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Vascular Access Patency and Complications in Patients on Maintenance Haemodialysis: A Prospective Observational Cohort Study

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ABS TRAC T

***Background*:** Vascular access failure is a leading cause of morbidity, hospitalisation and treatment interruption in maintenance haemodialysis. Prospective data on patency and complications using standardised definitions remain limited in Indian dialysis populations, in which late referral and catheter-based initiation are common. ***Methods*:** A prospective observational cohort study enrolled 160 adults on maintenance haemodialysis with a functioning vascular access at a tertiary care centre. Access type comprised arteriovenous fistula in 112, arteriovenous graft in 20 and tunnelled central venous catheter in 28 patients. Participants were followed for 12 months with clinical and duplex surveillance. Patency followed Society for Vascular Surgery reporting standards. The primary outcome was primary patency at 12 months; secondary outcomes were assisted primary and secondary patency, complications, interventions and abandonment. Kaplan-Meier and Cox regression methods were used. ***Results*:** Primary patency at 12 months was 68.8 per cent for fistulas, 45.0 per cent for grafts and 39.3 per cent for catheters (log-rank $p<0.001$); corresponding secondary patency was 87.5, 70.0 and 57.1 per cent. Complications occurred in 71 patients (44.4 per cent). Thrombosis was commonest in grafts (40.0 per cent) and access infection in catheters (39.3 per cent, $p<0.001$). On multivariable analysis, catheter use (adjusted hazard ratio 2.34, 95 per cent CI 1.29 to 4.25, $p=0.005$), diabetes (1.78, 1.09 to 2.91, $p=0.021$) and raised C-reactive protein (1.66, 1.02 to 2.71, $p=0.043$) independently predicted loss of primary patency. ***Conclusion*:** Arteriovenous fistulas showed clearly superior patency and the lowest complication burden. Diabetes, inflammation and catheter dependence predicted access failure, supporting early fistula creation and structured surveillance.

Keywords: *Haemodialysis, Vascular Access, Arteriovenous Fistula, Arteriovenous Graft, Central Venous Catheter, Primary Patency, Access Complications.*

INTRODUCTION

End-stage kidney disease imposes a rapidly expanding burden on health systems worldwide, and maintenance haemodialysis remains the modality by which the majority of affected patients are treated. The delivery of adequate haemodialysis depends absolutely on reliable and repeated access to the circulation, and for this reason the vascular access has long been described as the Achilles heel of the treatment. Access dysfunction interrupts the dialysis schedule, precipitates inadequate clearance and volume overload, generates a substantial proportion of unplanned hospital admissions in the dialysis population, and consumes a disproportionate share of the resources devoted to the care of these patients [1, 2]. The creation, maintenance and salvage of vascular access therefore occupy a central position in nephrology practice, and the durability of the access is one of the few modifiable determinants of outcome available to the treating clinician.

Three forms of access are in routine use: the autogenous arteriovenous fistula, the prosthetic arteriovenous graft and the tunnelled central venous catheter. Successive guidelines have placed the fistula first in the hierarchy of preference, on the grounds that it offers the longest functional life once matured, the lowest rate of infection, and the least requirement for maintenance intervention [1, 2]. The clinical basis for this preference is substantial. A large systematic review of cohort studies encompassing more than half a million participants found that, relative to fistula use, catheter

dependence was associated with a markedly higher risk of all-cause mortality, of fatal infection and of major cardiovascular events, while grafts occupied an intermediate position [3]. Registry analyses have reported concordant findings, with catheter-based access consistently associated with excess mortality even after adjustment for comorbidity and case mix [6, 7]. These observations underpin the recommendation that a functioning arteriovenous access should be established before the initiation of dialysis wherever the trajectory of chronic kidney disease permits [10].

The advantage of the fistula is nonetheless neither automatic nor universal. A substantial proportion of fistulas fail to mature sufficiently for cannulation, and among those that do mature the loss of unassisted patency over the first year is far from negligible. A systematic review with meta-analysis of fistula patency reported primary patency of approximately 60 per cent and secondary patency of approximately 71 per cent at one year, with wide variation attributable to differences in configuration, patient selection and surgical experience [4]. A further pooled analysis of all access types found two-year primary patency of 55 per cent for fistulas, 40 per cent for grafts and 50 per cent for catheters, with consistently poorer patency in older patients, in women, and in those with diabetes or coronary artery disease [5]. The mechanisms of failure are similarly heterogeneous. Juxta-anastomotic and outflow venous stenosis arising from neointimal hyperplasia and adverse outward remodelling accounts for the majority of late failures, and progresses to thrombosis when unrecognised. Prosthetic grafts are especially prone to stenosis at the venous anastomosis and to thrombosis, while catheters are dominated by lumen dysfunction, fibrin sheath formation, central venous stenosis and, most seriously, catheter-related bloodstream infection. Less frequent but clinically important problems include aneurysm and pseudoaneurysm formation, dialysis access-associated steal syndrome and venous hypertension of the access limb [1, 8].

Comparison across published series has historically been hampered by inconsistent terminology, with primary, assisted primary and secondary patency variously defined and occasionally conflated. The reporting standards issued by the Society for Vascular Surgery and the American Association for Vascular Surgery were framed specifically to address this problem, and their subsequent refinement into standardised definitions for haemodialysis vascular access has made meaningful comparison between cohorts possible [9]. Any contemporary study of access outcome is obliged to state its definitions explicitly and to apply them consistently to all access types.

The relevance of these questions to Indian practice is considerable and the available prospective evidence is correspondingly thin. Late referral to nephrology remains common, so that a substantial proportion of patients commence dialysis through a temporary or tunnelled catheter and undergo fistula creation only after the initiation of treatment, a sequence known to be associated with prolonged catheter exposure and inferior outcomes [8, 10]. The prevalence of diabetes among incident dialysis patients is high and rising, and diabetes exerts an adverse effect on both fistula maturation and subsequent patency. Structured surveillance programmes employing access flow measurement or systematic duplex assessment are available in relatively few centres, and access to timely endovascular salvage is uneven. Cost considerations further influence the choice between autogenous and prosthetic access. Against this background, most Indian data on access outcome derive from retrospective surgical series confined to fistulas, reported with heterogeneous definitions and without systematic ascertainment of complications across all access types.

The present study was therefore designed as a prospective observational cohort study to describe the patency of vascular access and the spectrum and frequency of access-related complications in patients receiving maintenance haemodialysis at a tertiary care centre, applying standardised definitions of patency uniformly across fistulas, grafts and tunnelled catheters, and to identify the clinical and biochemical variables independently associated with loss of access patency over a follow-up period of twelve months.

AIMS AND OBJECTIVES

The aim of the present study was to evaluate the patency of vascular access and to characterise the pattern, frequency and consequences of access-related complications in adult patients receiving maintenance haemodialysis at a tertiary care teaching hospital, using uniform and internationally accepted definitions applied across all three categories of access in current clinical use.

The primary objective was to determine the primary patency of the vascular access at twelve months of follow-up, both for the cohort as a whole and separately for arteriovenous fistulas, arteriovenous grafts and tunnelled central venous catheters. The secondary objectives were to determine the assisted primary and secondary patency of the access at six and twelve months; to document the incidence and nature of access-related complications, comprising thrombosis, haemodynamically significant stenosis, access-related infection, aneurysm and pseudoaneurysm formation, dialysis access-associated steal syndrome, venous hypertension of the access limb and bleeding or haematoma; to quantify the number and type of endovascular and surgical interventions required to establish or maintain patency and to determine the technical and clinical success of those interventions; to record the incidence of access abandonment, access-related hospitalisation and access-related mortality; and

to identify the demographic, clinical and biochemical variables independently associated with loss of primary patency by means of multivariable survival analysis.

MATERIALS AND METHODS

Study design and setting

This was a prospective, single-centre, observational cohort study conducted in the Department of Nephrology of Dr. D. Y. Patil Medical College, a tertiary care teaching institution in Pune, India, which maintains an in-centre haemodialysis unit serving approximately 160 patients. Consecutive eligible patients were enrolled between Nov 2023 and April 2024 and each participant was followed prospectively for twelve months from the date of enrolment, with the final follow-up assessment completed in April 2024. The protocol was approved by the Institutional Ethics Committee before the commencement of enrolment, and the study was conducted in accordance with the principles of the Declaration of Helsinki and reported in accordance with the STROBE statement for observational studies. Written informed consent was obtained from every participant before enrolment. No intervention was performed for the purposes of the study, and all clinical decisions regarding access creation, surveillance and salvage were made by the treating team according to prevailing institutional practice.

Participants

Adults aged 18 years and above who were receiving maintenance haemodialysis at least twice weekly for a minimum of three months, and who had a functioning vascular access in use at the time of screening, were considered eligible. Patients were included irrespective of the type of access, so that arteriovenous fistulas, arteriovenous grafts and tunnelled cuffed central venous catheters were all represented. Patients were excluded if the access in use was a non-tunnelled temporary catheter; if they were receiving haemodialysis for acute kidney injury with an expectation of renal recovery; if they were on a transplant waiting list with a scheduled transplantation date within the follow-up period; if they had an active malignancy or any condition conferring a life expectancy of less than twelve months; if they were pregnant; or if they were unwilling to provide consent or unlikely to remain under follow-up at the study centre. Where a patient had more than one access, the access in active use for dialysis at the time of enrolment was designated the index access and was the unit of observation throughout.

Sample size

The sample size was calculated for the estimation of a single proportion, namely the primary patency of the vascular access at twelve months. Taking the expected proportion as 62 per cent on the basis of published meta-analytic estimates of one-year primary patency, and specifying an absolute precision of 8 per cent with a two-sided confidence level of 95 per cent, the required sample size was 142 participants. Allowing for an anticipated attrition of 10 per cent from death, transplantation, transfer of care and loss to follow-up, the target enrolment was inflated to 160 participants.

Data collection

Baseline data were recorded at enrolment on a structured proforma and comprised age, sex, body mass index, the primary cause of end-stage kidney disease, dialysis vintage, dialysis frequency and duration, comorbid conditions including diabetes mellitus, hypertension, coronary artery disease and peripheral vascular disease, smoking history, and the use of antiplatelet and anticoagulant medication. Baseline laboratory variables comprised haemoglobin, serum albumin, serum calcium and phosphate, intact parathyroid hormone, C-reactive protein and the delivered dialysis dose expressed as single-pool Kt/V. Access-related variables recorded at enrolment comprised the type and anatomical site of the access, the date and indication of its creation, the operating surgeon or interventionist, whether preoperative duplex vessel mapping had been performed, whether the access had been created before or after the initiation of dialysis, the maturation interval for arteriovenous accesses, the cannulation technique in routine use, and the mean access blood flow achieved during dialysis.

Definitions

Patency was defined in accordance with the recommended reporting standards for arteriovenous haemodialysis access and their subsequent standardisation.(9,15) Primary patency was defined as the interval from enrolment to the first occurrence of thrombosis, of any intervention undertaken to maintain or restore patency, or of access abandonment, whichever came first. Assisted primary patency was defined as the interval from enrolment to thrombosis or abandonment, with prophylactic interventions performed on a patent access not counted as an event. Secondary patency was defined as the interval from enrolment until the access was abandoned, irrespective of the number of interventions performed to maintain its function. Haemodynamically significant stenosis was defined as a reduction of at least 50 per cent in luminal diameter on duplex ultrasonography or fistulography accompanied by a clinical or physiological abnormality, comprising a fall in access flow, an increase in venous pressure, a decrease in delivered dialysis dose, prolonged bleeding after needle withdrawal or an abnormal physical finding on examination of the access. Thrombosis was defined as the complete cessation of flow through the access confirmed by absence of thrill and bruit and by duplex examination. Access-related infection comprised localised infection of the exit site or tunnel and catheter-related or access-related bloodstream infection defined by concordant peripheral and access blood cultures in the absence of an alternative source. Aneurysm was defined as a

dilatation of the access exceeding three times the diameter of the adjacent normal segment. Dialysis access-associated steal syndrome was defined as ischaemic symptoms of the access limb attributable to the access and resolving on its ligation or revision.

Surveillance and follow-up protocol

All participants were reviewed at every dialysis session by the treating nursing and technical staff, who performed a structured physical examination of the access comprising inspection, palpation for thrill and pulsatility, and auscultation for bruit, and who recorded arterial and venous pressures, achieved blood flow, needling difficulty and duration of post-dialysis haemostasis. A formal clinical review was undertaken monthly and duplex ultrasonography of the access was performed at enrolment, at six months and at twelve months, and additionally at any time when clinical or dialysis-related parameters suggested access dysfunction. Delivered dialysis dose was measured monthly and laboratory variables were repeated at six and twelve months. Any suspected access dysfunction was referred for fistulography with a view to endovascular or surgical salvage, and the nature, date and outcome of every intervention were recorded prospectively. Episodes of access-related infection, hospitalisation, access abandonment, creation of a new access and death were recorded with dates and adjudicated by two investigators independently, with disagreement resolved by discussion.

Statistical analysis

Data were entered into a structured database and analysed using [SPSS version 26.0, IBM Corporation, Armonk, New York, United States]. The distribution of continuous variables was assessed using the Shapiro-Wilk test. Normally distributed continuous variables were expressed as mean with standard deviation and compared across access types using one-way analysis of variance with the Bonferroni correction for post hoc pairwise comparison, while skewed variables were expressed as median with interquartile range and compared using the Kruskal-Wallis test. Categorical variables were expressed as frequencies with percentages and compared using the chi-squared test or the Fisher exact test as appropriate. Patency was analysed by the Kaplan-Meier method, with patients censored at death, transplantation, transfer of care or completion of twelve months of follow-up, and survival curves were compared using the log-rank test. Complication rates were additionally expressed as events per patient-year of access exposure and compared using Poisson regression. Variables associated with loss of primary patency at a significance level below 0.10 on univariable Cox regression were entered into a multivariable Cox proportional hazards model, and the proportional hazards assumption was verified by inspection of log-minus-log plots and scaled Schoenfeld residuals. Hazard ratios were reported with 95 per cent confidence intervals. A two-sided p value of less than 0.05 was considered statistically significant.

RESULTS

Cohort characteristics

Two hundred and four patients on maintenance haemodialysis were screened, of whom forty-four were excluded, the commonest reasons being the use of a non-tunnelled temporary catheter in nineteen patients, an anticipated life expectancy of less than twelve months in eleven, a scheduled transplantation in seven and refusal of consent in seven. One hundred and sixty patients were enrolled and constituted the analytic cohort. The index access was an arteriovenous fistula in 112 patients (70.0 per cent), an arteriovenous graft in 20 patients (12.5 per cent) and a tunnelled central venous catheter in 28 patients (17.5 per cent). Nine patients died during follow-up before the twelve-month assessment and five were transferred to another centre; all contributed censored observation time.

Baseline characteristics of the cohort as a whole and stratified by access type are presented in Table 1. The mean age of the cohort was 52.4 +/- 13.1 years and 98 patients (61.3 per cent) were male. Diabetes mellitus was present in 78 patients (48.8 per cent), hypertension in 141 patients (88.1 per cent), coronary artery disease in 38 patients (23.8 per cent) and peripheral vascular disease in 17 patients (10.6 per cent). The median dialysis vintage was 26 months with an interquartile range of 14 to 42 months. Patients with a tunnelled catheter were older than those with a fistula and had a higher prevalence of peripheral vascular disease, but the differences in age (p=0.216) and in the prevalence of diabetes (p=0.128) did not attain statistical significance across the three groups. Mean serum albumin was 3.5 +/- 0.5 g/dL and median C-reactive protein was 6.4 mg/L with an interquartile range of 2.8 to 12.1 mg/L, the latter being significantly higher in catheter-dependent patients (p=0.014).

The characteristics of the index access are summarised in Table 2. Among the 112 fistulas, 68 (60.7 per cent) were radiocephalic, 36 (32.1 per cent) were brachiocephalic and 8 (7.1 per cent) were transposed brachiobasilic. Of the 20 grafts, 13 (65.0 per cent) were forearm loop configurations and 7 (35.0 per cent) were upper arm straight grafts, and of the 28 catheters, 24 (85.7 per cent) were placed in the right internal jugular vein. Preoperative duplex vessel mapping had been performed before creation in 96 patients (60.0 per cent), and the access had been created before the initiation of dialysis in only 58 patients (36.3 per cent). The mean maturation interval for arteriovenous fistulas was 8.2 +/- 2.6 weeks and the mean access blood flow achieved during dialysis was 812 +/- 214 mL/min for fistulas compared with 764 +/- 198 mL/min for grafts and 268 +/- 54 mL/min for catheters (p<0.001). Mean delivered single-pool Kt/V was 1.32 +/- 0.18 overall and was significantly lower in catheter-dependent patients at 1.18 +/- 0.16 (p<0.001).

Patency

Patency outcomes are presented in Table 3 and the Kaplan-Meier estimates of primary patency by access type are shown in Figure 1. For the cohort as a whole, primary patency was 76.9 per cent at six months and 60.6 per cent at twelve months. Primary patency at twelve months differed markedly by access type, being 68.8 per cent for arteriovenous fistulas, 45.0 per cent for arteriovenous grafts and 39.3 per cent for tunnelled catheters, a difference that was highly significant on log-rank testing (chi-squared 17.42, p<0.001). Pairwise comparison confirmed the superiority of fistulas over both grafts (p=0.021) and catheters (p<0.001), while the difference between grafts and catheters did not reach significance (p=0.412). Median time to loss of primary patency was not reached for fistulas, and was 10.4 months for grafts and 8.6 months for catheters.

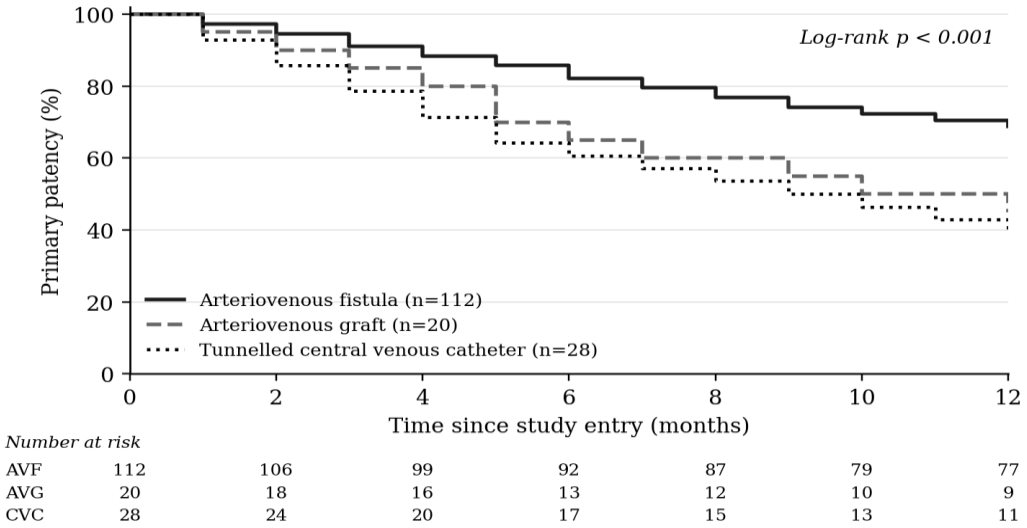

Figure 1: Kaplan-Meier estimates of primary patency of the index vascular access over twelve months of follow-up, stratified by access type. AVF, arteriovenous fistula; AVG, arteriovenous graft; CVC, tunnelled central venous catheter

Assisted primary patency at twelve months was 79.5 per cent for fistulas, 60.0 per cent for grafts and 50.0 per cent for catheters (p<0.001), and secondary patency at the same time point was 87.5 per cent, 70.0 per cent and 57.1 per cent respectively (p<0.001), giving an overall secondary patency of 80.0 per cent for the cohort. The absolute gain conferred by intervention, expressed as the difference between primary and secondary patency at twelve months, was 18.7 percentage points for fistulas, 25.0 percentage points for grafts and 17.8 percentage points for catheters, indicating that salvage procedures recovered a substantial proportion of accesses in every group and were proportionately most productive in prosthetic grafts.

Complications

Access-related complications are detailed in Table 4 and their distribution by access type is displayed in Figure 2. At least one complication occurred in 71 patients (44.4 per cent), and 94 discrete complication events were recorded over 143.6 patient-years of access exposure, giving an overall complication rate of 0.65 events per patient-year. The rate varied substantially by access type, being 0.62 events per patient-year for fistulas, 1.35 for grafts and 1.78 for catheters (p<0.001 on Poisson regression).

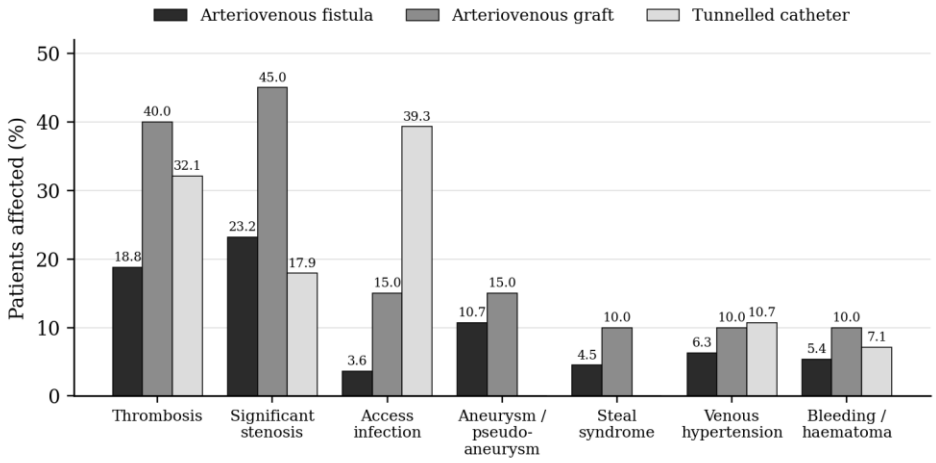

Figure 2: Proportion of patients experiencing each category of access-related complication over twelve months of follow-up, stratified by access type

Haemodynamically significant stenosis was the commonest single complication overall, affecting 26 patients with a fistula (23.2 per cent), 9 with a graft (45.0 per cent) and 5 with a catheter (17.9 per cent), a distribution that approached but did not attain significance (p=0.062). Thrombosis occurred in 21 fistulas (18.8 per cent), 8 grafts (40.0 per cent) and 9 catheters (32.1 per cent), and this difference was significant (p=0.032). Access-related infection showed the most striking gradient across access types, occurring in only 4 patients with a fistula (3.6 per cent) and 3 with a graft (15.0 per cent) but in 11 catheter-dependent patients (39.3 per cent), a highly significant difference (p<0.001); of the eleven catheter-related infections, seven were bloodstream infections and four were confined to the exit site or tunnel. Aneurysm or pseudoaneurysm formation was confined to arteriovenous access, occurring in 12 fistulas (10.7 per cent) and 3 grafts (15.0 per cent) and in no catheter (p=0.163). Dialysis access-associated steal syndrome was recorded in 5 fistulas (4.5 per cent) and 2 grafts (10.0 per cent), and required surgical revision in three instances. Venous hypertension of the access limb affected 7 fistulas (6.3 per cent), 2 grafts (10.0 per cent) and 3 catheter-dependent limbs (10.7 per cent, p=0.622), and bleeding or haematoma occurred in 6, 2 and 2 patients respectively (p=0.700). Catheter dysfunction with persistently inadequate blood flow complicated 10 of the 28 catheters (35.7 per cent).

Access-related hospitalisation was required by 34 patients (21.3 per cent) and was significantly more frequent among catheter-dependent patients, of whom 12 (42.9 per cent) were admitted, compared with 16 patients with a fistula (14.3 per cent) and 6 with a graft (30.0 per cent, p=0.003). The index access was abandoned during follow-up in 32 patients, comprising 14 fistulas (12.5 per cent), 6 grafts (30.0 per cent) and 12 catheters (42.9 per cent), a significant difference across groups (p<0.001). Fourteen patients (8.8 per cent) died during the follow-up period, and death was adjudicated as access-related in 3 instances (1.9 per cent), all of which followed catheter-related bloodstream infection.

Interventions

Interventions undertaken to establish or maintain access patency are summarised in Table 5. A total of 68 procedures were performed in 47 patients (29.4 per cent). Percutaneous transluminal angioplasty was the commonest procedure, performed in 29 patients (18.1 per cent), followed by new access creation in 18 patients (11.3 per cent), surgical thrombectomy in 14 (8.8 per cent) and surgical revision of the access in 11 (6.9 per cent); catheter exchange over a guidewire was performed on 13 occasions in 9 patients. The technical success rate of angioplasty, defined as residual stenosis of less than 30 per cent with restoration of thrill, was 86.2 per cent (25 of 29 procedures), and clinical success with restoration of adequate dialysis was achieved in 24 of 29 patients (82.8 per cent). Access survival at six months following the first intervention was 74.5 per cent. The intervention rate was 0.31 procedures per patient-year for fistulas, 0.85 for grafts and 0.96 for catheters.

Predictors of loss of primary patency

The results of univariable and multivariable Cox proportional hazards analysis are presented in Table 6. On univariable analysis, catheter use compared with fistula (hazard ratio 2.61, 95 per cent confidence interval 1.48 to 4.60, p=0.001), graft use compared with fistula (2.08, 1.09 to 3.97, p=0.026), diabetes mellitus (1.94, 1.22 to 3.09, p=0.005), peripheral vascular disease (2.14, 1.18 to 3.88, p=0.012), C-reactive protein above 10 mg/L (1.83, 1.14 to 2.94, p=0.012), serum albumin below 3.5 g/dL (1.71, 1.08 to 2.71, p=0.023) and age above 60 years (1.62, 1.02 to 2.57, p=0.041)

were each associated with loss of primary patency, while preoperative duplex vessel mapping was protective (0.62, 0.39 to 0.99, p=0.045). Female sex (1.48, 0.94 to 2.33, p=0.090) and antiplatelet use (0.71, 0.44 to 1.14, p=0.155) did not attain significance.

In the multivariable model, catheter use compared with fistula (adjusted hazard ratio 2.34, 95 per cent CI 1.29 to 4.25, p=0.005), diabetes mellitus (1.78, 1.09 to 2.91, p=0.021) and C-reactive protein above 10 mg/L (1.66, 1.02 to 2.71, p=0.043) remained independently associated with loss of primary patency. Graft use compared with fistula (1.92, 0.98 to 3.76, p=0.057), serum albumin below 3.5 g/dL (1.58, 0.97 to 2.57, p=0.066) and preoperative duplex mapping (0.64, 0.40 to 1.03, p=0.066) showed associations of similar magnitude that fell marginally short of conventional significance, while the association with age above 60 years was attenuated after adjustment (1.41, 0.87 to 2.29, p=0.163). The proportional hazards assumption was satisfied for all variables retained in the final model.

Table 1: Baseline demographic, clinical and biochemical characteristics of the cohort, overall and by access type

Variable	All (n=160)	AVF (n=112)	AVG (n=20)	CVC (n=28)	p value
Age, years, mean +/- SD	52.4 +/- 13.1	51.2 +/- 12.8	55.9 +/- 13.6	54.1 +/- 13.9	0.216
Male sex, n (%)	98 (61.3)	71 (63.4)	12 (60.0)	15 (53.6)	0.633
Body mass index, kg/m2	22.8 +/- 3.9	22.9 +/- 3.8	23.4 +/- 4.2	22.1 +/- 4.0	0.507
Diabetes mellitus, n (%)	78 (48.8)	49 (43.8)	13 (65.0)	16 (57.1)	0.128
Hypertension, n (%)	141 (88.1)	98 (87.5)	18 (90.0)	25 (89.3)	0.919
Coronary artery disease, n (%)	38 (23.8)	23 (20.5)	7 (35.0)	8 (28.6)	0.291
Peripheral vascular disease, n (%)	17 (10.6)	8 (7.1)	4 (20.0)	5 (17.9)	0.083
Current or former smoker, n (%)	42 (26.3)	28 (25.0)	6 (30.0)	8 (28.6)	0.845
Antiplatelet therapy, n (%)	71 (44.4)	51 (45.5)	9 (45.0)	11 (39.3)	0.834
Dialysis vintage, months, median (IQR)	26 (14-42)	29 (17-45)	24 (13-38)	15 (8-28)	0.004
Sessions per week, mean +/- SD	2.4 +/- 0.5	2.4 +/- 0.5	2.5 +/- 0.5	2.3 +/- 0.5	0.371
Haemoglobin, g/dL, mean +/- SD	9.4 +/- 1.4	9.5 +/- 1.4	9.3 +/- 1.5	9.1 +/- 1.3	0.398
Serum albumin, g/dL, mean +/- SD	3.5 +/- 0.5	3.6 +/- 0.5	3.4 +/- 0.5	3.3 +/- 0.6	0.021
Serum phosphate, mg/dL, mean +/- SD	5.2 +/- 1.5	5.2 +/- 1.4	5.4 +/- 1.6	5.1 +/- 1.7	0.760
Intact PTH, pg/mL, median (IQR)	312 (180-520)	318 (186-528)	296 (170-486)	298 (172-502)	0.681
C-reactive protein, mg/L, median (IQR)	6.4 (2.8-12.1)	5.6 (2.4-10.4)	7.8 (3.6-14.2)	9.6 (4.8-17.3)	0.014
Single-pool Kt/V, mean +/- SD	1.32 +/- 0.18	1.36 +/- 0.17	1.31 +/- 0.16	1.18 +/- 0.16	<0.001

AVF, arteriovenous fistula; AVG, arteriovenous graft; CVC, tunnelled central venous catheter; SD, standard deviation; IQR, interquartile range; PTH, parathyroid hormone. Continuous variables compared using one-way analysis of variance or the Kruskal-Wallis test and categorical variables using the chi-squared or Fisher exact test.

Table 2: Characteristics of the index vascular access

Variable	Value	p value
Access type, n (%)		Not applicable
Arteriovenous fistula	112 (70.0)	
Arteriovenous graft	20 (12.5)	
Tunnelled central venous catheter	28 (17.5)	
Fistula configuration, n (% of 112)		
Radiocephalic	68 (60.7)	
Brachiocephalic	36 (32.1)	
Transposed brachiobasilic	8 (7.1)	
Graft configuration, n (% of 20)		
Forearm loop	13 (65.0)	
Upper arm straight	7 (35.0)	
Catheter site, n (% of 28): right internal jugular	24 (85.7)	
Preoperative duplex vessel mapping performed, n (%)	96 (60.0)	
Access created before initiation of dialysis, n (%)	58 (36.3)	
Fistula maturation interval, weeks, mean +/- SD	8.2 +/- 2.6	
Access blood flow, mL/min: AVF	812 +/- 214	<0.001
Access blood flow, mL/min: AVG	764 +/- 198	
Access blood flow, mL/min: CVC	268 +/- 54	
Buttonhole cannulation technique in use, n (% of 132)	31 (23.5)	
Total access exposure, patient-years	143.6	

AVF, arteriovenous fistula; AVG, arteriovenous graft; CVC, tunnelled central venous catheter; SD, standard deviation.

The p value for access blood flow refers to comparison across the three access types.

Table 3: Primary, assisted primary and secondary patency at six and twelve months by access type

Patency outcome	All (n=160)	AVF (n=112)	AVG (n=20)	CVC (n=28)	p value
Primary patency at 6 months, %	76.9	82.1	65.0	60.7	0.011
Primary patency at 12 months, %	60.6	68.8	45.0	39.3	<0.001
Assisted primary patency at 6 months, %	84.4	88.4	75.0	71.4	0.028
Assisted primary patency at 12 months, %	71.9	79.5	60.0	50.0	<0.001
Secondary patency at 6 months, %	90.0	93.8	85.0	78.6	0.024
Secondary patency at 12 months, %	80.0	87.5	70.0	57.1	<0.001
Median time to primary patency loss, months	Not reached	Not reached	10.4	8.6	Not applicable
Access abandoned during follow-up, n (%)	32 (20.0)	14 (12.5)	6 (30.0)	12 (42.9)	<0.001
Gain from primary to secondary patency at 12 months, percentage points	19.4	18.7	25.0	17.8	Not applicable

AVF, arteriovenous fistula; AVG, arteriovenous graft; CVC, tunnelled central venous catheter. Patency estimated by the Kaplan-Meier method with comparison across access types by the log-rank test. Patency definitions follow the recommended reporting standards for arteriovenous haemodialysis access.

Table 4: Access-related complications over twelve months of follow-up

Complication	All (n=160)	AVF (n=112)	AVG (n=20)	CVC (n=28)	p value
Any complication, n (%)	71 (44.4)	43 (38.4)	11 (55.0)	17 (60.7)	0.056
Haemodynamically significant stenosis, n (%)	40 (25.0)	26 (23.2)	9 (45.0)	5 (17.9)	0.062
Thrombosis, n (%)	38 (23.8)	21 (18.8)	8 (40.0)	9 (32.1)	0.032
Access-related infection, n (%)	18 (11.3)	4 (3.6)	3 (15.0)	11 (39.3)	<0.001
Bloodstream infection, n	10	1	2	7	
Exit site or tunnel infection, n	8	3	1	4	
Aneurysm or pseudoaneurysm, n (%)	15 (9.4)	12 (10.7)	3 (15.0)	0 (0.0)	0.163
Steal syndrome, n (%)	7 (4.4)	5 (4.5)	2 (10.0)	0 (0.0)	0.235
Venous hypertension of limb, n (%)	12 (7.5)	7 (6.3)	2 (10.0)	3 (10.7)	0.622
Bleeding or haematoma, n (%)	10 (6.3)	6 (5.4)	2 (10.0)	2 (7.1)	0.700
Catheter dysfunction with inadequate flow, n (%)	10 (6.3)	Not applicable	Not applicable	10 (35.7)	Not applicable
Access-related hospitalisation, n (%)	34 (21.3)	16 (14.3)	6 (30.0)	12 (42.9)	0.003
Complication rate, events per patient-year	0.65	0.62	1.35	1.78	<0.001
Access-related death, n (%)	3 (1.9)	0 (0.0)	0 (0.0)	3 (10.7)	0.002

AVF, arteriovenous fistula; AVG, arteriovenous graft; CVC, tunnelled central venous catheter. Patients may have experienced more than one complication, so category totals exceed the number of patients with any complication. Complication rates compared using Poisson regression.

Table 5: Interventions performed to establish or maintain access patency

Intervention or outcome	All (n=160)	AVF (n=112)	AVG (n=20)	CVC (n=28)
Patients undergoing any intervention, n (%)	47 (29.4)	26 (23.2)	9 (45.0)	12 (42.9)
Total procedures performed, n	68	34	14	20
Percutaneous transluminal angioplasty, n (%)	29 (18.1)	18 (16.1)	8 (40.0)	3 (10.7)
Surgical thrombectomy, n (%)	14 (8.8)	8 (7.1)	5 (25.0)	1 (3.6)
Surgical revision of access, n (%)	11 (6.9)	8 (7.1)	3 (15.0)	0 (0.0)
Catheter exchange over guidewire, n	13	Not applicable	Not applicable	13
New access created, n (%)	18 (11.3)	7 (6.3)	3 (15.0)	8 (28.6)
Technical success of angioplasty, n/N (%)	25/29 (86.2)	16/18 (88.9)	7/8 (87.5)	2/3 (66.7)
Clinical success of angioplasty, n/N (%)	24/29 (82.8)	16/18 (88.9)	6/8 (75.0)	2/3 (66.7)
Access survival 6 months after first intervention, %	74.5	80.8	66.7	66.7
Intervention rate, procedures per patient-year	0.47	0.31	0.85	0.96

AVF, arteriovenous fistula; AVG, arteriovenous graft; CVC, tunnelled central venous catheter. Percentages for individual procedures are calculated on the number of patients in each column. Technical success of angioplasty was

defined as residual stenosis below 30 per cent with restoration of thrill.

Table 6: Univariable and multivariable Cox regression analysis for loss of primary patency

Variable	Unadjusted HR (95% CI)	p value	Adjusted HR (95% CI)	p value
Tunnelled catheter vs fistula	2.61 (1.48-4.60)	0.001	2.34 (1.29-4.25)	0.005
Arteriovenous graft vs fistula	2.08 (1.09-3.97)	0.026	1.92 (0.98-3.76)	0.057
Diabetes mellitus	1.94 (1.22-3.09)	0.005	1.78 (1.09-2.91)	0.021
Peripheral vascular disease	2.14 (1.18-3.88)	0.012	1.72 (0.92-3.22)	0.091
C-reactive protein > 10 mg/L	1.83 (1.14-2.94)	0.012	1.66 (1.02-2.71)	0.043
Serum albumin < 3.5 g/dL	1.71 (1.08-2.71)	0.023	1.58 (0.97-2.57)	0.066
Age > 60 years	1.62 (1.02-2.57)	0.041	1.41 (0.87-2.29)	0.163
Female sex	1.48 (0.94-2.33)	0.090	1.32 (0.82-2.13)	0.253
Preoperative duplex vessel mapping	0.62 (0.39-0.99)	0.045	0.64 (0.40-1.03)	0.066
Forearm vs upper arm arteriovenous access	1.36 (0.78-2.37)	0.279	Not entered	Not applicable
Antiplatelet therapy	0.71 (0.44-1.14)	0.155	Not entered	Not applicable
Coronary artery disease	1.29 (0.78-2.13)	0.322	Not entered	Not applicable
Current or former smoking	1.24 (0.75-2.05)	0.402	Not entered	Not applicable

HR, hazard ratio; CI, confidence interval. Variables associated with the outcome at p<0.10 on univariable analysis were entered into the multivariable model. The proportional hazards assumption was verified by inspection of log-minus-log plots and scaled Schoenfeld residuals.

DISCUSSION

This prospective cohort study of 160 patients on maintenance haemodialysis demonstrated a clear hierarchy of vascular access durability, with arteriovenous fistulas achieving primary patency of 68.8 per cent and secondary patency of 87.5 per cent at twelve months, substantially exceeding the corresponding figures for prosthetic grafts and tunnelled catheters. The complication burden followed the same hierarchy, with fistulas incurring 0.62 events per patient-year compared with 1.35 for grafts and 1.78 for catheters. Catheter dependence, diabetes mellitus and systemic inflammation emerged as independent predictors of loss of primary patency.

The patency figures obtained here correspond closely with the pooled international literature. The meta-analysis of fistula patency by Al-Jaishi and colleagues reported primary patency of approximately 60 per cent and secondary patency of approximately 71 per cent at one year across a large number of cohorts, and identified the same sources of heterogeneity, namely configuration, patient selection and operative experience, that plausibly account for the modestly higher figures observed in the present cohort [4]. The broader meta-analysis by Almasri and colleagues, which encompassed all three access types, reported two-year primary patency of 55 per cent for fistulas, 40 per cent for grafts and 50 per cent for catheters, and documented consistently poorer patency in older patients, in women and in those with diabetes or coronary artery disease, a pattern reproduced in the univariable analysis presented here [5]. The systematic review and meta-analysis comparing autogenous with prosthetic access likewise found superior patency and lower infection rates for autogenous access, although at the cost of a higher rate of primary failure before first use [11]. A large United States analysis of utilisation, patency and complications across access types reached concordant conclusions in a contemporary registry population [12].

The gradient in complications observed in the present study was in several respects more informative than the patency data alone. Access-related infection displayed the steepest gradient, affecting 39.3 per cent of catheter-dependent patients but only 3.6 per cent of those with a fistula, and accounting for all three access-related deaths. This finding is entirely consistent with the systematic review of access type and clinical outcomes, which reported that catheter use conferred a risk of fatal infection more than double that associated with fistula use, and with subsequent work demonstrating that access complications mediate a substantial part of the excess mortality attributed to catheters [3, 13]. Registry analyses in elderly incident dialysis populations have reported the same association between initial catheter use and adverse outcome [14]. Conversely, stenosis and thrombosis predominated in prosthetic grafts, in which the venous anastomosis is the characteristic site of neointimal hyperplasia, while aneurysm formation and steal syndrome were confined to arteriovenous access and were absent in catheters. This complementary distribution of risk means that no single access type is free of complication, and that the choice of access is properly framed as a selection of which risks are most acceptable for a given patient rather than as the pursuit of an ideal.

The independent association of C-reactive protein above 10 mg/L with loss of primary patency merits particular emphasis, since it is a finding with mechanistic plausibility rather than a statistical incidental. Neointimal hyperplasia and adverse outward remodelling, the histological substrate of the great majority of access stenoses, are driven by endothelial injury and by an inflammatory response involving monocyte recruitment and smooth muscle cell proliferation, so that a persistently elevated systemic inflammatory burden would be expected to accelerate access failure. The failure of fistulas to mature has been analysed in similar terms, with inflow arterial disease, impaired outward remodelling and aggressive neointimal proliferation identified as the principal mechanisms [24]. The parallel association with hypoalbuminaemia observed here, which fell marginally short of significance after adjustment, is consistent with the same inflammatory pathway rather than with nutritional status considered in isolation.

Not all published evidence points in a uniformly pro-fistula direction, and the contrary literature deserves fair statement. Work examining trade-offs in access selection among elderly patients initiating dialysis with a catheter has demonstrated that the survival advantage of subsequent fistula creation is attenuated in those with limited life expectancy, in whom the burden of maturation, repeated intervention and prolonged catheter exposure during the maturation interval may outweigh the eventual benefit [21]. Analyses of tunnelled catheter use have shown that in a defined subgroup of patients with exhausted access options or short anticipated survival, the catheter is a legitimate definitive choice rather than a failure of planning [22]. Comparative studies of upper arm access have found that transposed brachiobasilic fistulas and upper arm grafts yield broadly comparable outcomes once the higher primary failure rate of the fistula is taken into account, so that the presumption in favour of autogenous access is weaker in the upper arm than in the forearm [23]. The observation in the present cohort that assisted primary and secondary patency for grafts approached that of fistulas once salvage interventions were counted, with grafts showing the largest absolute gain from intervention, is consistent with this more nuanced position.

The finding that only 36.3 per cent of accesses in this cohort had been created before the initiation of dialysis is arguably the most actionable observation of the study, since it is a modifiable failure of care pathway rather than of biology. International comparisons from the Dialysis Outcomes and Practice Patterns Study have repeatedly demonstrated wide variation in access practice between countries and have linked facility-level fistula use to survival, with instrumental variable analysis supporting a causal interpretation that is difficult to obtain from conventional adjustment alone [7, 17]. The same body of work has shown that vascular access training and practice patterns, rather than patient case mix, account for much of the between-facility variation in access outcome, which implies that the deficiencies identified here are remediable through process change [19]. Trends analyses have documented a slow but real shift towards greater arteriovenous access use in several health systems [18]. The value of structured surveillance is more contested: the systematic review of surveillance for arteriovenous access found that surveillance with pre-emptive intervention reduced thrombosis without a demonstrable effect on access survival or mortality, a conclusion that should temper enthusiasm for surveillance programmes offered as a substitute for timely access creation [16]. The observation in the present cohort that preoperative duplex vessel mapping was associated with a lower hazard of patency loss, though not significantly so after adjustment, aligns with guideline positions favouring selective rather than universal mapping [1, 2]. A large Medicare analysis of arteriovenous access outcomes in incident patients provides a useful contemporary benchmark for these comparisons [20].

Several limitations must be acknowledged. The single-centre design limits generalisability, and the practice patterns of one tertiary unit, including its surgical experience and its access to endovascular salvage, exert an appreciable influence on patency that cannot be separated from patient-level determinants. The observational design precludes causal inference, and the association between catheter use and inferior patency is inevitably confounded by indication, since catheters are preferentially placed in patients who are older, more comorbid and more acutely unwell, and residual confounding by these factors is likely to persist despite multivariable adjustment. The number of patients in the graft and catheter strata was small, so that estimates for these groups carry wide confidence intervals and several between-group comparisons were underpowered, most notably the comparison between grafts and catheters. The follow-up period of twelve months, while adequate to characterise early and intermediate patency, is too short to capture the late attrition of arteriovenous access or to relate access outcome to patient survival. The index access rather than the patient was the unit of observation, so that outcomes of successor accesses created during follow-up were not analysed. Finally, the study was conducted at a centre with duplex surveillance and on-site endovascular capability, and its patency figures may therefore overstate what is achievable in units without these resources. Multicentre studies with longer follow-up, patient-level rather than access-level analysis, and prespecified evaluation of care pathway interventions are required to translate these observations into practice change.

CONCLUSION

In this prospective cohort of patients receiving

maintenance haemodialysis, the autogenous arteriovenous fistula was clearly the most durable form of vascular access, achieving primary patency of 68.8 per cent and secondary patency of 87.5 per cent at twelve months, compared with 45.0 and 70.0 per cent for prosthetic grafts and 39.3 and 57.1 per cent for tunnelled central venous catheters. The fistula also carried the lowest complication burden at 0.62 events per patient-year, and access-related infection, which accounted for every access-related death in the cohort, was more than ten times as frequent in catheter-dependent patients as in those dialysing through a fistula. Catheter dependence, diabetes mellitus and a raised C-reactive protein were independently associated with loss of primary patency.

These findings reinforce the principle that a functioning arteriovenous access should be established before the initiation of maintenance haemodialysis wherever the clinical trajectory permits, and that catheter exposure should be minimised in both prevalence and duration. The observation that fewer than two in five accesses in this cohort had been created before dialysis was started identifies late nephrology referral and delayed access planning as the most immediately correctable deficiencies in the local pathway. Structured physical examination at every session, systematic duplex surveillance and timely referral for endovascular or surgical salvage recovered a substantial proportion of failing accesses and should be embedded in routine dialysis practice. The choice of access nevertheless remains an individualised judgement, and in elderly patients with substantial comorbidity or limited life expectancy the burden of maturation and repeated intervention may reasonably outweigh the long-term patency advantage of an autogenous access.

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