Proximalization of the arterial inflow: A new technique to treat access-related ischemia

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Objective: Arteriovenous access-related ischemia is a serious complication occurring in 3.7% to 5.0% of patients after the creation of an arteriovenous (AV) access for hemodialysis. Catheter-based intervention to repair arterial stenoses, ligation of the access, and the distal recanalization-interval ligation (DRIL) procedure have been established as options for the treatment of ARI.

The use of radiologic interventions to treat arterial stenosis proximal to the AV access has become a generally accepted procedure. The closure of the access improves peripheral circulation immediately; however, a suitable vein is abandoned and a new access has to be created, again risking ARI symptoms. Different techniques of flow reduction (banding) have been used for many years. Based on reports about unsatisfactory improvement of ARI and high rates of access thrombosis, banding was not further recommended. The DRIL procedure has increasingly been applied during the last decade, providing impressive success and access patency rates. Hence, DRIL is regarded as the procedure of choice for the treatment of patients who are developing ARI.

Critical access-related ischemia (ARI) is a serious complication occurring in 3.7% to 5.0% of patients after the creation of an arteriovenous (AV) access for hemodialysis. Catheter-based intervention to repair arterial stenoses, ligation of the access, and the distal recanalization-interval ligation (DRIL) procedure have been established as options for the treatment of ARI.

Methods: From January 1999 to June 2005, the PAI technique was applied in 30 patients. The indication was seen in patients with severe distal ischemia who had a flow volume rate of <800 mL/min in a native fistula and <1000 mL/min in prosthetic access.

Results: Pain was the dominant symptom of ischemia in most patients before surgery. In 37%, a tissue loss was observed. The symptoms of access-related ischemia disappeared completely in 84% of patients and improved significantly in 16%. The significant hemodynamic improvement was confirmed by an increase of the intraoperatively measured mean distal arterial pressure from 32 ± 9 mm Hg to 63 ± 8 mm Hg. The digital-brachial index increased from 0.40 ± 0.10 to 0.83 ± 0.07. The mean access flow rate was 658 ± 80 mL/min after PAI and did not differ significantly with the preoperative value (634 ± 181 mL/min). With a mean follow-up interval of 26.1 ± 19.1 months, the primary and secondary patency rates were, respectively, 87% and 90% at 1 year and 67% and 78% at 3 years.

Conclusions: The PAI procedure represents a well-suited alternative to the DRIL technique for the treatment of patients who develop ischemia after creation of an arteriovenous access. Results for access salvage and disappearance of ischemic symptoms are equivalent to the DRIL technique. In contrast to the DRIL procedure, the PAI technique preserves the natural arterial pathway. Hence, PAI is preferable for surgeons who are reluctant to ligate an axial artery and are concerned about potentially disastrous consequences. (J Vasc Surg 2006;43:1216-21.)

PATIENTS AND METHODS

A prospective study was conducted on patients who underwent the PAI technique in our department from January 1999 to June 2005. The indication for PAI was seen in patients with severe ARI who had a flow rate of <800 mL/min in native AV fistulas and <1000 mL/min in AV grafts. If a flow rate exceeded these limits, banding with intraoperative monitoring of the access flow and the distal arterial pressure was preferred. The PAI technique was only performed if the fistula vein and venous outflow appeared well suited for long-term use.

Preoperatively, the patients underwent recording of complete and ARI-specific history. Symptoms and signs of ARI were recorded. Scans, using a Logic 400 MD color duplex ultrasound (GE/Kranzbühler, Solingen, Germany) with a 5-MHz to 10-MHz broadband linear array transducer, were done to exclude arterial or venous lesions and
to measure the inside diameter of axillary and brachial artery. A selective arteriography of the affected arm was preoperatively performed in all patients.

A flow volume measurement of the AV access and a digital plethysmography were performed before surgery and before discharge. The flow volume was calculated from the duplex ultrasound scan results by using the machine’s software on the basis of the time average mean velocity from five cardiac cycles and cross-sectional area of the access. The digital-brachial index was calculated by dividing the mean finger pressure by the brachial artery systolic pressure of the contralateral arm. Mean finger pressure was computed after excluding the highest and lowest recorded values and then averaging the remaining three values.

The operative procedure (Fig 1) includes the dissection of the arterialized fistula vein near the existing AV anastomosis and the exposure of the selected artery at a more proximal level (infraclavicular approach to distal brachial artery, axillary approach to distal axillary artery, infracavicular approach to proximal axillary artery). The vein is ligated, and the efferent vein leg is filled with a heparin solution. An ePTFE-graft with a diameter of 4 or 5 mm (Bard Peripheral Vascular, Tempe, Ariz) is placed in a curved subcutaneous tunnel between both incisions.

The decision to use a 4- or 5-mm ePTFE graft and to select the proximal or distal axillary for the arterial anastomosis is based on the preoperatively evaluated access flow, the inside diameter of the artery, and the stage of ARI. The selected graft diameter should not significantly exceed the diameter of the artery near the anastomotic site, and the desired access flow should be >600 mL/min. These parameters were used as a guideline, and it is obvious that a smaller graft diameter limits the access flow and would therefore further improve distal perfusion. A 4- to 7-mm tapered ePTFE graft is recommended only in cases where the AV fistula requires an extension of a very short subcutaneous tunnel between both incisions.

Next, the arterial anastomosis in a side-to-end fashion and an end-to-end anastomosis of the graft with the vein using continuous suture (6-0 or 7-0) are performed. The vein can be cannulated immediately; however, the graft should not be punctured, with the exception of 4- to 7-mm grafts.

Intraoperative monitoring was conducted to record changes in hemodynamics before and after reconstruction. The mean arterial pressure was recorded by direct puncture of the artery distally to the AV anastomosis with a 20-gauge needle attached to a pressure transducer. The flow of the AV access was measured by a Cliniflow II electromagnetic flow meter (Carolina Medical Electronics, Inc, King, NC) or a Butterfly 2004 transit time flow meter (MediStim AS, Oslo, Norway). Patients underwent regular follow-up after discharge.

The Kaplan–Meier life-table method was used to compute graft patency. Student’s t test was used for data comparison. Significance was assumed at $P < .05$. Values are expressed as mean ± standard error.

RESULTS

Between January 1999 and May 2005, we performed 2695 hemodialysis access procedures (2014 autogenous, 681 prosthetic) and 1334 revision procedures (417 in autogenous, 917 in prosthetic) in 2814 patients. Procedures to treat ARI were performed in 133 patients, including 44 patients referring from other institutions. The incidence rate of ARI requiring an intervention was therefore 8.3% in our patient population. The procedures performed to treat ARI were flow reduction using intraoperative flow measurement in 72 patients (54%), ligation of the access in 19 (14%), reconstruction of the arterial anastomosis in 8 (2%), reconstruction of proximal arterial lesions in 9 (7%), and PAI in 30 (23%).

During the report period, 13 women and 17 men presenting with severe ARI were treated by PAI. Patient characteristics are summarized in Table I. The patients had ischemia in different stages before reconstruction. Four patients (13%) had a pale or blue, cold hand and severe paresthesia, five (17%) had pain under exertion or during dialysis treatments (17%), and 10 (33%) had rest pain. In 11 patients, a tissue loss was observed, including ulcers in six (20%) and finger gangrene in five (17%).

The types of AV access that caused ischemia and were reconstructed by the PAI technique are presented in Table II. The artery of the next proximal level was used for the arterial anastomosis in 25 cases (83%). In five patients (17%) with a tissue loss, the proximal axillary artery had to be selected for this purpose owing to a narrow lumen (<4 mm) of the distal portion as determined preoperatively by duplex ultrasound scan. The diameter of the graft applied for bridging was 4 mm in nine patients (30%) and 5 mm in 13 patients (43%). A 4- to 7-mm tapered graft was used in eight patients (27%) including four cases of ARI caused by
The digital-brachial index increased from $0.40 \pm 0.10$ to $0.83 \pm 0.07$ ($P < .05$), corresponding to an average increase by $101\% \pm 55\%$ of the preoperative value (Fig 2). The intraoperatively measured mean distal arterial pressure increased from $32 \pm 9$ mm Hg to $63 \pm 8$ mm Hg ($P < .05$), corresponding to an increase of the preoperative value by $109\% \pm 33\%$ (Fig 3).

Mean duration of follow-up was $26.1 \pm 19.1$ months (range, 3 to 61 months). In the long-term course, only two patients had recurrent symptoms of ischemia at 12 and 19 months after PAI, respectively. In one patient, who complained about pain during dialysis, a newly developed stenosis of subclavian artery was detected and successfully repaired by angioplasty. In the second patient with paresis, conservative treatment proved sufficient. The access flow (mean $710 \pm 158$ mL/min) and the digital-brachial index (mean $0.78 \pm 0.11$) measured 12 months after reconstruction were not significantly different from the values determined immediately after reconstruction.

The primary patency rates of the AV access causing ischemia were $87\% \pm 6\%$ at 12 months and $67\% \pm 11\%$ at 36 months. The achieved secondary patency was $90\% \pm 5\%$ at 12 months and $78\% \pm 8\%$ at 36 months. Observed causes for thrombosis were a long-distance occlusive degeneration of the fistula vein unsuitable for further reconstruction in two patients, a stenosis at venous anastomosis in two prosthetic grafts, and a short stenosis at the anastomosis between the graft and the vein in three patients. An access thrombosis due to hypercoagulability and hypotonia, but without morphological cause, was observed in two patients. A graft infection at the puncture site occurred in one patient after 19 months, and the access was abandoned. By life-table analysis, patient survival rates were $97\% \pm 3\%$ at 12 months and $60\% \pm 11\%$ at 36 months.

**DISCUSSION**

In the study presented here, 30 patients with severe ARI were treated by PAI. ARI had developed in all but two patients. Pain was observed in most of the patients, of whom 37% had a tissue loss. The PAI technique was used in patients with severe ARI who had a flow rate of $<800$ mL/min in a native AV fistulas and $<1000$ mL/min in AV grafts.

After reconstruction, the ischemic symptoms disappeared completely in 84% of the patients and improved in 16%. A significant improvement of the distal perfusion was proven in all cases. The digital-brachial index and the intraoperatively measured mean pressure in the distal artery increased on average by more than 100% of the preoperative value. The mean access flow was $658 \pm 80$ mL/min after reconstruction by PAI, which was not significantly different from the preoperative flow. The choice of a small diameter (4 or 5 mm) graft is important because it avoids a high access flow and thereby ensures a sufficient improvement of the distal perfusion.

The graft works only as a feeder and should not be punctured. A short vein puncture section is an exception. Here we used a tapered 4- to 7-mm ePTFE graft for

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**Table I.** Patient characteristics

| Male/female | 17/3 |
| Mean age (y) | $67.1 \pm 9.0$ |
| Duration of dialysis (y) | $5.8 \pm 4.1$ |
| Number of previous accesses | $2.4 \pm 0.9$ |
| Diabetes mellitus | $24 (80\%)$ |
| Hypertension | $10 (33\%)$ |
| Hyperlipidemia | $17 (57\%)$ |
| Smoking | $11 (37\%)$ |
| Peripheral arterial occlusive disease | $19 (63\%)$ |
| Coronary artery disease | $13 (43\%)$ |

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**Table II.** Access types and selected arterial segments for reconstruction using the proximal arterial inflow procedure

<table>
<thead>
<tr>
<th>Type of arteriovenous access</th>
<th>Used artery</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autogenous radial-cephalic direct access</td>
<td>Distal brachial artery</td>
<td>4</td>
</tr>
<tr>
<td>Autogenous brachial-cephalic direct access</td>
<td>Distal axillary</td>
<td>17</td>
</tr>
<tr>
<td>Autogenous brachial-cephalic direct access</td>
<td>Proximal axillary artery</td>
<td>3</td>
</tr>
<tr>
<td>Autogenous brachial-cephalic transposition</td>
<td>Proximal axillary artery</td>
<td>2</td>
</tr>
<tr>
<td>Prosthetic brachial-axillary access</td>
<td>Distal axillary artery</td>
<td>4</td>
</tr>
</tbody>
</table>

a prosthetic brachial-axillary access. In 24 patients, surgery was performed with local anesthesia, whereas a general anesthesia was decided upon in six cases. No anticoagulant agents were used in the postoperative course, with the exception of two patients with known hypercoagulability.

No early postoperative complications occurred in any patient. The ischemic symptoms improved significantly in all patients who underwent reconstruction with the PAI technique. A closure of the access was not necessary in any patient. Twenty-five patients (84%) had immediate and complete pain relief and quick healing of ulcers, respectively. In four patients (13%), a mild finger paresthesia remained during dialysis.

One patient (3%) had severe hand ulcers and gangrene in three fingers after the construction of a brachial-cephalic upper-arm access. The access reconstruction using PAI with the proximal axillary artery was performed, and the gangrenous fingers were amputated. Symptoms improved markedly. The ulcers remained, however, and a moderate rest pain was reported. We decided not to perform any further reconstruction because of significantly improved hemodynamics. This patient was free of symptoms 5 months postoperatively. In five patients (17%) an amputation of gangrenous fingers was performed without significant wound complications.

The mean access flow volume was $634 \pm 181$ mL/min preoperatively and $658 \pm 80$ mL/min after PAI was performed (NS). These values were calculated by duplex ultrasound scans and corresponded well to the intraoperative flow volume measured by flow probe.
cannulation. Hence, the advantages of autogenous access can be widely preserved.

Primary and secondary patency rates were, respectively, 87% and 90% at 12 months and 67% and 78% at 36 months. The poor patient survival rate of 60% at 36 months is in accordance with data of other studies regarding patients with ARI.9,10

The PAI technique is based on the conversion of the arterial supply of the AV access to a more proximal artery. This artery has a larger diameter and thus a larger capacity. Hence, the arterial pressure drop distal of the AV anastomosis is significantly lower at the same access flow. Additionally, the collateral flow to the hand is higher compared with a more distally performed anastomosis.

Gradman and Pozrikidis14 have published a flow model based on an electrical analogue that compares the potential of different surgical reconstructions to treat ARI. This model supports the general idea of PAI. According to this publication, the ratio (Z) of the distal brachial flow before and after PAI is equivalent or better than for the DRIL procedure at the different arterial diameters. If the diameter of the arterial bypass of DRIL

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**Fig 2.** Change of digital-brachial index (DBI) by PAI technique (proximalization of the arterial inflow).

**Fig 3.** Change of mean arterial pressure (RRmean) (RR = Riva – Rocchi) by PAI technique (proximalization of the arterial inflow).
is <6 mm, then this prediction is even more in favor of the PAI procedure.

The rationale of the PAI technique is simple and straightforward; therefore, it is perhaps somewhat surprising that a comparable technique has not been supported in the numerous reports dealing with ARI. Only very few publications with similar considerations can be found. Jendrisak and Anderson\textsuperscript{18} used side branches of the axillary artery for graft implantation. The basic mechanism of this procedure is mainly a flow reduction, owing to the small size of these arteries, rather than a proximalization of the arterial inflow. Schanzer et al\textsuperscript{6} mentioned that they used the axillary artery as inflow vessel in some cases. Gradman and Pozrikidis\textsuperscript{14} recommended the conversion to an axillary-axillary loop procedure that we suggest.

The achieved success and patency rates after reconstruction by PAI reconstruction are equivalent to the results reported for the DRIL procedure that has been established as the standard to treat ARI. The PAI technique can be regarded as a somewhat less invasive procedure than DRIL and is easy to perform. The harvest of a vein for the arterial bypass is not necessary.

The major advantage of the PAI technique, however, is the preservation of the natural arterial continuity. A patent axial artery is ligated as part of the DRIL technique. The patency rates of the arterial bypass to re-establish the distal perfusion were reported as 86\textsuperscript{2}\textsuperscript{6} to 100\textsuperscript{9} to \textsuperscript{13} at 12 months. However, this patency appears questionable in patients with occlusions of distal axial arteries or a small vessel disease that was observed in most of the patients in this report.

In our opinion, the implicit trust in the long-term patency of the constructed bypass, even if a PTFE graft is used as bypass,\textsuperscript{7,10,11} or in a sufficient collateral circulation can be challenged. The ligation of an axial artery as part of the DRIL procedure may induce a difficult to treat ischemia of the forearm and hand in patients who often have pre-existing, silent, pathologic distal perfusion. Some surgeons who favor DRIL are reluctant to ligate an axial artery\textsuperscript{14} or have performed a bypass procedure alone because of significant arterial lesions of the forearm.\textsuperscript{8} In contrast to DRIL, a deterioration of distal perfusion cannot arise from the PAI procedure even if it fails.

A potential disadvantage of the PAI technique may be seen in the use of an ePTFE graft; however, we observed that it did not represent a real problem. The development of a stenosis at the anastomosis between graft and vein, which can be easily managed, was observed in only three cases during follow-up. The creation of an anastomosis between the graft and a matured vein with enlarged diameter and changed wall texture along with the high access flow ensures the demonstrated long-term patency of the PTFE graft. The saphenous vein as autogenous material might, in principle, be used, too. However, we have had poor results with the transposition of saphenous vein in access surgery in the upper limb. Especially in the case of dilatation of the saphenous vein, the result is a markedly increased flow, which may again aggravate the distal perfusion.

**CONCLUSION**

The proximalization of the arterial inflow procedure is a well-suited alternative to the DRIL technique for the treatment of ARI patients. The described technique is preferable for surgeons who are reluctant to ligate an arterial artery.

**AUTHOR CONTRIBUTIONS**

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

**REFERENCES**

INVITED COMMENTARY

Mark F. Fillinger, Lebanon, NH

This is a very interesting article about a novel method to treat limb ischemia after dialysis access procedures. As with the distal revascularization-interval ligation (DRIL) procedure, it is not immediately obvious why the procedure should work. However, just as with the now-established DRIL procedure, there are fundamental hemodynamic reasons for the success rates reported here.

The reason an access results in distal ischemia is primarily because the arterial inflow is inadequate to support the flow rate of the fistula (or graft), producing pressure drops across the anastomosis or even the inflow vessel itself, resulting in distal ischemia. Collateral flow will also be inadequate to compensate for this induced distal ischemia. This is surprisingly infrequent with dialysis access, but the incidence is high enough that any large dialysis access practice has had to deal with these extremely difficult cases.

Zanow et al have reported a clever method of solving the hemodynamic problem without ligating a major artery within the ischemic limb and thus relying on the patency of the bypass for continued limb perfusion. Specifically, they provide inflow to the fistula or graft by using a larger, more proximal artery, which in theory should be more capable of handling the high flow rate and may already be partially dilated due to the prior presence of the existing fistula. They limit flow rates by limiting the size of the conduit “feeding” the fistula, thereby avoiding higher flow rates and simply re-creating the original problem. If the new conduit fails, the fistula or graft may thrombose, but this will not induce limb ischemia since the patient’s native arterial anatomy remains undisturbed.

There is no reason to believe that the proximal arterial inflow (PAI) procedure will be more effective than the DRIL procedure, and some of the technical aspects may even be more difficult. Nonetheless, it appears that this will provide an acceptable alternative with at least some significant advantages, as outlined by the authors in the Discussion.

Just as with the DRIL procedure, there will likely be a large number of skeptics who initially cannot imagine how this procedure could possibly work. However, just as with the DRIL procedure, I predict others will try the PAI procedure, initially out of desperation, and will find that the authors are correct. I personally have not performed the specific PAI procedure described in this article, but have performed a similar procedure—a bypass without interval ligation, placing the proximal and distal Anastomosis of the bypass well away from the fistula and avoiding interval ligation.

Based on hemodynamic theory, reports in the literature, and clinical experience, there is every reason to think that the PAI procedure will work as long as one follows the very careful evaluation and work-up detailed by the authors of this article. This does not mean that the DRIL procedure will cease to be an important method of treatment for these patients, but rather that the PAI procedure will become a very acceptable alternative in appropriately selected patients. In some patients, the PAI procedure will be preferred because of the lack of vein conduit or other reasons. Thus, I suspect this article will change clinical practice for a number of readers.