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Original Article

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Retrograde catheterization of haemodialysis fistulae and grafts: angiographic depiction of the entire vascular access tree and stenosis treatment

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Abstract

Background. The European Best Practice Guidelines on Vascular Access propose magnetic resonance angiography (MRA) of dysfunctional dialysis fistulae and grafts if visualization of the complete arterial inflow and outflow vessels is needed. In a prospective multi-centre study we determined the technical success rate of complete vascular access tree depiction by digital subtraction angiography (DSA) as an alternative to MRA. Instead of a more invasive brachial artery of femoral artery approach, we performed a retrograde catheterization of the venous outflow or graft, and stenoses were treated in connection with DSA.

Methods. A catheter was advanced into the central arterial inflow after retrograde puncture of the venous outflow or graft for depiction of the complete inflow, access region and complete outflow. Access DSA through femoral artery puncture was done if the retrograde approach failed to depict the complete vascular access tree. Stenoses with a luminal diameter reduction $\geq$50% were treated, if possible, in connection with DSA.

Results. A total of 116 dysfunctional haemodialysis fistulae and 50 grafts were included. Retrograde DSA depicted the complete vascular tree in 162 patients (97.6%). The arteriovenous anastomosis of four fistulae could not be negotiated by a catheter. DSA demonstrated 247 significant stenoses: 30, 128 and 89 were located in the arterial inflow (12.1%), AV anastomosis and graft region (51.8%) and venous outflow (36.0%), respectively. Ten patients (6.0%) had no stenosis. Eight (4.8%), 55 (33.1%) and 33 (19.9%) patients demonstrated stenoses in only inflow, access region or outflow, respectively. Stenoses in two or three vascular territories were present in 53 (31.9%) and 7 (4.2%) patients, respectively. A technically successful endovascular intervention was obtained in 135 of the 139 patients (97.1%) who underwent angioplasty and/or stent placement. Additional sheath insertion by antegrade outflow puncture was needed in 46 patients (33.1%) for the treatment of coexisting venous outflow stenoses, located downstream from the retrograde positioned sheath. Two minor complications were observed at DSA/angioplasty.

Conclusion. As an alternative to MRA, full retrograde DSA is safe and effective for stenosis detection and stenosis treatment. However, access evaluation by a non-invasive imaging modality such as colour duplex ultrasound will be sufficient in most cases as proximal inflow stenoses are encountered in a minority of patients. Full retrograde DSA, including complete arterial inflow depiction, may then be reserved for cases with an unsuccessful outcome following endovascular intervention of stenoses depicted at ultrasound.

Keywords: angioplasty; digital subtraction angiography; haemodialysis; stenosis; vascular access

Introduction

Maintenance of functional vascular access is a vital issue for patients on permanent haemodialysis. The development of haemodialysis access stenosis and concomitant thrombosis is a major cause of morbidity and multiple hospital admissions [1,2].

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A timely detection and treatment of stenoses may prevent access thrombosis and, therefore, may prolong the functionality of haemodialysis fistulae and grafts [3–5]. A preferred method of access surveillance involves monitoring of access flow rates with an ultrasound dilution technique [6,7]. A flow decline at serial measurements suggests the development of a flow limiting stenosis. Vascular access assessment for detection of these stenoses can then be done by a variety of imaging modalities, such as color Doppler ultrasonography, contrast-enhanced magnetic resonance angiography (CE-MRA), multi-detector computed tomography angiography and digital subtraction angiography (DSA) [8,9]. DSA is the standard of reference for stenosis detection. A major advantage of DSA over the other imaging modalities is the possibility of performing the endovascular intervention immediately, in case a haemodynamically significant stenosis has been detected.

Depiction of arteriovenous fistulae (AVF) and grafts (AVG) by DSA is usually limited to the assessment of small segments of the arterial inflow, access site and outflow veins [8,10]. Although DSA studies have shown that stenoses are preferentially located at anastomotic sites and within the native outflow veins, recent studies report on the presence of arterial inflow stenoses in a substantial percentage of dysfunctional accesses [8,10–12]. Depiction of the complete vascular access tree may be performed after femoral artery puncture, followed by selective catheterization of the upper limb bearing the vascular access, or through retrograde brachial artery catheterization. Alternatively, retrograde puncture of an outflow vein and advancement of a catheter into the central arterial inflow of the access can be performed instead. Femoral artery catheterization may necessitate hospitalization of patients for a short period following DSA, whereas a routine brachial artery approach may be accompanied by a relatively high risk of complications [13]. Although less invasive and therefore preferable, one may not always be able to negotiate the arteriovenous anastomosis of an arteriovenous fistula (AVF) with a catheter after retrograde puncture of an outflow vein.

Currently, no data are available that address the stenosis distribution in dysfunctional fistulae and grafts, in case DSA comprises depiction of the complete access vasculature. In a multi-centre study, we therefore prospectively determined the technical success of complete vascular access tree depiction and endovascular stenosis treatment after retrograde puncture of the venous outflow or access site and catheter advancement into the central arterial inflow or aortic arch.

Subjects and methods

Patients

Three hospitals, one university hospital and two teaching hospitals, participated in the study. All patients who presented at the dialysis facilities with a dysfunctional haemodialysis access were eligible for inclusion. Patients were allowed to be included only once during the study period. Referral criteria for DSA were divided into the following categories: (1) decreased flow rates detected by an ultrasound dilution technique (Transonic Systems Inc., Ithaca, NY, USA; flow rate <600 mL/min. or a flow decline of $>25\%$ at serial measurements in combination with an absolute flow of <1000 mL/min.) (105 cases, 63.3%); (2) non-maturation, defined as a fistula not functional within 2 months after creation (24 cases, 14.5%); (3) repeated problematic access cannulation (16 cases, 9.6%); (4) symptoms of haemodynamic steal (10 cases, 6.0%) or (5) other (11 cases, 6.6%).

As part of a quality assurance program, relevant haemodialysis-related data are stored in a database. From 2001, patients on haemodialysis are evaluated at weekly, multidisciplinary sessions attended by vascular surgeons, nephrologists, interventional radiologists and dialysis nurses. Data on risk factors for peripheral arterial disease, presence of peripheral arterial obstructive disease, causes of end-stage renal disease and access age were extracted from the above-mentioned database.

From April 2006 through December 2007, a consecutive series of 166 accesses (116 fistulae and 50 grafts) were depicted with DSA in 88 men and 78 women. The mean age of the study population was 67.2 years (age range 31.0–89.3 years) and the difference in age between men (mean age 69.3 years, range 36.9–89.3 years) and women (mean age 64.9 years, range 31.0–85.5 years) was statistically significant ($P = 0.015$). The study was approved by the ethical review board of the participating hospitals. Written informed consent was obtained from all patients.

DSA

All angiograms were performed with commercially available DSA systems using non-ionic contrast. A 5- or 6-French introducer sheath (Terumo Europe N.V., Leuven, Belgium; Cordis, Roden, The Netherlands) was inserted after retrograde puncture of the venous outflow (AVF, AVG) or after retrograde puncture of the loop (AVG). The location of access cannulation was at the radiologists' discretion although puncture near an anastomosis was avoided in order to prevent anastomotic damage and to allow enough working space for sheath introduction. First, DSA images of the complete venous outflow were acquired by repeated manual injection of 5–10 cc of contrast. Images of the access region and its distal inflow tract were obtained during flow interruption. After intravenous administration of 2500–5000 units of heparin, the arteriovenous anastomosis of the fistula or arterial anastomosis (and if applicable, venous anastomosis) of the graft was traversed with a hydrophilic guide wire (0.014 inch or 0.035 inch, Terumo Europe N.V., Leuven, Belgium). A diagnostic catheter (standard 4 Fr straight catheter or pigtail-shaped catheter, Cordis, Roden, The Netherlands; hydrophilic 5 Fr straight or cobra curved catheter, Terumo Europe N.V., Leuven, Belgium) was advanced into the brachiocephalic trunc (in the case of a right-sided access) or subclavian artery (in the case of a left-sided access) and complete arteriography of the inflow was performed to reveal stenoses upstream. The catheter was placed into the aortic arch if the most proximal part of the inflow could not be visualized properly by backflow of contrast after catheter positioning in the brachiocephalic trunk or subclavian artery. Magnification

images and angled views of suspected stenoses were obtained. Parameters included a matrix size of 1024 × 1024 and a field of view of 14–40 cm. The mean DSA examination time was recorded for each procedure and included access puncture and access DSA without the time needed for any intervention or manual compression of the puncture site after the dilator removal.

Access DSA through femoral artery puncture, followed by selective catheterization of the upper limb harbouring the access, was performed if retrograde access puncture failed to depict the complete vascular access tree.

Endovascular intervention

In connection with DSA, percutaneous transluminal angioplasty (PTA) was attempted of inflow stenoses, anastomotic stenoses and outflow stenoses showing a ≥50% diameter reduction at DSA. Additional sheath insertion using an antegrade puncture of the access outflow was performed if treatment of coexisting venous outflow stenoses, located downstream from the retrograde positioned sheath, was indicated. The type of balloons (normal-pressure Opta balloon or high-pressure Powerflex balloon, Cordis, Roden, The Netherlands; ultra-high-pressure Conquest balloon, Bard, Tempe, Arizona; cutting balloon, Boston Scientific, Letterkenny, Ireland; curved balloon, Heart Medical, Cornwall, Canada) and stents (smart-control, Cordis, Miami, Florida; Herculink, Guidant, Santa Clara, California) used were at the radiologist's discretion. In general, (ultra) high-pressure balloons and cutting balloons were reserved for stenoses that were resistant to normal-pressure balloon angioplasty. Additional stent placement was performed of lesions demonstrating a >30% residual stenosis due to recoil, even after angioplasty with dedicated balloons.

Outcome parameters recorded and follow-up

Endovascular intervention was defined as technically successful if there was a <30% residual stenosis after angioplasty or stent placement. During the study period, all accesses were monitored routinely by monthly flow measurements. In the case of a flow decline, the pre- and post-interventional access flow (measured by ultrasound dilution technique within 1 week after PTA and/or stent placement) was recorded. In the case of ischaemic symptoms, medical records were reviewed for resolution of symptoms following endovascular intervention and a non-maturing access was considered to be salvaged if the access could be used for two-needle haemodialysis after intervention.

Image analysis

For image analysis, the vascular access tree was divided into the following segments (Figure 1): upper arm arterial inflow, starting at the feeding artery from its origin at the aortic arch (I); forearm arterial inflow (II); arterial anastomosis, including 1 cm of vessel length on both sides of the anastomosis (III, in the case of a graft); graft (IV); venous anastomosis, including 1 cm of vessel length on both sides of the anastomosis (V, in the case of a graft); arteriovenous anastomosis, including 1 cm of vessel length on both sides of the anastomosis (VI, in the case of a fistula); venous outflow forearm (VII) and venous outflow of the upper arm up to the right atrium (VIII). A significant stenosis was allocated to the segment comprising the dominant part of the stenosis in case the lesion was situated at the transition of two segments. Grading of stenoses at DSA was performed by using an electronic calliper. The measured diameter of the residual lumen at the point of maximal narrowing in a segment (D) was compared with the measured diameter at a normal point in that segment (N) using the following formula: stenosis percentage $= (1-[D/N]) \times 100\%$. Reading of the examination was done by the interventional radiologist who performed the angiography. Stenoses with a luminal diameter reduction exceeding 50% were considered to be haemodynamically significant.

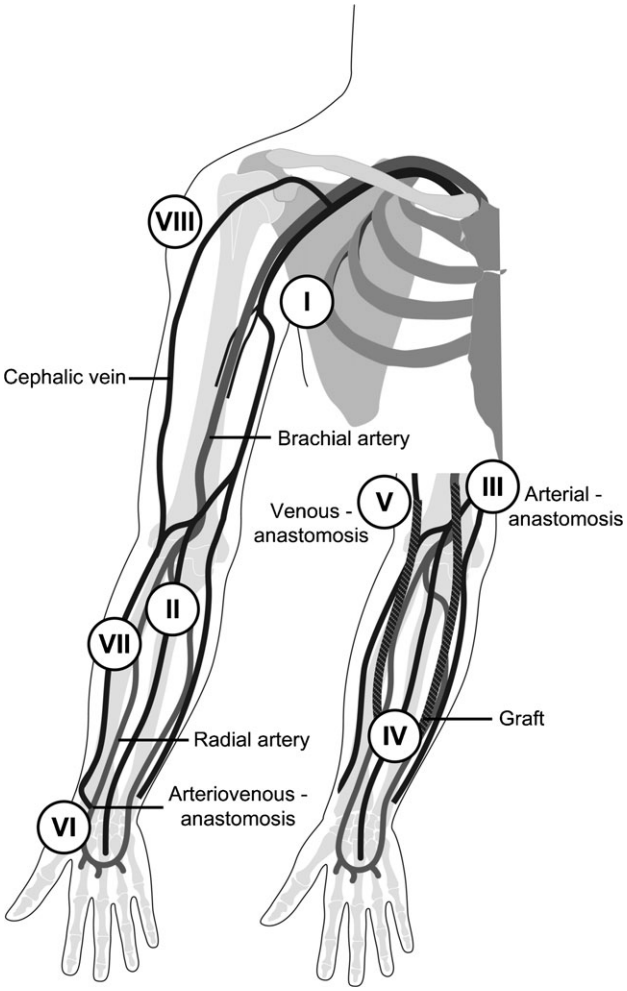


Fig. 1. Schematic overview of both access types with the different vascular segments. The larger drawing shows a radiocephalic AVF, and the smaller drawing shows a PTFE loop graft. I upper arm arterial inflow, starting at the feeding artery from its origin at the aortic arch; II forearm arterial inflow; III arterial anastomosis, including 1 cm of vessel length on both sides of the anastomosis (in the case of a graft); IV graft; V venous anastomosis, including 1 cm of vessel length on both sides of the anastomosis (in the case of a graft); VI arteriovenous anastomosis, including 1 cm of vessel length on both sides of the anastomosis (in the case of a fistula); VII venous outflow forearm and VIII venous outflow of the upper arm up to the right atrium.

Table 1. Characteristics of the patient population

Number of patients	166
Gender, No (%)	
Males	88 (53.0)
Females	78 (47.0)
Type of access, No (%)	
Arteriovenous fistulae	116 (69.9)
Radiocephalic AV-fistula	48 (28.9)
Brachiocephalic AV-fistula	55 (33.1)
Brachio-basilic AV-fistula	13 (7.8)
Arteriovenous grafts	50 (30.1)
Forearm graft	47 (28.3)
Upper arm graft	3 (1.8)
Cause of end-stage renal disease, No (%)	
Hypertension	36 (21.7)
Diabetic nephropathy	32 (19.3)
Renal artery stenosis	26 (15.7)
Obstructive uropathy	11 (6.6)
Polycystic kidney disease	10 (6.0)
Amyloidosis	10 (6.0)
Chronic pyelonephritis	8 (4.8)
Glomerulonephritis	7 (4.2)
IgA nephropathy	5 (3.0)
Haemolytic uraemic syndrome	3 (1.8)
Others	13 (7.8)
Unknown	5 (3.0)

Statistical analysis

We determined the absolute number and percentage of stenoses, both per vascular segment as well as per haemodialysis access. For the groups with and without an arterial inflow stenosis, we compared gender distribution, age, type of access, the number of risk factors for peripheral arterial disease, the presence of peripheral arterial disease, the age of the access, whether previous shunt interventions had been performed and the referral criterion for DSA. For continuous variables a Mann–Whitney *U*-test was performed, and for dichotomous variables a chi-squared test. We considered a two-sided *P*-value of <0.05 to be statistically significant. To assess the risk factors for an inflow stenosis, we performed univariable and multivariable logistic regression analyses. Of the final logistic regression model, we assessed Nagelkerke's R^2 as a measure of explained variance. All analyses were performed using SPSS 11.0.1 (SPSS Inc., Chicago, IL, USA).

Results

The causes of end-stage renal disease of the study patients are summarized in Table 1. Diabetes mellitus, hypertension and dyslipidaemia were present in 53 (31.9%), 123 (74.1%) and 53 (31.9%) patients, respectively, whereas 56 (33.7%) of patients were smokers. Sixteen (9.6%) patients had none of these risk factors for peripheral arterial disease and one up to four risk factors were seen in 62 (37.3%), 51 (30.7%), 27 (16.3%) and 10 (6.0%) patients, respectively. The presence of peripheral arterial disease was documented in 104 (62.7%) patients.

The mean access age of the 166 patients at the time of the DSA examination was 20 months (range 1–242 months).

Table 2. Significant stenoses (≥50%) demonstrated at digital subtraction angiography (DSA) in 166 haemodialysis accesses–segment level data

	No. of accesses	Vascular segment						
		I	II	VI	VII	VIII		
Arteriovenous fistulae	116	14	8	71	21	52		
Radiocephalic AV-fistula	48	5	8	32	21	10		
Brachiocephalic AV-fistula	55	4	0	33	0	34		
Brachio-basilic AV-fistula	13	5	0	6	0	8		
		I	II	III	IV	V	VII	VIII
Arteriovenous grafts	50	8	0	18	10	29	1	15
Forearm graft	47	6	0	16	9	29	1	13
Upper arm graft	3	2	0	2	1	0	0	2

I = arterial inflow, upper arm; II = arterial inflow, forearm; III = arterial anastomosis, in the case of a graft; IV = graft; V = venous anastomosis, in the case of a graft; VI = arteriovenous anastomosis, in the case of a fistula; VII = venous outflow, forearm; VIII = venous outflow, upper arm (including central venous outflow).

Of the 166 accesses, 74 (44.6%) had a history of surgical revision and/or previous endovascular intervention.

Complete access DSA and stenosis distribution

After retrograde access puncture, the arteriovenous anastomosis of three radiocephalic AVFs and one brachiocephalic AVF could not be depicted or traversed at DSA. Angiography using the femoral artery route showed a total of one inflow stenosis, two anastomotic stenoses and two outflow stenoses in these patients.

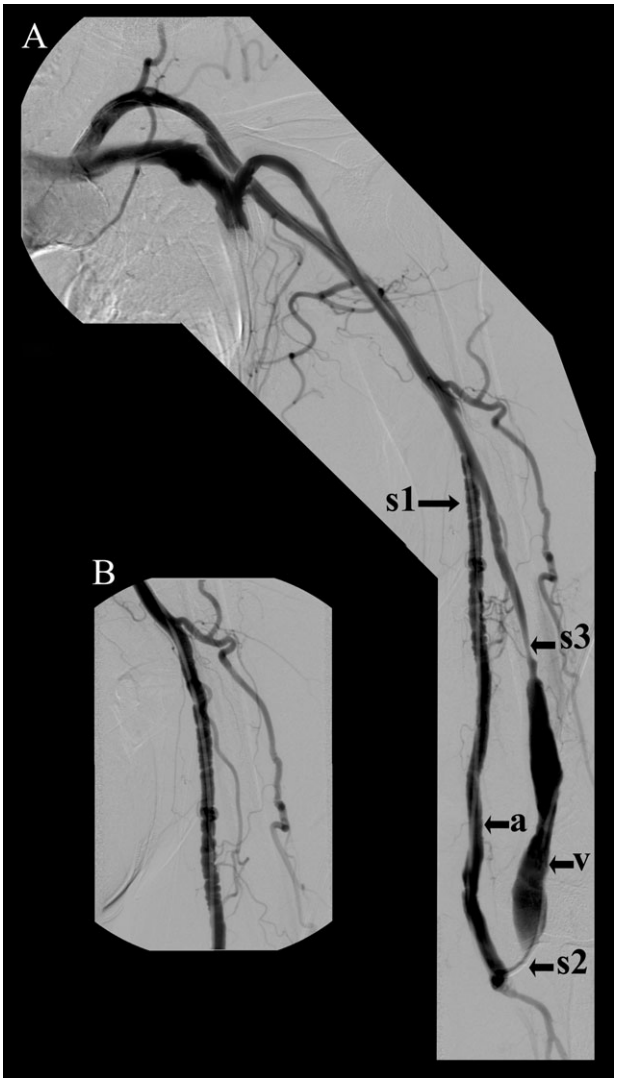
After retrograde venous access puncture, a diagnostic catheter could be advanced successfully into the aortic arch in the remaining 162 patients (97.6%). The mean examination time of the 112 AV fistulae and 50 loop grafts was 15 min (range, 8–32 min) and 8 min (range, 5–13 min), respectively. This difference was statistically significant ($P < 0.001$). In one patient, the DSA examination had to be terminated prematurely due to progressive haematoma formation after sheath insertion. Haemostasis was obtained by manual compression and successful DSA was performed at a later stage. We observed no DSA-related complications in the other patients.

A total of 247 stenosed vascular segments were identified at DSA (Table 2). The largest number of stenoses were found at anastomotic sites (segments III, V+VI: 118 stenoses, 47.8%). Of the 116 AVFs, 71 (61.2%) showed a stenosis at the arteriovenous anastomosis (segment VI) and 29 out of 50 AVGs (58.0%) had a stenosis at the venous anastomosis (segment V). Another predilection site for stenosis development was the access outflow: 36.0% of the stenotic vascular segments comprised the outflow of the forearm (segment VII: 22 stenoses) or upper arm (segment VIII: 67 stenoses). DSA showed no stenosis in 10 patients (6.0%, Table 3). Stenosis formation was limited to the arterial inflow in 8 cases (4.8%), whereas 55 (33.1%) and 33 (19.9%) accesses showed a stenosis only at the access site or venous outflow, respectively. The remaining 60 fistulae and grafts (36.1%) had stenoses in more than one vascular territory. Almost a quarter of all accesses (39/166, 23.5%) showed a combination of an access site stenosis and an outflow stenosis, whereas seven patients (4.2%) had

Table 3. Significant stenoses (≥50%) demonstrated at digital subtraction angiography (DSA) in 166 haemodialysis accesses–access level data

Access type	No stenosis	Inflow[a]	Access[b]	Outflow[c]	Inflow + access	Inflow + outflow	Access + outflow	Inflow + access + outflow	Total
Arteriovenous fistulae	8	6	28	26	5	5	32	6	116
Radiocephalic AV-fistula	2	1	14	9	4	4	10	4	48
Brachiocephalic AV-fistula	5	2	14	15	0	0	17	2	55
Brachio-basilic AV-fistula	1	3	0	2	1	1	5	0	13
Arteriovenous grafts	2	2	27	7	3	1	7	1	50
Forearm graft	2	2	27	6	2	1	7	0	47
Upper arm graft	0	0	0	1	1	0	0	1	3
Total	10	8	55	33	8	6	39	7	166

AVG = arteriovenous graft; AVF = arteriovenous fistula.
[a]From the origin of the feeding artery at aortic arch level to 1 cm upstream of the arterial anastomosis (AVG) or 1 cm upstream of the arteriovenous anastomosis (AVF).
[b]AVG: graft, including 1 cm of vessel length on both sides of the arterial and venous anastomosis; AVF: arteriovenous anastomosis, including 1 cm of vessel length on both sides of the anastomosis.
[c]From 1 cm downstream of the venous anastomosis (AVG) or 1 cm downstream of the arteriovenous anastomosis (AVF) up to the right atrium.



Figs. 2. Semicoronal DSA image (obtained by retrograde venous access puncture) of a brachiocephalic arteriovenous fistula with declined access flow shows multiple inflow stenoses due to fibromuscular dysplasia of the brachial artery (s1), a stenosis of the arteriovenous anastomosis (s2) and an outflow stenosis of the cephalic vein (s3). a = artery, v = vein.

stenotic segments in both inflow, access site and outflow (Figure 2). A total of 29 accesses (17.5%) showed an inflow stenosis, whether or not in combination with stenoses located at the access site or outflow.

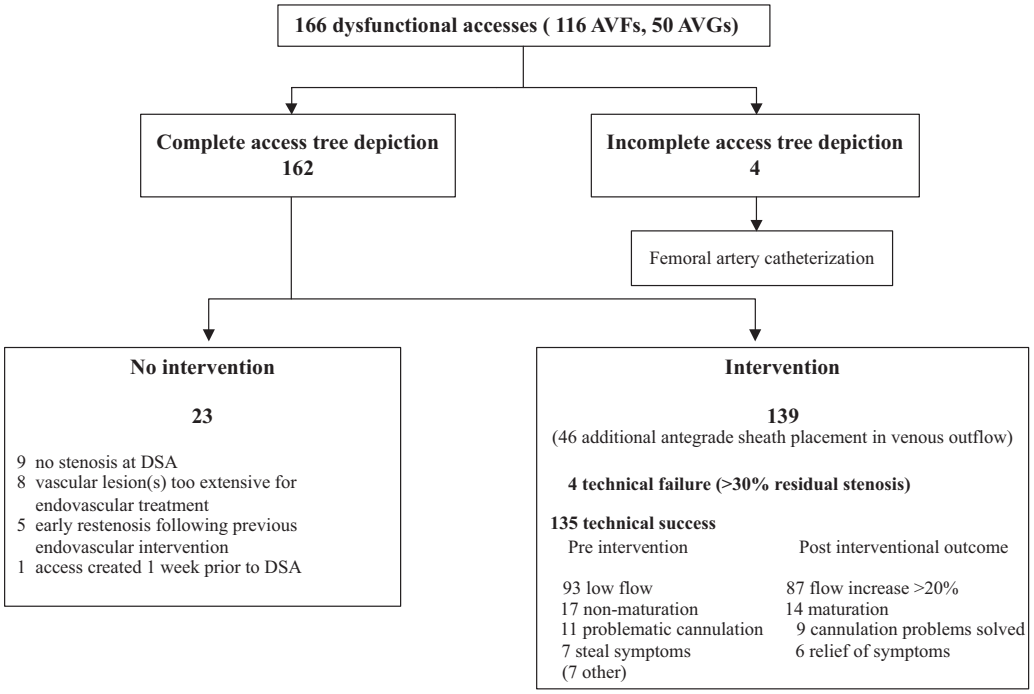
The characteristics of patients with and without inflow stenosis are shown in Table 4. There were statistically significant differences between these two patient groups in type of access, access age and referral criterion for DSA. Relatively more inflow stenoses were found among patients with radiocephalic (27.1%) and brachio-basilic (38.5%) AVFs. Furthermore, among patients with an inflow stenosis, the age of the access was significantly lower. Lastly, we found relatively more inflow stenoses among patients that were referred for non-maturation of their shunt (25%) and for steal symptoms (60%). In the univariable logistic regression analyses these same three variables were predictors of the presence of inflow stenosis. The most significant predictor was the type of access; this variable explained 15.2% of the variance in the occurrence of inflow stenosis. Compared with patients with a brachiocephalic fistula, there was a higher probability of inflow stenosis for patients with a radiocephalic fistula (OR 4.7, 95% CI 1.4–15.7), patients with a brachio-basilic fistula (OR 9.0, 95% CI 1.8–36.1) and patients with an upper arm graft (OR 25.5, 95% CI 1.9–345.8). There were not enough patients with an inflow stenosis to perform multivariable analyses.

Interventional outcome

After complete access DSA through retrograde catheterization, endovascular intervention was not performed in 23 of 162 patients (14.2%; Figure 3). DSA depicted no stenoses in nine of these patients, whereas the interventional radiologist considered endovascular intervention either not feasible or inappropriate in 14 patients. Inflow stenoses were present in two of the latter group of patients, whereas 12 patients showed stenoses at the access site and/or outflow. For the treatment of significant stenoses located downstream from the retrograde positioned sheath, additional antegrade sheath insertion was necessary in 46 of the 139 patients (33.1%) who underwent endovascular intervention.

Table 4. Characteristics of patients with inflow stenoses compared to patients with normal inflow–access level data

Patient characteristic	Inflow stenosis ($n = 29$)	No inflow stenosis ($n = 137$)	*P*-value
Gender, No (%)			
Males	14 (15.9)	74 (84.1)	
Females	15 (19.2)	63 (80.8)	
Mean age, years	69.2	66.8	0.52
Type of access, No (%)			0.0015
Arteriovenous fistulae	22 (19.0)	94 (81.0)	
Radiocephalic AV-fistula	13 (27.1)	35 (72.9)	
Brachiocephalic AV-fistula	4 (7.3)	51 (92.7)	
Brachio-basilic AV-fistula	5 (38.5)	8 (61.5)	
Arteriovenous grafts	7 (14.0)	43 (86.0)	
Forearm graft	5 (10.6)	42 (89.4)	
Upper arm graft	2 (66.7)	1 (33.3)	
Mean number of risk factors for peripheral arterial disease	1.7	1.7	0.85
Peripheral arterial disease			0.44
Present	20 (19.2)	84 (80.8)	
Not present	9 (14.5)	53 (85.5)	
Mean access age, months	11.7	21.5	0.023
Previous access PTA and/or access surgery, No (%)			0.98
Yes	13 (17.6)	61 (82.4)	
No	16 (17.4)	76 (82.6)	
Referral criterion for DSA, No (%)			0.0019
Decreased flow rate	14 (13.3)	91 (86.7)	
Non-maturation	6 (25.0)	18 (75.0)	
Problematic access cannulation	3 (18.8)	13 (81.3)	
Steal symptoms	6 (60.0)	4 (40.0)	
Other	0 (0)	11 (100)	



AVF, arteriovenous fistula; AVG, arteriovenous graft; DSA, digital subtraction angiography

Fig. 3. Retrograde venous catheterization of dysfunctional AV fistulae and AV grafts: endovascular interventional outcome.

Eight (5.8%), 54 (38.8%) and 25 (18.0%) patients had stenoses in either inflow, access region or outflow, respectively. Stenoses in two or three vascular territories were present in respectively 46 (33.1%) and 6 (4.3%) patients. Technical success (<30% residual stenosis after intervention) was obtained in 135 out of 139 patients (97.1%). Access flow of the 93 cases with a flow decline improved from 493 ± 183 mL/min to 818 ± 275 mL/min after endovascular intervention. A flow increase of >20% was achieved in all but six of these 93 patients. Fourteen out of seventeen

non-matured accesses (82.4%) could be salvaged by angioplasty and/or stent placement. Access cannulation problems were restored in 9 out of 11 patients (81.8%) and 6 out of 7 patients (85.7%) with steal showed a relief of symptoms after successful angioplasty.

Angioplasty was complicated by venous rupture in one patient, which was then controlled by a simple 5-min low-pressure balloon occlusion.

Discussion

Using a retrograde puncture technique, we were able to depict the complete vascular access tree in 97.6% of patients. This technique was always successful in the case of AV grafts; retrograde puncture and catheter advancement into the aortic arch is a standard procedure for this type of access, due to the straightforward anatomy and the absence of acute anastomotic angles. The mean examination time, needed for the depiction of grafts, proved to be significantly shorter than the time needed for fistula depiction. Moreover, in four out of 116 AV fistulae (3.4%), the DSA procedure was aborted due to the inability to traverse the arteriovenous anastomosis with a catheter and guidewire. Negotiation of the anastomosis may be difficult, especially in the case of a radiocephalic fistula. Complete arterial assessment was not achieved in 6.3% of radiocephalic fistulae (3/48), whereas the failure rate for elbow fistulae (brachiocephalic fistulae and brachio-basilic fistulae) was only 1.5% (1/68).

In our series, the majority of stenoses were located at the access site, especially at the venous anastomosis of AV grafts and at the arteriovenous anastomosis of AV fistulae, and in the venous outflow. We do not have an explanation for the relatively high rate of anastomotic stenoses in the radiocephalic fistulae. These fistulae were created in an end vein to side artery fashion and no differences in stenosis development between different anastomosis techniques are currently known from the literature [14,15]. Given the predominant location of stenoses at anastomotic sites and in the venous outflow, one may argue whether it is worthwhile to assess the complete arterial inflow in dysfunctional fistulae and grafts. Arterial inflow depiction, in addition to depiction of the access site and outflow, may not always be successful, requires more examination time, and harbours a probable cerebrovascular complication risk due to catheter manipulation in the region of the carotid and vertebral arteries. Davies and Humphrey reported a permanent neurological complication rate of 2.5% following selective carotid DSA in patients at high risk for carotid artery stenosis [16], whereas no severe complications were observed in a more recent study [17]. As depiction of the complete arterial inflow does not comprise selective catheterization of the cerebral arteries, the risk of cerebrovascular complications should be very low. Visualizing the entire arterial inflow may be essential as several recent studies report on the presence of centrally located arterial stenoses in accesses with limitation of flow and in patients with steal syndrome [11,12,18]. Also, previous reports have indicated that approximately one-third of patients fail to show an increase in blood flow after successful angioplasty [19–21]. This absence of effect may be due to recoil of the lesion between the angioplasty and first flow rate measurement following angioplasty, but this finding may also indicate that other haemodynamically important stenoses were not identified and treated. It may be helpful if, prior to DSA of a dysfunctional access, patients can be identified with a risk above average for the presence of inflow stenoses. Of the 247 stenoses we identified at DSA, 30 (12.1%) were arterial inflow lesions. Moreover, 29 (17.5%) of the 166 fistulae and grafts showed inflow lesions, whether or not accompanied by access site stenoses and/or outflow stenoses. There were significant differences between fistulae that did and did not show inflow lesions in type of access, access age and referral criterion for DSA. The most predictive variable was the type of access. Compared with patients with a brachiocephalic fistula, patients with a radiocephalic fistula, with a brachio-basilic fistula and with an upper arm graft had a higher probability of inflow stenosis. Unfortunately, the number of accesses showing inflow lesions was too small to perform multivariable analyses and type of access explained only 15% of the variance of the occurrence of inflow stenosis; therefore, patients at risk for inflow stenosis could not be reliably identified from our study. Consistent with those in other reports [12,18], our findings show that arterial inflow stenoses may be the only abnormality in a dysfunctional access. Therefore, depiction of the complete inflow should at least be considered for those dysfunctional fistulae and grafts that demonstrate unsatisfactory clinical improvement after a technically successful intervention of anastomotic stenoses or outflow stenoses.

Apart from DSA, radiological evaluation of an access may involve color Doppler ultrasonography (CDUS), contrast-enhanced magnetic resonance angiography (CE-MRA), or multi detector computed tomography angiography (MD-CTA). CDUS is an inexpensive, readily available and noninvasive method although the quality of the images is operator-dependent [22,23]. Moreover, CDUS has limited value for the detection of central venous obstruction and data regarding the value of CDUS for the detection of more centrally located arterial stenoses are lacking [8,24]. Finally, CDUS does not provide an angiographic map, which may be desired for surgery or percutaneous therapy. CE-MRA is minimally invasive, lacks ionizing radiation, provides an angiographic map of the complete vascular access tree and has a high accuracy for stenosis detection [12,25]. CE-MRA, as does CDUS, facilitates the interventionalist to perform a DSA and angioplasty through providing an appropriate puncture location [8]. Drawbacks of CE-MRA are high imaging costs, limited availability of MR scan time and the absence of MR-guided access intervention [26]. Moreover, the MR technique requires a venous puncture for contrast administration, whereas American and European guidelines indicate that puncture of peripheral veins should be avoided under the doctrine of venous preservation [6,7]. In addition, gadolinium may have some nephrotoxicity properties in patients with residual renal function and the administration of gadolinium in patients with impaired renal clearance has recently been associated with nephrogenic systemic fibrosis [27–29]. The use of gadolinium-based contrast agents should be avoided when possible in patients with renal failure, although the risk of

inducing nephrogenic systemic fibrosis is lower after administration of more stable gadolinium chelates such as gadoversetamide [30,31].

Data addressing the value of MD-CTA for the evaluation of a dysfunctional access are limited to one study: Ko *et al*. reported an accuracy for stenosis detection comparable to that of CE-MRA, although the arterial inflow was excluded from analysis in their series of 20 fistulae and 16 grafts [8].

To our knowledge, our study is the first in which the standard of reference for stenosis detection, DSA, is used to evaluate the complete vasculature of dysfunctional accesses and to determine stenosis distribution in AV fistulae and AV grafts. Antegrade brachial artery puncture does not allow visualization of the central arterial inflow and interventional experts argue that this technique may be accompanied by a relatively high risk of complications [13]. Moreover, using the antegrade brachial artery approach, a 12% complication risk for angioplasty of stenoses has been reported [32]. As an alternative to brachial artery catheterization for DSA and endovascular intervention, one may use a combination of an antegrade arterial puncture with a 20 Gauge needle to determine access patency, and a retrograde venous puncture for angioplasty of stenoses [33]. Again, this technique does not allow a proper evaluation of the complete inflow and always necessitates an additional puncture to perform angioplasty.

A clear advantage of DSA above other imaging modalities is the availability to perform access intervention in combination with DSA. In the majority of our study population, the retrograde catheterization technique was highly effective and safe for the treatment of stenoses that were located upstream from the sheath. After a complete diagnostic angiography, retrograde advancement of angioplasty balloons or stents for the treatment of upstream stenoses was always possible. On the other hand, DSA also has its limitations and drawbacks. In our series, a second antegrade venous puncture was needed for angioplasty of significant outflow stenoses in one-third of the patients. A reduction in the number of these additional punctures may be achieved by puncturing an access more centrally and thus allowing a larger number of stenoses to be located upstream from the sheath insertion. Elastic recoil of the stenotic lesions may have been responsible for the lack of effect on flow increase in the six patients with a technically successful angioplasty procedure [34]. Finally, administration of iodinated contrast agent may cause a further deterioration of residual renal function. There are conflicting reports, however, on whether administration of gadolinium-based contrast agent for CE-MRA reduces the rates of contrast-induced nephropathy when compared with the use of iodinated contrast for DSA [35,36].

To minimize the risk of anastomotic damage, endovascular intervention of arterial stenoses in the upper extremity may be performed by a femoral artery approach as an alternative to a retrograde venous puncture. However, we did not observe any anastomotic complications following retrograde advancement of angioplasty balloons or stents. Moreover, many centres routinely hospitalize patients for a period of 4–6 h following femoral artery catheterization. Another limitation of the femoral approach can be the lack of long shafts of angioplasty balloons and stents, especially if an inflow stenosis is located at a remote distance in the forearm.

We currently perform a complete vascular access DSA in patients with access dysfunction, who are referred to the interventional radiology department for the first time. Atherosclerotic lesions gradually arise over years and in comparison with venous endovascular intervention, inflow stenoses usually have a lower rate of recurrence [33,37]. Therefore, repeated complete arterial inflow DSA is reserved for those patients with a history of arterial intervention of the upper limb. Otherwise, a repeated DSA is routinely limited to the depiction of the distal arterial inflow, access region and complete venous outflow.

For imaging purposes, one would like to know whether arterial inflow DSA can be replaced by colour Doppler ultrasonoghraphy for the detection of inflow stenoses. In a prospective study, we are currently investigating the accuracy of CDUS for the detection of these stenoses in a consecutive series of patients undergoing both DSA and CDUS of the total vascular access tree. Complete arterial inflow DSA may be omitted if ultrasonography proves to be a reliable imaging modality for the detection of inflow stenoses.

In summary, we found that full retrograde DSA is safe and effective for stenosis detection in dysfunctional fistulas and grafts. However, inflow stenoses were encountered in only 17.5% of patients. Access evaluation may therefore best be performed by non-invasive colour duplex ultrasound, which has previously been proven to be accurate for the detection of access site stenoses and outflow stenoses. Full imaging of the access vasculature, including the complete arterial inflow, can then be reserved for those patients with an unsuccessful outcome following endovascular intervention of stenoses depicted at ultrasound. Although the European Best Practice Guidelines on Vascular Access propose MRA for the visualization of the complete arterial inflow and venous outflow vessels [7], we recommend retrograde venous access catheterization instead. Contrary to contrast-enhanced MRA with gadolinium administration, iodinated contrasts agents for diagnostic angiography are not correlated with increased risk for nephrogenic systemic fibrosis, and additional intervention is possible at the same time.

Conflict of interest statement. None declared.

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