Flow reduction in high-flow arteriovenous access using intraoperative flow monitoring

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Purpose: This study used intraoperative monitoring of the access flow to evaluate the results of flow reduction in the management of high-flow arteriovenous access-related symptoms of distal ischemia and cardiac insufficiency.

Methods: A retrospective study was conducted of 95 patients (78 with ischemia, 17 with cardiac failure) who underwent flow reduction between 1999 and 2005. A preoperatively measured access flow-volume rate >800 mL/min for autogenous accesses (n = 77) and >1200 mL/min for prosthetic accesses (n = 18) was the selection criterion for the use of a flow reduction procedure. Flow reduction was achieved using a spindle-like narrowing suture near the anastomosis and final placement of a polytetrafluoroethylene strip while a flow meter was used for intraoperatively measuring the access flow. The desired postoperative flow was 400 mL/min for autogenous and 600 mL/min for prosthetic accesses. The mean follow-up was 25 months (range, 1 to 73 months). Complete long-term relief of symptoms was observed in 86% of patients with ischemia and in 96% of patients with cardiac failure. Reconstruction significantly increased the digital-brachial index (0.41 ± 0.12 vs 0.74 ± 0.11; P < .05) and mean distal arterial pressure (47 ± 17 mm Hg vs 79 ± 21 mm Hg; P < .05) in patients with ischemia.

Primary patency rates were significantly better for reconstructed autogenous accesses compared with rates of prosthetic accesses (91% ± 4% vs 58% ± 12% at 12 months; 81% ± 6% vs 41% ± 14% at 36 months; P < .001). The low patency of reconstructed prosthetic accesses is due to the high thrombosis risk of accesses that have a flow <700 mL/min.

Conclusions: Flow reduction using intraoperative access flow monitoring is an effective and durable technique allowing for the correction of distal ischemia and cardiac insufficiency in patients with a high-flow autogenous access. The desired postoperative access flow of 400 mL/min is not associated with an increased risk of thrombosis. Flow reduction of prosthetic access is as effective; however, a higher access flow than the desired 600 mL/min seems to be necessary to achieve an acceptable patency in prosthetic accesses. (J Vasc Surg 2006;44:1273-8.)

Creation of an arteriovenous (AV) access for hemodialysis has a significant impact on local hemodynamics. High blood flow through the access also affects the pressure and flow in the arteries distal to the AV access and may result in inadequate distal perfusion. Symptomatic distal ischemia occurs in 3.7% to 5.0% of patients. The objective of different treatment options is the relief of ischemic symptoms and the maintenance of the access. Limiting access flow, thereby augmenting pressure and flow in the distal artery, was an obvious approach for treatment. Different techniques of flow reduction have been widely used; however, several previous studies reported a high rate of thrombosis and flow reduction was not further recommended.

A strong correlation between inadequate flow and risk of subsequent access thrombosis was demonstrated. Consequently, access flow represents a crucial indicator to reduce thrombosis risk after flow reduction. The main reason for frequent thrombosis after flow reduction documented in several reports may be seen in an inadequate assessment of the lumen reduction. In accordance with Poiseuille’s law, the access flow is related to the fourth power of the radius, implying that small changes in the lumen may produce significant flow changes. Adequate flow adjustments, therefore, can only be obtained by applying intraoperative flow measurement.

The access flow measured preoperatively by duplex scan was used when making decisions about our optimal approach for treatment. Flow reduction was performed in cases with a high-flow access, and alternative techniques were applied in normal-flow accesses.

High-output cardiac failure is another rare complication of high-flow accesses, and flow reduction is recommended for these patients to reduce cardiac load. Our report describes the results of flow reduction using intraoperative flow monitoring to treat ischemia or cardiac failure.

METHODS

We conducted a retrospective review of 95 consecutive patients with ischemia (n = 78) or cardiac failure (n = 17) caused by a high-flow access who underwent reconstruction by flow reduction at the Queen Elisabeth Hospital from January 1999 until December 2005. During this period, 2882 access constructions (2172 autogenous, 710 prosthetic) and 1393 revision procedures were performed. The following procedures were performed in 152 patients.
to treat ischemia: proximalization of the arterial inflow\(^\text{10}\) (n = 34), ligation of the access and creation of a new AV (n = 17) or arterioarterial access\(^\text{11}\) (n = 5), endovascular repair of proximal (n = 11) or distal arterial stenosis (n = 3), and reconstruction of arterial anastomosis (n = 4). The rate of patients who received an access in our institution requiring an intervention for ischemia was 3.2%.

Data were retrieved from hospital charts, vascular laboratory records, clinic records, and a protocol of the intraoperative flow measurement. Follow-up information was obtained through regular postoperative control.

The indication for a flow reduction procedure was seen in patients who had symptomatic ischemia or cardiac insufficiency related to a high-flow access. High flow was defined as a flow volume rate $>800$ mL/min for autogenous and $>1200$ mL/min for prosthetic accesses. The clinical diagnosis was made from typical symptoms of ischemia (pain at rest or during dialysis or exercise, tissue loss) or cardiac insufficiency (dyspnea at rest or with varying degrees of exertion). The diagnosis was confirmed by duplex ultrasound scan and digital plethysmography (digital arterial pressure) or echocardiography (left ventricle hypertrophy, cardiac index $>3$ L/[min · m\(^2\)].)

A color duplex ultrasound scan was conducted to exclude arterial or venous lesions. A preoperative arteriography was performed in all patients with ischemia but not in those with cardiac failure. Two patients underwent endovascular repair of proximal inflow stenosis before flow reduction. Fistulography was conducted in two patients with suspected central venous lesion. The results of the duplex ultrasound scan were used to calculate the access flow volume by using the software provided with the machine. The average of three measurements was used.

The flow of the AV access was measured intraoperatively by a Cliniflow II electromagnetic flow meter (Carolina Medical Electronics, Inc, King, NC) in the first consecutive 12 patients of this study or a Butterfly 2004 transit time flow meter (MediStim AS, Oslo, Norway). Preoperative and postoperative digital plethysmography was conducted in 31 patients with ischemia. The mean arterial pressure in 36 patients was measured intraoperatively by direct puncture of the artery distal to the AV anastomosis using a 20-gauge needle.

The procedure was normally performed with local anesthesia. In six patients, general anesthesia was used because an additional procedure was performed. The fistula vein or graft near the AV anastomosis was dissected free at a length of 3 to 4 cm. The artery was exposed for AV grafts to conduct the flow measurement. The measurement was performed by application of the flow probe at the exposed segment of the fistula vein, and the flow of the prosthetic accesses was calculated as the difference of the flow in the artery proximally and distally to the AV anastomosis considering retrograde arterial flow. In patients with reconstruction of a prosthetic axilloaxillary chest loop and femorofemoral looped access, we refrained from exposing the artery because of the higher risk of nerve damage and time consuming dissection. We used duplex ultrasound scan-
RESULTS

There were 41 women and 54 men with a mean age of 59 ± 13 years. The average number of previous vascular accesses was 2.1 (range, 0 to 6). The access was created in 47 patients (43%) in another institution. The mean follow-up was 25 months (range, 1 to 73 months).

Ischemia was the indication for reconstruction in 78 of the 95 patients, of whom 22 (28%) had a tissue loss, with finger gangrene (16%) or ulcers (12%). Pain under exertion or during dialysis was observed in 15 patients (19%), and 41 patients (53%) had pain at rest. Cardiologists referred 17 patients for flow reduction of a high-flow access because of significant cardiac comorbidity and symptoms of cardiac failure.

Patients in whom flow reduction was indicated were subdivided into two groups: those with ischemia (group A) and those with cardiac failure (group B). An autogenous access was reconstructed in 77 patients (81%), and in 18 (19%), a prosthetic access (Table). In group A, 88% of the patients had an autogenous access vs 80% in group B. The high portion (41%) of wrist fistulae in group B was notable.

Diabetes was prevalent in half of the patients in group A. Among the patients with a tissue loss, 77% had diabetes compared with 40% of the patients with ischemic pain (χ² = 6.41; P < .05). No group B patient had diabetes. Other comorbidities were peripheral artery disease in 24% and coronary artery disease in 33%.

The time between construction and flow reduction was 10.2 ± 8.1 months for prosthetic and 30.2 ± 27.2 months for autogenous accesses (P < .01). Only seven patients (7.4%) required a reconstruction for early ischemia during the first month, six of whom had a prosthetic access. During the first year, 72% of prosthetic and 37% of autogenous AV accesses (χ² = 6.86; P < .01) underwent flow reduction, which included 48% of the patients in group A vs 28% in group B (χ² = 6.86; NS).

The mean preoperative flow of all accesses was 1691 ± 767 mL/min estimated by duplex scan and 1600 ± 649 mL/min measured by flow probe (NS). The difference of flow rates measured by both methods was <10% in 68 patients (76%). Significant differences were seen mainly in patients with considerable variations of the systemic blood pressure.

Fig 2 demonstrates the preoperative and postoperative access flow of different access types. A relationship between flow and access type was not observed. The preoperative flow was significantly (P < .05) higher in the patients of group B (2084 ± 463 mL/min) than in group A (1469 ± 638 mL/min). Flow was also higher in the subgroup of patients with pain compared with patients with a tissue loss (1609 ± 708 mL/min vs 1211 ± 425 mL/min; P < .05). A significant difference of the preoperative flow volume between group A patients with and without diabetes was observed (1860 ± 637 mL/min vs 1166 ± 469 mL/min; P < .0001). This difference mainly results from the lower flow observed in diabetic patients with an autogenous access (non-diabetic patients, 1936 ± 659 mL/min; diabetic patients, 1070 ± 319 mL/min; P < .0005). The flow was reduced to 499 ± 175 mL/min for autogenous and to 676 ± 47 mL/min for prosthetic accesses.

Postoperatively, ischemic symptoms improved in all patients of group A. The symptoms were completely relieved in 67 patients (86%) 4 weeks after reconstruction. An insufficient improvement of ischemic symptoms was observed in 11 patients (14%): 10 complained about slight or moderate pain during dialysis, and one patient, who had a femorofemoral looped access, required a below-knee amputation because of progressive wound infection after transmetatarsal amputation. Eight patients with insufficient improvement of ischemia had diabetes, and nine had a tissue loss. An uneventful amputation of one or more gangrenous fingers was performed in eight patients.

The digital-brachial index increased from 0.41 ± 0.12 to 0.74 ± 0.11 (P < .05). The mean distal arterial pressure rose from 47 ± 17 mm Hg to 79 ± 21 mg (P < .05). An example of the intraoperative change of distal arterial pressure and access flow during flow reduction is demonstrated in Fig 3.

**Table.** Types of accesses reconstructed by flow reduction

<table>
<thead>
<tr>
<th>Access type</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autogenous radial-cephalic direct wrist access</td>
<td>10</td>
</tr>
<tr>
<td>Autogenous brachial-cephalic upper arm direct access</td>
<td>42</td>
</tr>
<tr>
<td>Autogenous brachial-basilic upper arm transposition</td>
<td>11</td>
</tr>
<tr>
<td>Autogenous brachial-cephalic-basilic upper arm direct access</td>
<td>14</td>
</tr>
<tr>
<td>Prosthetic brachial-axillary access</td>
<td>10</td>
</tr>
<tr>
<td>Prosthetic axillary-axillary upper arm loop access</td>
<td>2</td>
</tr>
<tr>
<td>Prosthetic axillary-axillary chest loop access</td>
<td>3</td>
</tr>
<tr>
<td>Prosthetic femoral-femoral looped inguinal access</td>
<td>3</td>
</tr>
</tbody>
</table>
During the follow up, ischemic symptoms reoccurred or deteriorated in only two patients. These patients, who were asymptomatic after flow reduction, had moderate pain during dialysis and received conservative treatment.

A relief of symptoms of cardiac failure was observed in 16 group B patients (96%) 1 month after flow reduction of the high-flow access. In only one case symptoms did not improve significantly. Two patients underwent repeated flow reduction because recurrent dyspnea and high access flow after 24 and 37 months, respectively. An increase of the access flow by $\frac{1}{3}$ of the initial postoperative value was observed in eight patients 6 to 37 months after reconstruction.

The cumulative survival rate for all patients was 90% at 12 months and 69% at 36 months. No deaths were access related. The survival rate was similar for patients with autogenous or prosthetic access or between groups A and B; however, the survival rate was significantly lower for patients with a tissue loss compared with patients who complained about pain (67% vs 98% at 12 months; 43% vs 74% at 36 months; $P < .001$). Eight of the 11 patients with insufficiently improved ischemia after flow reduction died during the first year.

The cumulative patency rate for all accesses was 85% ± 4% at 12 months and 73% ± 6% at 36 months. Patency rates were significantly better for reconstructed autogenous accesses compared with those of AV grafts (91% ± 4% vs 58% ± 12% at 12 months; 81% ± 6% vs 41% ± 14% at 36 months; $P < .001$). There was no difference in patency between groups A and B. A correlation of the patency with the age of the reconstructed access or with comorbid diabetes was not observed.

The postoperative flow of subsequently thrombosed prosthetic accesses was 639 mL/min compared with 698 mL/min for patent grafts (NS). By contrast, the flow of autogenous accesses that subsequently became occluded was higher compared with the long-term patent fistulae (551 vs 492 mL/min; NS).

A significantly decreased patency of prosthetic accesses was seen after stratification into postoperative flow volume. The patency rate of 10 prosthetic accesses with a postoperative flow <700 mL/min was significantly lower than patency of grafts with a flow that exceeded this value (38% vs 74% at 12 months; $P < .05$). During the first 6 months, an access thrombosis occurred in six prosthetic accesses. All of them had a flow <700 mL/min; in contrast, no difference of patency was observed for 12 autogenous accesses with a flow <350 mL/min.

**DISCUSSION**

A flow reduction procedure increases the venous outflow resistance through an AV access, thereby improving the distal arterial flow. The retrograde flow share in the distal artery is diminished or reversed and the antegrade flow share is increased.

Several studies6,7,12-15 with a limited case number demonstrated the favorable effect of flow reduction to treat distal ischemia, however the results were overshadowed by the reported poor patency rate. Our study represents results of flow reduction with intraoperative monitoring of the access flow in 78 patients with distal ischemia and in 17 patients with cardiac failure related to a high-flow access. The ischemic symptoms improved in all patients after flow reduction of the access.

Sessa et al16 suggested that a flow reduction leads to slight improvement of arterial flow that is more related to physiologic compensation rather than to the technique itself, and flow reduction would be only effective for patients with mild ischemic symptoms. However, 81% of our patients had a tissue loss or pain at rest, and a complete relief of ischemic symptoms was achieved in 86%. The digital-brachial index and distal pressure increased significantly. A complete relief of ischemic symptoms appeared unrealistic to achieve, even by access ligation, in the 11 patients with residual symptoms. During a follow-up period of 25 months, we observed a long-term relief of ischemia in almost all patients that corresponds well to results of alternative methods.10,16-18
We consider a simultaneous monitoring of distal arterial flow not as essential for clinical routine. An improved distal perfusion can be assumed by the preoperative selection of patients with a high-flow access and reduction of access flow to the desired value. If the effect of flow reduction is insufficient, an alternative procedure to treat ischemia has to be applied. In addition, other techniques to manage ischemia have to be used in patients with ischemia caused by normal-flow access, who represented 49% of our cases.

Flow reduction of a high-flow access resulted in relief of symptoms in 16 of the 17 patients with significant cardiac comorbidity and cardiac failure. The validity of this result is, however, somewhat limited owing to the unavailability of long-term comprehensive cardiologic data.

The difficulty is in the assessment of the optimal lumen reduction that is required to relieve ischemia and to sustain patency of the access. Detection of improved distal arterial flow or measurements of access flow were used as an intraoperative control in earlier reports.

Odland et al performed a flow reduction of 16 prosthetic forearm loops with intraoperative digital plethysmography. The goal of graft narrowing was to obtain a digital blood pressure of 50 mm Hg or a digital-brachial index of >0.6. This approach was successful in improvement of distal ischemia, but the patency rates were only 62% at 6 months and 38% at 12 months. As expected, the authors did not detect a relationship between patency and digital blood pressure. DeCaprio et al observed a thrombosis in 90% during the first week after banding of 11 grafts with similar monitoring. Anderson et al reported a banding with intraoperative use of an electromagnetic flow meter. Others used intraoperative duplex ultrasound scanning for control of flow reduction in a few cases, with good long-term patency and relief of ischemia.

Obviously, monitoring only the distal arterial flow without measurement of adequacy of the access flow substantially increases the risk of thrombosis. An acceptable patency rate can be achieved only by intraoperative control of the access flow and narrowing of the shunt lumen such that a defined flow minimum is reached.

During the study period, we defined a flow volume rate of 400 mL/min for autogenous and 600 mL/min for prosthetic accesses as the minimum that was adequate to maintain an effective dialysis and prevent thrombosis. The patency rate of the reconstructed autogenous accesses of 81% at 3 years is excellent and does not differ from that of unreconstructed fistulae; however, the cumulative primary patency rates of prosthetic accesses were only 58% at 12 months and 41% at 36 months. This patency of prosthetic accesses (after flow reduction) is significantly lower compared with our results of unreconstructed accesses and below the patency targets for AV grafts of National Kidney Foundation Kidney Disease Outcomes Quality Initiative guidelines. The poor patency rate of reconstructed prosthetic access results from the high thrombosis rate of grafts with a postoperative flow <700 mL/min, even a statistical significance could not be demonstrated. By contrast, the patency of autogenous AV accesses is not influenced by the flow, which meets the results of other studies.

The value of the access flow to predict the risk of subsequent thrombosis in AV grafts was proven in several reports. A flow of <500 mL/min to 700 mL/min was associated with an increased risk of graft thrombosis.

The goal of those studies was a monitoring of accesses to detect stenoses and improve patency. Even without evident stenosis, however, the desired access flow after flow reduction of 600 mL/min for AV grafts appears too low to maintain long-term patency. We have increased the value for desired postoperative flow to 750 mL/min as result of our study. Moreover, we now prefer the conversion of a prosthetic brachial-axillary access to an axillary loop, independently of the preoperative access flow.

The intraoperative monitoring of access flow is mandatory. We have occasionally experienced erroneous estimations of the access flow when we have refrained from the intraoperative control. The desired flow volume rate has to be adapted to specifics of the patient. For examples, a higher flow is required in cases of significant hypotonia after dialysis or an extremely enlarged fistula vein.

The flow can be reduced by different techniques, including a narrowing suture, plication, banding, or tapering. We prefer the narrowing suture technique near the AV anastomosis because the effect of lumen reduction on the access flow can be more precisely adjusted compared with other techniques. A subsequent fixation of a PTFE strip at the narrowed fistula vein segment, without an additional reduction of lumen, prevents dilatation of stenosed vein and recurrent flow increase.

The survival rate of patients was similar to other reports. A significantly higher mortality was seen for the patients with a tissue loss and incomplete improvement of ischemic symptoms. That can be regarded as an indication of the multifactorial cause of distal ischemia. Moreover, the question arises whether it is feasible to attempt complete relief by using a more extensive procedure in every case. The alleviation of rest pain and averting tissue loss or major amputation by a simple flow reduction can be viewed as an appreciable success.

An interesting detail of this study is the high proportion of patients with a late onset of ischemia. A marked earlier revision for ischemia of prosthetic and autogenous accesses was observed in our patients with ischemia caused by a normal-flow access and was reported in several studies.

The flow in prosthetic accesses reaches its maximum early after construction and tends to decrease thereafter. By contrast, autogenous accesses are characterized by subsequent dilatation of the vein and artery and a progressive increase of flow rates. Normally, the flow of newly created autogenous accesses may be maximal at 6 weeks. It seems, however, a gradual increasing flow, perhaps in combination with chronic changes of peripheral arterial resistance by peripheral vasodilatation and progressive arteriosclerosis, resulted in the observed late onset of ischemia in most of the patients in this study. This assump-
tion is supported by other reports. The lack of a relationship between access type and preoperative flow can be regarded as additional evidence for possible long-term increase of access flow, because a lower flow of forearm access compared with upper arm would have to be expected.

CONCLUSION

A flow reduction by a spindle-like narrowing suture near the AV anastomosis under intraoperative monitoring of the access flow is an effective and durable technique to correct distal ischemia and cardiac insufficiency in patients with a high-flow autogenous access. The desired postoperative access flow of 400 mL/min is not associated with an increased risk of thrombosis. However, a flow of 600 mL/min after flow reduction appears too low to safely prevent safely an increased thrombosis rate in prosthetic accesses. Further studies are necessary to define efficiency and safety of flow reduction for AV grafts, if a higher postoperative access flow is applied.

AUTHOR CONTRIBUTIONS

Conception and design: JZ
Analysis and interpretation: JZ, UK
Data collection: MP, KP, HS
Writing the article: JZ, UK
Critical revision of the article: MP, KP, HS
Final approval of the article: JZ, KP, MP, UK, HS
Statistical analysis: JZ, UK
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