Distal revascularization–interval ligation:
A durable and effective treatment for ischemic steal syndrome after hemodialysis access

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Purpose: The treatment of hemodialysis access–induced ischemic steal syndrome is challenging. Despite promising early results with the distal revascularization–interval ligation (DRIL) procedure, the operation has not been widely adopted because of concerns about its complexity and long-term efficacy. The purpose of this report was to determine the efficacy and durability of the DRIL procedure in relieving hand ischemia and in maintaining access patency in the setting of hemodialysis access–induced ischemia.

Methods: A retrospective review was performed of all patients who underwent the DRIL procedure for access-induced ischemia. Demographic information was compiled, as were data regarding access and bypass patency, limb salvage, and patient survival. Arteriovenous access and brachial artery bypass patency rates were determined with life-table methods.

Results: Between 1995 and 2001, we performed 55 DRIL procedures in 52 patients (35 women and 17 men; mean age, 60.8 years; range, 30 to 86 years). The indications for surgery were ischemic pain in 27 patients, tissue loss in 20 patients, loss of neurologic function in four patients, and pain on hemodialysis in one patient. Most patients (92%) had diabetes. The mean interval from access placement to DRIL was 7.4 months (range, 1 to 84 months). The mean follow-up interval was 16 months (range, 1 to 67 months). The brachial artery bypass primary patency rate was 80% at 4 years, and the arteriovenous access primary patency rate was 83% at 1 year. Forty-seven of 52 patients (90%) had substantial or complete relief of ischemic hand symptoms, and 15 of 20 patients with digital ischemic lesions have healed completely.

Conclusion: DRIL is a durable and effective procedure that reliably accomplishes the twin goals in the treatment of angioaccess–induced ischemia: persistent relief of hand ischemia and continued access patency. (J Vasc Surg 2002;36:250-6.)
made of the recipient artery of the DRIL procedure, the type of bypass conduit, the outcome of the DRIL procedure concerning symptom relief, and procedure-related complications.

Any noninvasive vascular laboratory testing performed before the DRIL procedure and during subsequent follow-up was reviewed (Fig 1). As part of the routine evaluation for steal syndrome, all patients underwent arteriography with and without compression of the arteriovenous access (Fig 2). Performance of the DRIL procedure was similar to that described originally by Schanzer et al and subsequently reported by Berman et al. In brief, a bypass constructed of reverse autogenous vein was anastomosed to the brachial artery at least 3 cm proximal to the origin of the arteriovenous access. This graft then was anastomosed distally in the forearm to either the brachial, radial, or ulnar artery. The recipient artery then was ligated just proximal to the distal bypass anastomosis to eliminate direct retrograde flow toward the fistula (Figs 3 and 4).

Primary patency rates of the DRIL procedure and the index access procedure were calculated with life-table methods. Data comparisons were performed with \( \chi^2 \) and Student t tests where appropriate. Statistical analyses were performed with Statview software (Abacus Concepts Inc, Berkeley, Calif).

RESULTS

Between January 1995 and May 2001, we performed 1138 primary hemodialysis access procedures in 599 men and 539 women. During this period, we performed 55 DRIL procedures in 52 patients for an overall ISS incidence rate of 4.6%. Pertinent demographic data are summarized in Table I. Only two patients had ESRD resulting from conditions other than diabetes mellitus or hypertension. In these latter patients, ESRD was attributed to systemic lupus erythematosus and multiple myeloma. The indications for the DRIL procedure included 27 patients (52%) with rest pain, 20 patients (38%) with tissue loss, four patients (8%) with loss of neurologic function, and one patient (2%) with persistent pain during dialysis treatments. DRIL was performed in more than twice as many women as men, and Hispanic women comprised the largest subgroup of patients, accounting for 42% of the entire series. In fact, the incidence rate of ISS in our series by gender was 2.8% in men and 6.5% in women. Women were statistically more likely than men to have rest pain as the indication for the DRIL (\( P = .04; \chi^2 = 8.1 \)); 60% of women had rest pain compared with only 35% of men. The primary indication for DRIL in men was tissue necrosis (59%).

The index access procedure resulting in the steal syndrome included 19 brachiocephalic arteriovenous fistulae (36.5%; Kaufman), 19 upper arm expanded polytetrafluoroethylene (ePTFE) arteriovenous grafts (36.5%), 12 forearm ePTFE arteriovenous grafts (23%), and two basilic vein...
transposition arteriovenous fistulae (4%). Three of the 19 upper arm grafts were constructed with 4-mm to 7-mm tapered ePTFE grafts. All these fistulae were based on brachial arterial inflow. The men who needed DRIL were more likely to have a native fistula than were the women \((P = .02; \chi^2 = 11.8)\). The mean interval from access placement to onset of ischemic symptoms was \(7.4 \pm 1.6\) months, with a range of 0 to 84 months.

Most patients (78%) received bypass grafts comprised of reversed greater saphenous vein, with 36 (65%) harvested from the thigh and seven (13%) harvested from the calf or ankle. Eleven bypasses (20%) were constructed with reversed cephalic vein, and one (2%) was performed with lesser saphenous vein. The distal bypass anastomotic insertion sites were the brachial artery in 24 cases (44%), the radial artery in 20 cases (36%), and the ulnar artery in 11 cases (20%). In five cases (9%), significant wound complications developed. These occurred at the site of saphenous vein harvest in four patients (7%) and at an antecubital incision in one patient (2%). No other significant peri-procedural complications occurred.

The DRIL procedure successfully alleviated ischemic symptoms in 47 of 52 patients (90%). In three patients, the DRIL failed to adequately resolve the ischemia and access ligation was necessitated. In three other patients, a second

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**Table I.** Demographic data of patients for DRIL \((n = 52)\)

<table>
<thead>
<tr>
<th>Age (y)(\bar{\text{H}})</th>
<th>60.8 (\pm) 10.7 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Women</td>
<td>35 (67%)</td>
</tr>
<tr>
<td>Men</td>
<td>17 (33%)</td>
</tr>
<tr>
<td>Race</td>
<td></td>
</tr>
<tr>
<td>Hispanic</td>
<td>24 (46%)</td>
</tr>
<tr>
<td>Native American</td>
<td>15 (29%)</td>
</tr>
<tr>
<td>White</td>
<td>10 (19%)</td>
</tr>
<tr>
<td>African American</td>
<td>3 (6%)</td>
</tr>
<tr>
<td>Etiology of ESRD</td>
<td></td>
</tr>
<tr>
<td>DM/HTN</td>
<td>26 (50%)</td>
</tr>
<tr>
<td>DM</td>
<td>23 (44%)</td>
</tr>
<tr>
<td>HTN</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Other</td>
<td>2 (4%)</td>
</tr>
</tbody>
</table>

*Data expressed as mean \(\pm\) standard deviation. DM, Diabetes mellitus; HTN, hypertension.

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**Fig 3.** Diagram of upper arm brachiocephalic fistula and brachial artery bypass with interval brachial artery ligation. In this case, brachial artery was divided below origin of fistula and distal anastomosis of vein bypass graft was performed end-to-end to distal brachial artery.

**Fig 4.** Completion arteriogram shows both forearm loop arteriovenous (AV) fistula and brachial artery bypass.
DRIL procedure was successfully performed after the first DRIL failed because of graft thrombosis. These patients all had recurrent symptoms develop marked by rest pain. After repeat bypass, these three patients had resolution of their symptoms. The period of primary patency of the initial DRIL procedure in these three latter patients was 8.7 months. In two patients, no improvement in symptoms was seen, but access ligation was not necessitated. These patients were believed to no longer have symptoms related to steal but rather as the result of ischemic monomelic neuropathy. Postoperative noninvasive testing, which showed pulsatile digital arterial waveforms, significant improvement in digital pressures, and abnormal nerve conduction studies, supported this diagnosis. The outcomes of the DRIL procedures appear in Table II, which tabulates outcome versus indication.

The primary life-table patency rates of the index access procedure causing the ISS were 83% at 12 months and 71% at 36 months. No significant difference was seen in primary patency between upper arm prosthetic arteriovenous grafts, forearm loop arteriovenous grafts, and native arteriovenous fistulas at 12 months with the log-rank analysis (89% versus 82% versus 74%, respectively; \( P = .36 \)). The primary patency rates of the DRIL procedure with life-table methods were 86% at 12 months and 80% at 48 months. Life-table patient survival rates were 86% at 12 months and 56% at 48 months.

**DISCUSSION**

The maintenance of vascular access for hemodialysis is the single most valuable component of renal replacement therapy, in terms of both patient morbidity and costs. The most common reason for a patient with ESRD to need medical care is for maintenance of hemodialysis access. Access thrombosis is the usual reason for access failure and presents dual challenges to the clinician: (1) resolving the ischemia and (2) maintaining the access. Other access complications of clinical significance include dialysis-related steal, which is the result of compensatory distal arterial vasodilation and the progressive development of a rich arterial collateral network around the fistula. A large arteriovenous fistula is a most potent stimulus for such collateral arterial development.

Although physiologic asymptomatic steal is nearly universal, clinically significant steal develops only when inherent compensatory mechanisms are inadequate to maintain or restore distal arterial perfusion pressure to a level sufficient to meet peripheral metabolic requirements. Clinically significant steal, manifest as either severe pain in the hand, tissue loss, or loss of hand function, is much less prevalent. Several retrospective reviews showed an incidence rate of ISS between 1% and 8%. Goff et al identified clinically significant steal needing intervention in 6% of patients who underwent arteriovenous access construction. In a similar prospective study examining intraoperative digital brachial indices, we identified a similar incidence rate of significant steal of 6% in 100 consecutive arteriovenous access patients (Berman SS, Gentile AT, unpublished data, 2000). The factors that contribute to clinically significant steal remain somewhat elusive. Some risk factors have been identified, such as female gender, age more than 60 years, diabetes mellitus, construction of an autogenous fistula, and brachial artery inflow. The prevalence of these factors is supported with this report. However, the inability to accurately and prospectively predict the development of steal solely on the basis of initial postoperative measurements of digital perfusion highlights the complexity of the problem.

Once severe steal has been identified, a number of options for treatment have been proposed. Ligation of the arteriovenous access universally eliminates the ischemia problem but with a significant penalty—loss of the access. Although the ischemia is resolved, a new access route for the patient to continue renal replacement therapy must be
created. Ligation does have a role to play in access-induced ischemia, although in a limited, defined circumstance. When severe ischemia occurs distal to a radiocephalic (Brescia-Cimino) arteriovenous fistula at the wrist, ligation of the distal radial artery effectively eliminates the steal without adversely impacting the access. In our own experience, this technique has been used on only two occasions (not included in this series) with complete relief of ischemia.

Another technique designed to treat access-induced ischemia is banding of the access. Banding is based on the premise that increasing fistula resistance will indirectly increase perfusion to the extremity distal to the fistula origin. By incrementally increasing the resistance in the access, the relative resistance of the peripheral arterial bed is decreased. However, fistula flow is related to fistula diameter only for small arteriovenous fistulae. This relationship is nonlinear, and a recent review by Wixon et al. draws comparisons between the physiology of the arteriovenous access components and the electrical resistance of a Wheatstone bridge. On the basis of these considerations, banding an arteriovenous fistula would increase the total resistance of the circuit, and banding sufficient to reliably alleviate steal would be predicted to reduce fistula flow to the point of thrombosis.

The reported clinical experience with banding has been mixed but generally poor. A number of authors have recently promoted the use of intraoperative perfusion measurements during the banding procedure to quantify the degree of banding needed to achieve the delicate balance. Odland et al. recently reported a series of patients treated with banding with intraoperative photoplethysmography. In this report, the targeted endpoints of banding were a digital arterial pressure of 50 mm Hg or digital/brachial index of 0.6. With this strategy, they achieved access patency rates of 62.5% at 6 months and 38.5% at 12 months. In a smaller series of five patients, Rivers et al. used pulse volume recordings during surgery to gauge the degree of application needed to improve distal perfusion. All five patients had resolution of ischemic symptoms and maintained a functional access when the pulse volume recordings were increased by 5 mm or more. A palpable radial pulse was restored in only three patients, however, and long-term relief of steal was not documented. Finally, in a review by DeCaprio et al. of all patients with steal syndrome during a 3-year period, banding was used in 11 of 18 patients. In all but one of these patients, the fistula occluded within 6 months of banding.

These results highlight the inherent problem with banding techniques: inconsistent and unreliable success in maintaining access patency. In general, banding the access sufficiently to relieve ischemia usually leads to access thrombosis. In the early 1980s, a tapered ePTFE graft was introduced to reduce access-induced ischemia. By interposing a smaller arterial end to a larger venous end, net access resistance would be increased. Unfortunately, the initial enthusiasm for the tapered graft has been tempered by a lack of clinical efficacy in reducing access-induced ischemia. In our own series reported herein, we placed a total of 30 tapered grafts during the study period for prevention of steal; three patients with upper arm–tapered arteriovenous grafts had significant steal develop. Again, both banding and tapered grafts have the same physiologic flaw: they increase fistula resistance. Predictably, increasing fistula resistance will not reliably prevent or treat ISS, although it may reduce access patency.

The concept of treating significant access-induced ischemia with a bypass graft and ligation of the artery between the fistula and the bypass was first reported by Schanzer et al. in 1988. Despite their initial success with three cases, the technique was not widely adopted. Schanzer et al. and Haimov et al. subsequently reported their experience with an expanded series of 14 patients in 1992 and 23 patients in 1996. Success was achieved in 13 of 14 patients in the first series. In the 1996 series, they showed improvement in all 23 patients who underwent the DRIL procedure, with a bypass patency rate of 95.6% at 2 years. Unfortunately, despite these reports of near universal success in relieving the ischemia and maintaining access patency, this technique still received little recognition. Katz and Kohl subsequently published a small series of six patients treated with revascularization and ligation with similar success. The premise behind the procedure is simple, elegant, and physiologically sound. The bypass graft functions as a large low-resistance arterial collateral and improves perfusion pressures in the antebrachial arteries distal to the arteriovenous access. The interval ligation eliminates the pathway for flow reversal and therefore steal with its placement between the access origin and the distal bypass anastomosis.

We embraced this technique in 1994 and subsequently published what was then the largest series of patients who underwent this procedure. In this report, we coined the acronym DRIL to describe the critical components of the procedure. Since that publication, the awareness of the DRIL procedure as a superior alternative to banding or ligation has become evident. However, what was lacking in our previous report and in those of other investigators were long-term data regarding the durability of the DRIL procedure in both relieving the ischemia and maintaining access patency. In simple terms, is a procedure of this magnitude and complexity durable enough that it should be used as the procedure of choice for access-induced ISS?

This report not only provides the largest reported experience to date with the DRIL procedure but also establishes the durability of the technique in fulfilling the dual challenges of access-induced ISS. In this report, 47 of 52 patients (90%) showed significant or complete symptomatic improvement. Three patients needed access ligation after failing to show adequate resolution of symptoms despite a patent bypass. The failure in these patients is possibly caused by concomitant small vessel disease. The proximity of the bypass origin to the origin of the access and therefore its pressure sink region may also have adversely affected these patients. Only two patients with rest pain had no improvement in symptoms despite noninvasive
Doppler testing showing resolution of steal with markedly improved digital arterial pressures. These patients were thought to have ischemic monomelic neuropathy. All patients with tissue loss have healed or healing lesions.

Prosthetic arteriovenous grafts have a reported 12-month primary patency rate of 40% to 50%, with native arteriovenous fistulae achieving a primary patency rate of 80% at 12 months. In this report, the 12-month actuarial primary patency rate of prosthetic arteriovenous grafts was nearly 85%. The superior arteriovenous graft patency in this subgroup of patients is likely the result of selection bias. The fistulae had been patent for a mean interval of more than 7 months before ISS developed and therefore represented well-functioning, stable fistu- lae. In addition, patients with significant steal characteristically have high flow fistulae. The DRIL procedure, with a 48-month primary patency rate of 80%, reliably improved distal perfusion without sacrificing significant fistula blood flow. These considerations likely account for the high primary patency rate of the prosthetic arteriovenous grafts in our series.

A number of issues remain unclear in the treatment of patients with arteriovenous access-induced ISS. Foremost is the problem of identifying patients at risk. To date, no preoperative or intraoperative measure of extremity perfusion can accurately and consistently predict which patients will have ISS develop. This problem likely relates to the variability of collateral flow to the hand around the antebrachial arteries. This issue also impacts the design of the DRIL procedure and the choice of distal target artery for the bypass. We generally prefer to perform the distal anastomosis to the brachial artery, especially if there is at least one continuous vessel to the hand. In this series, 42% of the bypasses were inserted into the brachial artery, and 37% and 24%, respectively, were inserted into the radial and ulnar arteries. This decision was usually based on preoperative angiography, and the most dominant vessel supplying the hand was chosen. The variability of the forearm and palmar arterial blood supply necessitates careful attention to preoperative angiography and completion angiography at the time of the DRIL procedure.

Angioaccess-induced ISS is an infrequently encountered complication in patients with ESRD. Successfully treating significant steal poses dual challenges: maintaining access patency and eliminating the ischemia. Of the available treatment options, the DRIL procedure provides the method that most reliably accomplishes these twin goals. This report also substantiates the long-term durability of the DRIL in the management of these complicated cases.

REFERENCES


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DISCUSSION

Dr Wayne Gradman (Los Angeles, Calif). Dr Knox and his colleagues have reviewed 55 DRIL procedures performed over a 6-year period. All fistulas were based on the distal brachial artery. They report an impressive 4-year primary patency rate for the distal bypass of 80% and substantial or complete relief of ischemia or tissue necrosis in 90%. Nonetheless, an average approaching one DRIL procedure per month strikes me as rather high, and so it would be of interest to learn the incidence of the DRIL procedure in your access population.

Two reasons for such a high incidence might be a failure first, to identify patients at risk and take steps to mitigate the steal at the time of the initial surgery, and second, to consider other options when one develops. You have shown that diabetes and hypertension are associated with but not predictive of a steal syndrome, but shouldn’t anatomic factors be more important? What do you do when you encounter a tiny or diseased brachial artery on exploration? Do you have a protocol for the surgeon if the hand appears suspiciously pale? In other words, do you ever perform DRIL on the spot, or do you always take a wait-and-see approach?

While you note that tapered grafts did not prevent a clinical steal in three of your patients, the remaining 16 of your 19 upper-arm PTFE grafts were uneventful. In our experience, 4- to 6-mm or 4- to 7-mm grafts with the arterial end tapered to 4.5 or 5.0 mm do indeed reduce the incidence of steal syndromes and seldom thrombose because of arterial inflow problems.

Once an ischemic steal syndrome develops, you may ask what is so objectionable about proceeding directly to a DRIL procedure, our de facto “gold standard.” Well, only in Tucson do surgeons ligate a perfectly normal artery so they can do a saphenous vein bypass, without at least some remorse. In addition, it appears you also advocate preoperative and intraoperative arteriography.

DRIL proponents act smug because the only widely acknowledged alternative to the DRIL procedure is fistula banding, which produces frequent graft thrombosis and therefore is justifiably maligned. Treatment of the steal syndrome begs for reasonable alternatives besides DRIL, so I would like to offer three for your consideration and comment.

In this manuscript, you describe your technique as constructing the bypass first, then ligating the intervening artery. Have you ever stopped to assess the circulation to the hand before you ligate the interval artery? The bypass by itself functions as a giant collateral and usually restores the wrist pulses that were presumably present before the initial surgical procedure, thus obviating the need for interval ligation. Distal flow is even greater if you don’t have to cross the elbow and you can use 6-mm PTFE instead of vein. The high retrograde flow at the distal anastomosis keeps the PTFE bypass open. I have yet to ligate the intervening artery when I use PTFE for the bypass.

Another effective operation in steal patients with high-flow autogenous vein fistulas (say, greater than 1000 cc/minute) is to do a distal brachial anastomosis, cut a triangular wedge out of the vein, and reimplant it with a 4.5- or 5-mm tapered anastomosis. Such a tapered conduit behaves quite differently from one that is banded in situ, in that it is much less likely to clot. The increase in hand flow is proportional to the increase in fistula resistance.

Finally, my favorite operation is to construct a loop fistula based on the axillary artery. A loop axillary fistula is topologically equivalent to the DRIL procedure. Conversion of a straight upper-arm graft to a loop axillary graft dramatically increases flow in both the fistula and the distal arm, even though the literature and intuition suggest that distal arm flow should decrease. This procedure is especially useful in the intraoperative period to avoid a steal, and in the immediate postoperative period to correct one.

Although these three procedures increase distal arm flow less than DRIL, they are clinically quite effective at reversing steal symptoms. It is indeed possible to create large numbers of access procedures and never need to ligate a normal brachial artery or harvest saphenous vein.

I did enjoy reading your manuscript. Your work remains an important benchmark for all studies of the steal syndrome and its treatment.

Dr Robert Knox. First, I would like to thank Dr Gradman for his thoughtful comments. To answer your first question, we have found that the incidence of ischemic steal syndrome (ISS) in our patient population is in line with that reported in the literature. Approximately 10% of our arteriovenous access patients develop some element of clinical steal, the majority of which are mild and resolve with time as the patient develops collaterals. Approximately 5% to 6% of our patients develop symptoms severe enough to require intervention.

After fistula placement, we routinely evaluate hand perfusion with continuous-wave Doppler. In our experience, the absence of a pulse far exceeds the incidence of severe steal and is therefore not an accurate predictor of problems. Those with no audible radial or ulnar Doppler flow would undergo immediate intervention; one patient in our series underwent an immediate DRIL procedure.

We perform preoperative angiography on all of our DRIL patients. This is necessary to facilitate choosing an adequate target vessel. In addition, if the patient has a stenosis in the inflow artery, we would treat that lesion without performing a DRIL procedure. We do not routinely perform intraoperative angiography.

Our group has unpublished data in which we performed the distal bypass and measured pressures prior to brachial artery ligation. We found no consistent improvement in digital pressures. We surmise this is because the patients will steal from the newly constructed bypass as well. After interval ligation, however, the digital pressures increase significantly. These observations are consistent with Schanzer’s original findings. We acknowledge your understandable hesitance to ligate a “normal” brachial artery. However, this brachial artery segment is hemodynamically non-functional due to the presence of reversed or to-and-fro flow. Therefore, nothing is lost clinically, and the intended ligation prevents retrograde flow from the newly constructed bypass back up the fistula.

The techniques Dr Gradman describes function to increase fistula resistance and theoretically may compromise fistula patency. Our approach has been to concentrate on increasing distal blood flow rather than increasing fistula resistance.

The critical question is how to predict who will develop severe steal. We have identified risk factors such as female sex, diabetes, and upper-arm AV fistulas but have not been able to accurately predict the development of ISS prospectively in each individual patient.