2.96)	1.97 (0.99–4.93)	.55	1.97 (0.99–4.15)
Chronic kidney disease cause (%)			.11	
Diabetes mellitus	13 (22.8%)	28 (35.9%)		41 (30.4%)
Hypertension	6 (10.5%)	7 (9.0%)		13 (9.6%)
Glomerulonephritis	11 (19.3%)	9 (11.5%)		20 (14.8%)
Interstitial disease	9 (15.8%)	6 (7.7%)		15 (11.1%)
Cystic disease	6 (10.5%)	3 (3.8%)		9 (6.7%)
Unknown	12 (21.1%)	25 (32.1%)		37 (27.4%)
Comorbidities/risk factors				
Diabetes mellitus	18 (31.6%)	40 (51.3%)	.02	58 (43.0%)
Hypertension	50 (87.7%)	65 (83.3%)	.89	115 (85.2%)
Dyslipidaemia[b]	24 (42.1%)	34 (43.6%)	.64	58 (43.0%)
Coronary artery disease	8 (14.0%)	23 (29.5%)	.04	31 (23.0%)
Peripheral arterial disease (lower limbs)[c]	2 (3.8%)	9 (12.0%)	.12	11 (8.6%)
Antithrombotic treatment[d,e]	18 (34.0%)	41 (52.6%)	.04	59 (45.0%)
Aspirin	11 (20.8%)	19 (24.4%)	.34	30 (22.9%)
Clopidogrel	4 (7.5%)	12 (15.4%)		16 (12.2%)
Aspirin and clopidogrel	2 (3.8%)	5 (6.4%)		7 (5.3%)
Acenocoumarol	1 (1.9%)	4 (5.1%)		5 (3.8%)
Aspirin and acenocoumarol	0 (0%)	1 (1.3%)		1 (0.8%)
None	35 (66.0%)	37 (47.4%)		72 (55.0%)

AVF = arteriovenous fistula; IQR = interquartile range.
[a] 74 patients.
[b] History of dyslipidaemia or use of lipid lowering agents.
[c] Missing data in seven patients.
[d] Missing data in four cases.
[e] Defined as history of intermittent claudication, critical limb ischaemia, or lower limb revascularisation.

p = .017, OR 3.8, 95% C.I. 1.2–11.5), but no other predictors were identified.

AVF patency results

Mean follow-up time was 20.7 and 17.2 months for radiocephalic and brachiocephalic AVFs respectively. Primary, primary assisted, secondary, and functional secondary patency were similar for the two AVF types (p = .62, p = .62, p = .54, and p = .32, respectively).

Radiocephalic AVF. No predictors of radiocephalic vein primary patency were identified. The single predictor of inferior primary assisted patency was patient age ≥52 years (higher three quartiles) (compared with younger patients, p = .045). Predictors of inferior secondary patency included

Table 2. Pre-operative ultrasound findings and functionality outcome measures of the radiocephalic and brachiocephalic AVF study groups.

	AVF type Radiocephalic (n = 57)	Brachiocephalic (n = 78)	p value	All AVFs (n = 135)
AVF side, L/R	46/11	57/21	.18	103/32
Pre-operative cephalic vein diameter, minimum, mm, median (IQR)	3.8 (3.4–4.2)	4.4 (3.8–5.1)	.001	4.0 (3.5–4.7)
Pre-operative arterial diameter, minimum, mm, median (IQR)	3.0 (2.5–3.2)	4.8 (4.1–5.6)	<.001	3.7 (3.0–5.0)
Outcome measures of AVF functionality[a]				
Immediate thrombosis	3 (5.4%)	4 (5.3%)	.65	7 (5.3%)
Ligation (steal)	0 (0%)	2 (2.7%)		2 (1.5%)
Remaining failure patterns	8 (14.3%)	12 (16.0%)		20 (15.3%)
Successfully used (functional) AVF	45 (80.4%)[b]	57 (76.0%)[c]		102 (77.9%)
Time to use, days, median (IQR)	60 (52–85)	61 (54–77.5)	.96	61 (54–78.75)

IQR = interquartile range.
[a] Excluding four patients in whom the AVF could not be assessed for possible use (1 patient with a radiocephalic AVF with renal function recovery that prompted AVF ligation and 3 patients with brachiocephalic AVF, including the single post-operative death, a late death, and an AVF not needled because of pre-emptive kidney transplantation), including [b]three and [c]10 AVFs used after elevation.

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a cephalic vein diameter <4.3 mm (lower three quartiles) (4 year patency 19.6% vs. 91.7% for larger veins, $p = .01$, Fig. 1) and female gender compared with males ($p = .035$). An inferior secondary patency was also observed for patients ≥52 years (higher three quartiles) compared with younger patients ($p = .086$), but not retained on Cox regression, which demonstrated cephalic vein <4.3 mm (lower three quartiles) as the single predictor of inferior secondary patency ($p = .030$, relative risk 10.1, 95% CI 1.3—83.3). Predictors of inferior FSP included a cephalic vein <4.3 mm (lower three quartiles) (4 year patency 16.5% vs. 91.7% for larger veins, $p = .005$) and female gender compared with males ($p = .021$). An inferior secondary patency was also observed for patients ≥52 years (higher three quartiles) compared with younger patients ($p = .033$), but not retained on Cox regression, which demonstrated cephalic vein <4.3 mm (lower three quartiles) as the single predictor of inferior FSP ($p = .02$, relative risk 11.2, 95% CI 1.44—90.9).

Brachiocephalic AVF. Primary patency predictors on univariate and multivariate analysis are shown in Table 3. On multivariate analysis, dyslipidaemia and brachial artery ≤4.1 mm were retained as independent predictors.

Predictors of inferior primary assisted patency included a brachial artery diameter ≤4.1 mm (lowest quartile) and a cephalic vein diameter ≤3.8 mm (lowest quartile), but also the clinical characteristics of dyslipidaemia, dual anticoagulation, hypertension, and use of anticoagulation, although the last two variables were not significant (Table 3). In the presence of the combination of a small cephalic vein (≤3.8 mm) with a small brachial artery (≤4.1 mm), primary assisted patency at 18 months was 0% (vs. 72.3% for a large artery and vein, $p = .000002$, Fig. 2); the difference remained significant after excluding AVFs that failed to become functional. In patients with small arteries and large veins, primary assisted patency was intermediate (Fig. 2), a difference that was not significant when compared with the groups of small artery/small vein and large artery/large vein. On multivariate analysis a brachial artery diameter ≤4.1 mm and dyslipidaemia were retained as significant predictors of inferior primary assisted patency.

Predictors of inferior secondary patency included a brachial artery diameter ≤4.1 mm (lowest quartile) and dual anticoagulation, and both were retained on multivariate analysis (Table 3).

Predictors of inferior FSP included a brachial artery diameter ≤4.1 mm (lowest quartile) ($p = 0.007$, Fig. 3), PAD, and dual anticoagulation, and all three variables remained significant on multivariate analysis (Table 3). The number of risk factors demonstrated risk stratification capabilities for functional secondary patency (Fig. 4).

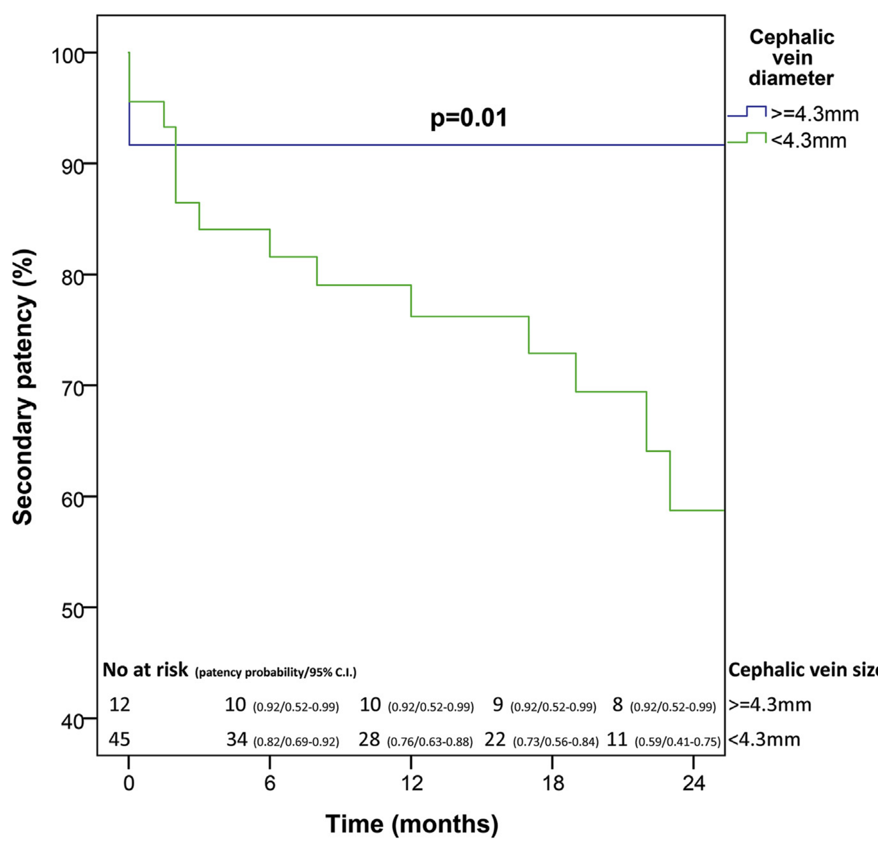

Figure 1. Secondary patency of radiocephalic AVFs in relation to cephalic vein diameter. Results were significantly inferior in the presence of a cephalic vein diameter <4.3 mm (lower three quartiles) compared with larger veins. Kaplan-Meier curves are truncated at 24 months. The number of patients at risk, patency probability, and 95% CI at each follow-up interval are shown at the bottom of the figure.

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Table 3. Predictors of brachiocephalic AVF patency on univariate and multivariate analysis.

Patency predictors	Results Patency results[a]	Univariate analysis[b]	Multivariate analysis[b]
Primary patency			
BA Ø ≤4.1 mm (LQ)	**21.9% vs. 49.4% @ 3 years, $p = .002$**	**HR 2.69, 95% CI 1.39–5.2, $p = .003$**	**HR 2.65, 95% CI 1.37–5.15, $p = .004$**
CV Ø ≤3.8 mm (LQ)	27.6% vs. 46.6% @ 3 years, $p = .066$	HR 1.81, 95% CI 0.94–3.50, $p = .078$	NS
Dyslipidaemia	**11.3% vs. 45.2% @ 5 years, $p = .029$**	**HR 2.00, 95% CI 1.04–3.85, $p = .037$**	**HR 1.97, 95% CI 1.02–3.80, $p = .043$**
Primary assisted patency			
BA Ø ≤4.1 mm (LQ)	**21.9% vs. 55.9% @ 3 years, $p = .001$**	**HR 3.38, 95% CI 1.65–6.90, $p = .001$**	**HR 3.1, 95% CI 1.5–6.4, $p = .002$**
CV Ø ≤3.8 mm (LQ)	**29.6% vs. 51.9% @ 4 years, $p = .021$**	HR 1.97, 95% CI 0.97–4.00, $p = .061$	NS
Dyslipidaemia	**21.2% vs. 64.9% @ 4 years, $p = .015$**	**HR 2.36, 95% CI 1.15–4.87, $p = .020$**	**HR 2.23, 95% CI 1.08–4.61, $p = .002$**
Hypertension	36.1% vs. 82.1% @ 5 years, $p = .053$	HR 3.68, 95% CI 0.88–15.44, $p = .075$	NS
Antithrombotic agents	31.0% vs. 56.7% @ 4 years, $p = .069$	HR 1.93, 95% CI 0.93–3.99, $p = .078$	NS
Dual antithrombotic agents	**27.8% vs. 77.4% @ 6 months, $p = .031$**	**HR 3.52, 95% CI 1.01–12.24, $p = .048$**	NS
Secondary patency			
BA Ø ≤4.1 mm (LQ)	**27.8% vs. 54.0% @ 3 years, $p = .011$**	**HR 2.62, 95% CI 1.20–5.72, $p = .015$**	**HR 2.6, 95% CI 1.17–5.6, $p = .019$**
Dual antithrombotic agents	**27.8% vs. 85.2% @ 6 months, $p = .007$**	**HR 4.99, 95% CI 1.36–4.99, $p = .015$**	**HR 4.64, 95% CI 1.27–16.94, $p = .020$**
Functional secondary patency			
BA Ø ≤4.1 mm (LQ)	**26.9% vs. 47.5% @ 4 years, $p = .007$**	**HR 2.44, 95% CI 1.23–4.81, $p = .010$**	**HR 3.43, 95% CI 1.66–7.07, $p = .001$**
Peripheral arterial disease	**33.3% vs. 57.0% @ 2 years, $p = .021$**	**HR 2.73, 95% CI 1.11–6.75, $p = .029$**	**HR 3.47, 95% CI 1.35–8.88, $p = .010$**
Dual antithrombotic agents	**22.2% vs. 57.8% @ 6 months, $p = .009$**	**HR 3.80, 95% CI 1.27–11.36, $p = .017$**	**HR 3.41, 95% CI 1.14–10.19, $p = .028$**

BA = brachial artery; CV = cephalic vein; HR = hazard ratio; LQ = lowest quartile; Ø = diameter.
[a] Comparison with the log-rank test.
[b] Derived from Cox regression. Significant associations appear in **bold**.

During follow-up 14 of 127 patients died as a result of cardiovascular ($n = 11$) or infectious ($n = 3$) causes. Patient survival at 1, 2, and 3 years was 94.4%, 85.7%, and 82.7%, respectively.

DISCUSSION

This study has demonstrated that in patients undergoing brachiocephalic AVF, functionality, primary, primary assisted, secondary, and functional secondary patency were all inferior in the presence of a brachial artery diameter ≤4.1 mm. These associations were confirmed on multivariate analysis, indicating that an alternative access site may be the preferred option. Although cephalic vein diameter was a predictor of primary assisted patency, it was not retained on multivariate analysis. The presence of PAD of the lower limbs or use of dual antithrombotics were also independently associated with a reduction in secondary patency, and it was suggested that the presence of multiple risk factors mandates the construction of an alternative access.

In patients undergoing radiocephalic AVF, a cephalic vein diameter <4.3 mm was the single independent predictor of inferior secondary and functional secondary patency.

No association was found between radial artery diameter and primary failure. There is conflicting evidence in the literature, with some studies showing that pre-operative radial artery diameters <1.5–1.6 mm predict early failure,[8,10,11] while other studies similar to this one, using a 2 mm minimum diameter failed to demonstrate an association.[7,16] Similarly, no association was found between cephalic vein diameter and primary radiocephalic AVF failure, probably the result of including patients with a minimum cephalic vein diameter of 3 mm, unlike others who used a minimum diameter of 1.8 mm.[10,11]

The present study confirmed the results of two studies showing that in upper arm fistulas that failed to become functional, pre-operative brachial artery diameters were significantly smaller compared with those that became functional[5,14]; these studies did not provide minimum diameters useful in clinical practice. However, a third study failed to confirm these findings.[16] Regarding optimum minimum venous diameter, patients with a larger vein have a higher probability of functionality,[6] particularly in the presence of a vein >4 mm in diameter,[4,5] although another study failed to demonstrate such an association.[16] The

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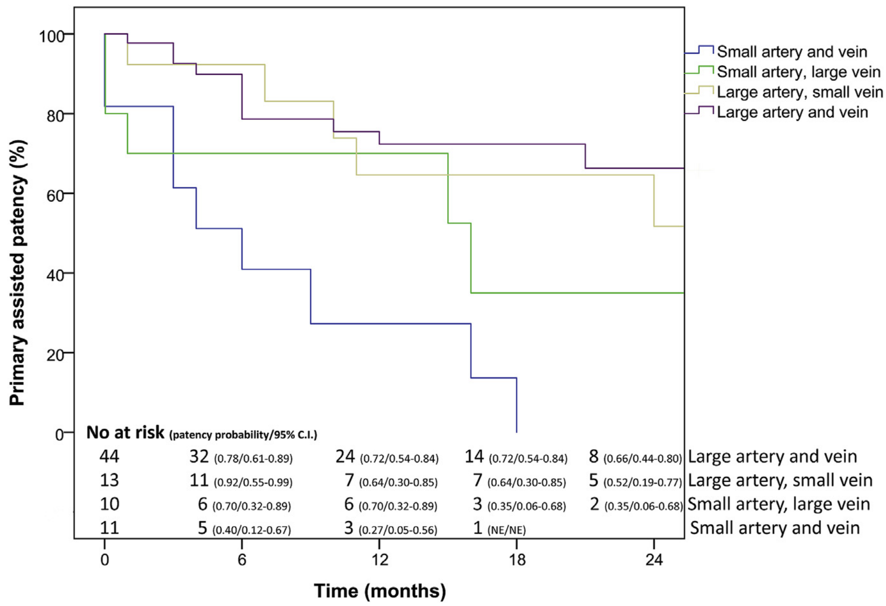

Figure 2. Primary assisted patency in relation to brachial artery and cephalic vein diameters. Patency at 18 months was 0% in the presence of a small brachial artery ($\leq$4.1 mm) and cephalic vein ($\leq$3.8 mm), significantly inferior compared with the results obtained with the subgroups of patients with a large artery and vein (72.3%, $p = .000002$) and also a large artery and a small vein (64.6%, $p = .002$). In patients with a small artery and a large vein, primary assisted patency was intermediate and when compared with the groups of small artery/small vein and large artery/large vein, no statistical significance was observed ($p = .16$ and $p = .13$, respectively). Kaplan-Meier curves are truncated at 24 months. The number of patients at risk, patency probability, and 95% CI at each follow-up interval are shown at the bottom of the figure. NE = not estimatable.

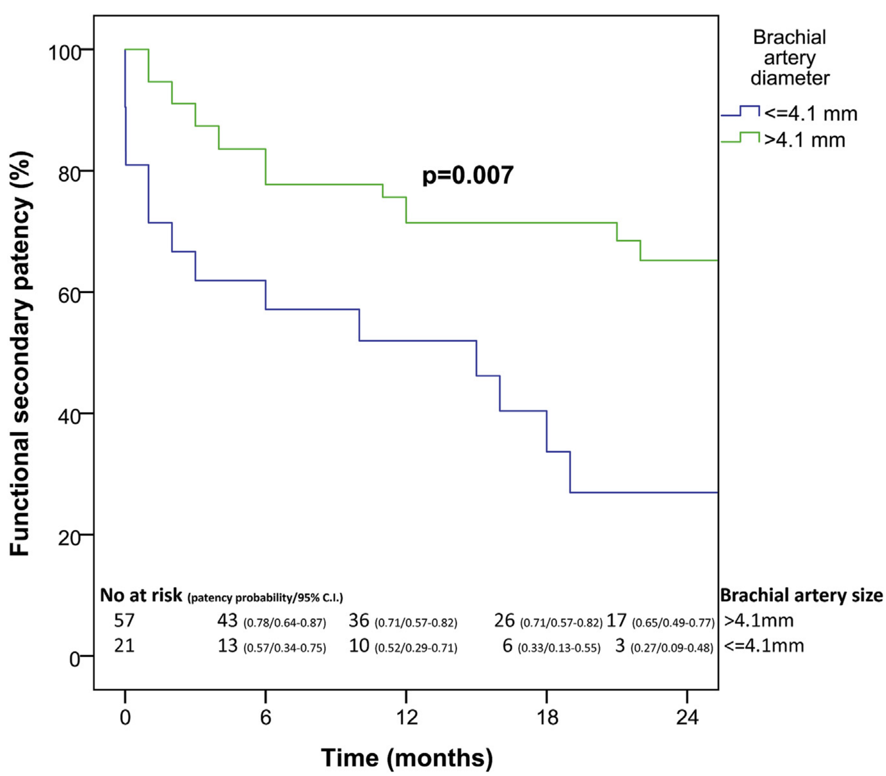

Figure 3. Functional secondary patency of brachiocephalic AVFs in relation to brachial artery diameter. Results were significantly inferior in the presence of a brachial artery diameter $\leq$4.1 mm (lowest quartile) compared with larger arteries. Kaplan-Meier curves are truncated at 24 months. The number of patients at risk, patency probability, and 95% CI at each follow-up interval are shown at the bottom of the figure.

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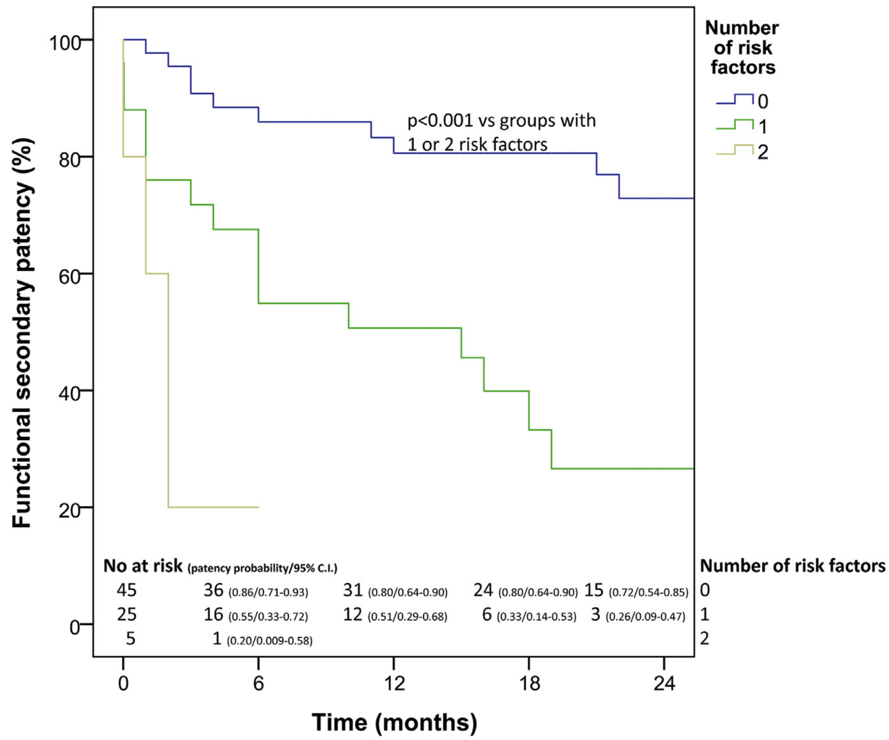

Figure 4. Functional secondary patency of brachiocephalic AVFs in relation to the number of risk factors identified by multivariate (Cox regression) analysis. No patient had three risk factors. Kaplan-Meier curves are truncated at 24 months. The number of patients at risk, patency probability, and 95% CI at each interval are shown at the bottom of the figure.

present study also failed to confirm these associations, and this is considered to be the result of appropriate use of pre-operative vessel mapping to exclude small and diseased cephalic veins, unlikely to be successfully used for dialysis. Of note, one study on a mixed population showed that AVFs made with small arteries and veins had a higher rate of early thrombosis than those with more advantageous anatomy; however, no minimum diameters were provided.[20]

Patient age $\geq$52 years was shown to be the single predictor of inferior primary assisted patency of radiocephalic AVFs; however the clinical utility of this observation is limited. Predictors of secondary and functional secondary patency included male gender and cephalic vein diameter, but only the last parameter was retained on multivariate Cox regression, confirming the clinical experience of excellent outcomes being obtained with large often clinically evaluated cephalic veins. One study has shown an association between radial artery diameter and primary patency[7]; such an association could not be confirmed here.

The present study showed that a brachial artery diameter $\leq$4.1 mm was an independent predictor of inferior results of all four types of brachiocephalic AVF patency. One study showed that arterial diameter did not predict primary patency of brachiobasilic vein fistulas,[15] but there is a paucity of information regarding long-term patency of brachiocephalic AVFs. Although it was demonstrated here that cephalic vein diameter was a predictor of primary assisted patency of brachiocephalic AVFs, this association was not retained on multivariate analysis. Another study showed that patients with a small vein on pre-operative vein mapping undergoing a brachiobasilic or brachiocephalic AVF had inferior long-term patency,[6] confirming the present findings. Furthermore, primary assisted patency results were stratified by arterial and venous diameters and demonstrated very poor results when both vessels were small; this implies that in the presence of this unfavourable combination, alternative access sites (e.g. in the contralateral upper limb) or procedure types should be considered (such as the median antebrachial vein or brachiobasilic AVFs if the basilic vein is larger than the cephalic vein or alternatively a brachiocephalic AVF with transposition of a larger main cephalic vein rather than a smaller median cephalic vein). Certainly, the present findings could be incorporated into decision models.[21]

This study demonstrated that patients with PAD or on dual antithrombotics undergoing brachiocephalic AVFs had a high risk for loss of secondary patency, independent of the arterial diameter. The presence of multiple risk factors may dictate the construction of an alternative access; however, in the absence of randomised trials, the level of evidence would be low and grade of recommendation weak. In view of the association between dyslipidaemia and primary and primary assisted patency, and the controversial effect of statins,[22,23] recommendation grade for statin use would also be weak. Nevertheless, functionality rates also affect the cost effectiveness of the procedure and should be taken into account during pre-operative planning,[24] while similar recommendations may be applicable for patients with poor

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FSP rates, for example less than 25% at 1 year, at the additional cost of multiple maintenance angioplasty and/or thrombectomy procedures.

Limitations of the present study include its relatively small size, retrospective nature, and single centre design. A larger study with longer follow-up could identify additional predictors, for example thrombophilia or genetic testing, keeping in mind that long-term failures do not depend only on vessel anatomy. Future work could incorporate risk factors for poor outcome demonstrated by others (e.g. calcification status of the inflow artery), external validation of the present results, and generation of a better predictive score. Reproducibility of vessel diameter should be investigated, including the effect of ambient temperature. Finally, cost effectiveness analysis could be incorporated into future work, as not all predictors may be clinically important.

In conclusion, among patients having a radiocephalic AVF, a cephalic vein diameter $<$4.3 mm was the single independent predictor of inferior primary assisted, secondary, and functional secondary patency. Among patients having a brachiocephalic AVF, functionality rates and also patency were inferior in the presence of a brachial artery diameter $\leq$4.1 mm. The presence of PAD or use of dual antithrombotics was associated with a high risk of loss of secondary patency, independent of the arterial diameter.

CONFLICT OF INTEREST

None.

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