Arteriovenous Access and Hand Pain: The Distal Hypoperfusion Ischemic Syndrome

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An ischemic hand in a hemodialysis patient is a serious condition. It causes significant pain and discomfort but also can lead to tissue necrosis and the eventual loss of digits and even the entire hand. Although stealing of blood away from the high-resistance forearm arteries into the low-resistance arteriovenous access generally is assumed to be the cause, a great majority of both wrist and elbow accesses demonstrate retrograde flow without any evidence of hand pain or ischemia. Consequently, demonstration of retrograde flow alone does not predict or indicate the existence of distal ischemia. In this context, the term "arterial steal syndrome" is a misnomer to indicate the presence of peripheral ischemia. Recent studies have shown that, in many cases, arterial stenotic lesions cause distal hypoperfusion and result in hand ischemia. In other cases, distal arteriopathy as a result of generalized vascular calcification and diabetes is the culprit. Because any or a combination of the three mechanisms (retrograde flow, stenotic lesions, and distal arteriopathy) can lead to peripheral ischemia, distal hypoperfusion ischemic syndrome is a more appropriate term to denote hand ischemia. Treatment should start with a detailed history and physical examination to help rule out other (nonischemic) causes of hand pain. A complete arteriogram to evaluate the circulation of the extremity from the aortic arch to the palmar arch is essential. The choice of treatment modality and procedure to apply should be based on this evaluation. This report reviews the pathophysiology and presents current strategies to ameliorate distal hypoperfusion ischemic syndrome.

Hand ischemia in patients with an arteriovenous access is a serious complication in patients who receive long-term hemodialysis (HD). Although the term "arterial steal syndrome" often has been used in the literature, the expression might not be totally appropriate to denote hand ischemia. This is because a great majority of arteriovenous accesses demonstrate evidence of arterial steal yet only a few patients demonstrate the symptoms of ischemia (1–3). In this context, peripheral hypoperfusion and ischemia assume a more central role than the arterial steal itself. Perhaps digital hypoperfusion ischemic syndrome (DHIS) might be a more appropriate term. This term indicates that there is peripheral hypoperfusion to the point of causing ischemia. Consequently, for the purpose of this review, the term DHIS is used instead of arterial steal syndrome.

Depending on the definition used, the prevalence of DHIS varies from 1 to 20% (4–7). It is more common in patients with proximal (brachial artery based) than distal (radial artery based) accesses (5). The syndrome usually manifests as hand pain (on and off dialysis) and less frequently as loss of distal function and tissue death. Although acute ischemia immediately after access creation in general requires access ligation, a variety of options are available for hand ischemia in patients who are on chronic dialysis. This review presents pathophysi-

ology, clinical features, and differential diagnosis. It focuses on recently developed strategies to ameliorate DHIS in chronic HD patients.

Pathophysiology

The pathophysiologic mechanisms that govern DHIS are complex and poorly understood. Whereas shunting of blood to a low-resistance area (arteriovenous access), resulting in hypoperfusion distal to the anastomosis, has been suggested as the cause, increased resistance to blood flow offered by the presence of arterial stenosis also can play a critical role (5,8–10). Furthermore, distal arteriopathy that commonly is seen in patients with vascular calcification and diabetes may be an important factor that leads to the development of DHIS (11,12).

True Steal from the Forearm Arteries

High blood flow volume through an arteriovenous anastomosis may cause stealing of blood from forearm arteries. This steal can lead to distal hypoperfusion and produce peripheral ischemia ("true steal"). It is important to note, however, that in a great majority of forearm as well as proximal arteriovenous accesses, clinically silent retrograde flow can be seen (1–3). In this context, demonstration of retrograde flow alone does not predict or indicate the existence of DHIS.

Presence of Occlusive Arterial Stenoses

Recent data have emphasized that significant ($\geq$50%) arterial stenoses commonly are seen in dialysis patients who present with symptoms of hand ischemia or vascular access dysfunc-

tion (5,8–10,13–16). These lesions can occur anywhere within the arteries of the upper extremities, including the proximal arteries, and have been demonstrated to cause peripheral ischemia in HD patients (5,8–10). Using arteriography, the incidence of arterial stenosis in patients with peripheral ischemia has been reported to range from 62 to 100% (5,8–10). In one study (8), complete arteriography from the aortic to the palmar arch was performed to assess the presence of arterial stenosis in HD patients who presented with symptoms of peripheral ischemia ($n = 13$). It was found that 62% of the 13 patients who were referred for the evaluation of symptoms of steal syndrome demonstrated a significant ($\geq$50%) arterial stenosis. In another report (5), stenosis in the inflow circulation was found in 100% of the patients who underwent complete arteriography ($n = 5$).

Distal Arteriopathy

In addition to arterial stenosis and true stealing of blood from the forearm arteries, distal arteriopathy as a result of vascular calcification and diabetes is an important factor that also may contribute to the development of symptoms of arterial steal syndrome (11,12). Vascular calcification affects both intimal and medial layers (12). Disturbance in mineral metabolism in the uremic milieu, calcium-containing phosphate binders and vitamin D treatment of secondary hyperparathyroidism, increased oxidized LDL cholesterol, increased oxidative stress, and hyperhomocysteinemia may contribute to the pathogenesis (11).

Clinical Features and Differential Diagnosis

Symptoms of hand ischemia are more frequent in diabetics and smokers (17–21). Commonly encountered symptoms include cold hand, numbness, and hand pain on and/or off dialysis. Lowering of BP and provocation of peripheral vasoconstriction might explain the development of pain during dialysis (22). Advanced cases reveal trophic changes that are characterized by the development of ischemic ulcers and dry gangrene of one or more digits. In acute situations, the duration from access creation to the development of hand pain generally is short, with ischemia immediately apparent after access creation. In patients who are on chronic dialysis, however, the onset may be insidious and delayed for days, weeks, and even months. In one study, time of onset of symptoms was found to be 8 ± 2 mo from the time of access creation (10). In this study, the duration of symptoms was 2 ± 0.5 mo at the time of diagnosis. Although symptoms have been known to resolve with time as a result of the development of collateral circulation, deterioration in the severity of clinical features, perhaps as a result of progression of arterial occlusive lesions, also has been reported (10).

In addition to arterial insufficiency, hand pain can be caused by carpal tunnel syndrome, tendopathies and arthropathies, which can occur in patients who are on long-term HD (23). Carpal tunnel syndrome is due to entrapment of the median nerve. Diagnostic clues include pain in both hands, because median nerve entrapment is bilateral in a large proportion of cases. Wasting of the lateral thenar muscles often is present at diagnosis, denoting advanced nerve compression (23–25). An electromyelogram showing reduction of motor conduction can help to establish the diagnosis (24).

Destructive arthropathy of the hands is common in chronic HD patients (26). This condition is not the result of the deposition of amyloid in the joint. Histologic studies of the synovial membrane and subchondral bone demonstrate an absence of amyloid even in patients with clinical or roentgenographic evidence of amyloidosis at other sites. Electron microscopy studies also failed to disclose crystals or amyloid (26). The pathophysiology of the condition remains poorly understood. Deformities of phalangeal joints, instability, and localized tenderness are some of the features that assist in making the diagnosis of this entity. Joint space obliteration and subchondral erosions are seen on radiographic examination.

Another condition that can result in hand pain after an arteriovenous access creation is reflex sympathetic dystrophy syndrome (27). This syndrome is characterized by pain and swelling of an affected extremity. It is seen most commonly after trauma. Reflex sympathetic dystrophy syndrome should be included in the differential diagnosis of unexplained limb pain coupled with swelling after an arteriovenous access placement.

Diabetes can be associated with limb pain as a result of isolated nerve involvement (28). This neuropathy generally is symmetrical. This differs from ischemic monomelic neuropathy (IMN), which is a complication of vascular access that is observed almost exclusively in patients with diabetes, particularly those with preexisting neuropathy (29,30). This entity is characterized by the development of acute pain, weakness, and paralysis of forearm and hand muscles and often is associated with sensory changes. IMN occurs very early (minutes to hours) after the creation of an arteriovenous access. It is caused by ischemic infarction of the vasa nervosa. IMN can be diagnosed clinically on the basis of an acute onset of pain after access creation, a history of diabetes, and dominant neurologic symptoms and signs. Typically, the hand is warm and the radial pulse is variably present.

Diagnosis

For the most part, the diagnosis of DHIS can be made on clinical grounds. A good history and physical examination as well as a careful analysis of differential diagnosis should help to establish the diagnosis in a majority of patients (Table 1).

Cold fingers with a pale or blue-purple discoloration can be observed in patients with DHIS. Distal radial pulses usually are palpable only when the arteriovenous fistula has been compressed manually. However, the volume of the radial pulse may be normal on palpation, yet the patient demonstrates DHIS (10) (Figure 1). It is for this reason that the pulse examination is helpful but not diagnostic of symptoms of distal ischemia. Intuitively, one could imagine that by performing a physical examination, the cause of arterial steal would be disclosed. In this context, the appearance of a radial pulse with access occlusion would indicate that the arteriovenous access was stealing too much blood away from the forearm, creating ischemia, and flow reduction through the access was indicated. Although logical, findings of a recent study cast doubt on this

Table 1. Common causes of hand pain in HD patients and their differentiating features[a]

	DHIS	IMN	CTS	DA
Predominant feature	Cold hand with pain on or off dialysis	Weakness and paralysis of muscles with prominent sensory loss	Hand weakness and pain with numbness of fingers	Pain localized to phalangeal joints mainly
Presentation	Acute and chronic	Acute	Chronic	Chronic
Access type	Common with upper arm but also seen with forearm accesses	Only with upper arm accesses	No impact of access type	No impact of access type
Tissue involved	Skin > muscle > nerve	Nerves	Nerves	Joints and phalangeal bones
Cause	Vascular insufficiency leading to distal hypoperfusion	Vascular insufficiency causing nerve damage	Accumulation of β2-microglobulin amyloidosis	Poorly understood
Radial pulse	Usually diminished	Usually present	Present	Present
Diagnostic evaluation	Thorough history, physical examination, and arteriography	History and the clinical features	History, physical examination, and NCVS	History, physical examination, and hand x-ray
More prevalent in	Patients with diabetes, peripheral vascular disease, smokers	Patients with diabetes, peripheral vascular disease	Long-term HD patients	Long-term HD patients
Management strategies	Percutaneous and surgical interventions	Access ligation	Supportive management and surgery	No specific therapy

[a]CTS, carpal tunnel syndrome; DA, destructive arthropathy; DHIS, distal hypoperfusion ischemic syndrome; HD, hemodialysis; IMN, ischemic monomelic neuropathy; NCVS, nerve conduction velocity studies.

notion (10). In this report, a majority (91%; $n = 12$) of patients showed pulse with access occlusion, yet only a minority (18%) of patients were found to be candidates for a flow-reduction procedure after a more detailed evaluation. It was possible to have good radial and ulnar pulses yet have hand ischemia (Figure 1). In addition, pulse examination in a patient with axillary artery stenosis did not indicate a difference in volume of the brachial artery pulse compared with the contralateral side. In this study, capillary refill also was not found to be helpful. Although physical examination is emerging as one of the most valuable tools in the diagnosis of stenosis associated with a dialysis access, on the basis of the published information (10), its utility in differentiating between patients with and without arterial stenosis was less than optimal. Nevertheless, physical examination is helpful in providing diagnostic information that might be helpful in establishing other diagnoses (localized tenderness of the joints, evaluation of thenar and hypothenar muscles [carpel tunnel syndrome], and neurologic evaluation of the extremity [carpal tunnel, diabetes, and neuropathy]).

Demonstration of retrograde flow associated with a vascular access does not predict or indicate the existence of a clinical steal syndrome (1–3). Hemodynamic evidence of arterial steal can be found in most patients, those with forearm as well as proximal arteriovenous accesses. However, ischemic symptoms develop in only a minority of cases. A variety of noninvasive investigations such as digital BP, digital/brachial index (DBI) measurement, digital plethysmography, duplex ultrasonography, and transcutaneous oxygen saturation determination are available to assist in the evaluation of patients with symptoms that suggest arterial steal (31–36).

The use of DBI immediately after access creation has been somewhat controversial. In one study of 109 patients, it was reported to have a specificity of only 59% and a positive predictive value of 18% (33). However, in a subsequent study of 35 cases (32), it was concluded that a DBI of <0.6 that was obtained on the day of surgery was reasonably predictive of a risk for the development of symptoms of arterial steal (31).

Oxygen saturation also has been used to diagnose and assess the response to treatment (34). In this study, pulse oximeter found an oxygen saturation of only 42 to 63% in five patients who presented with symptoms of arterial steal. After intervention, these investigators documented an increase in oxygen saturation in all five patients (80 to 100%) with resolution of symptoms. However, a small sample size and the lack of a control group without hand pain are major limitations of this study. Finally, a digital oxygen level below which ischemic symptoms are inevitable has not been established.

Although these hemodynamic parameters have been cited by many investigators as important in establishing the diagnosis of DHIS, certain admonitions should be followed in performing these measurements. Sumner (36) emphasized that measurements of digital BP, DBI, and oxygen saturation require extreme caution. Such studies should be performed in a warm (25°C), draft-free room with the patient relaxed. All efforts should be made to allay apprehension. Even in this scenario, some patients may remain vasoconstricted and require soaking of the hand in warm water. In this way, vasoconstriction that can confuse the interpretation of results can be avoided. The operator should consider performing digital pressure in all fingers to localize the problem to digital *versus* palmar arch. When performed correctly, hemodynamic evaluation is very valuable in the evaluation of patients who present with symptoms of DHIS. However, this type of environment generally is not available in most interventional suites. The noninvasive
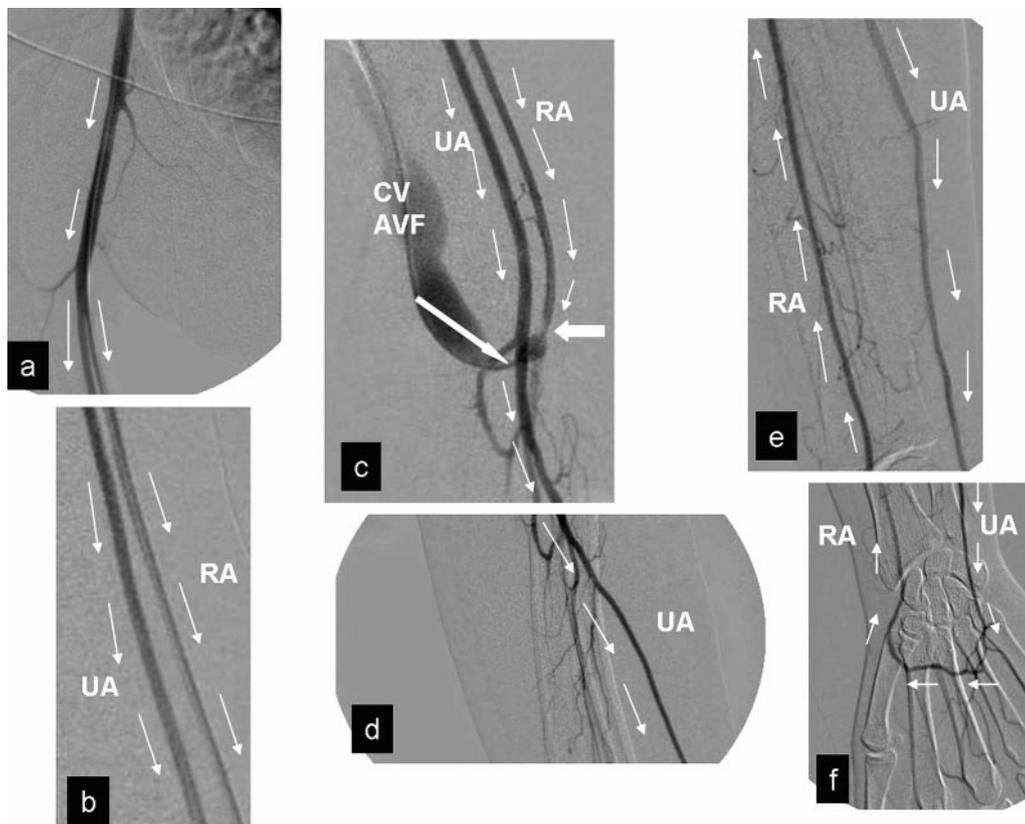
Figure 1. Arteriography in a patient with symptoms of arterial steal syndrome. Arrows indicate the direction of blood flow. The short bold arrow indicates 60% stenosis of the artery just proximal to the anastomosis. The long bold arrow shows a juxta-anastomotic venous stenosis. Even this stenosis was not able to protect the patient against hand ischemia. Retrograde flow was noted through the radial artery into the access. Physical examination could confirm the retrograde filling of the radial artery by occluding the ulnar artery and performing palpation of the radial artery. This patient showed a good radial and ulnar artery pulse on physical examination yet had hand ischemia. This case required an axillary loop fistula (proximalization procedure) using the outflow of the existing fistula. RA, radial artery; UA, ulnar artery; CVAVF, cephalic vein arteriovenous fistula. Reprinted from reference (10), with permission.

vascular laboratory is a more optimal location for the performance of most hemodynamic studies.

Good arteriography is the most important tool in making the diagnosis as well as developing a treatment strategy for DHIS (10). This can be achieved by digital subtraction angiography (DSA). Because steal from the distal vessels can be expected, arteriography should be performed with and without occlusion of the arteriovenous access. Optimally, images should be recorded from the aortic to the palmar arch so that the lesions in the more proximal arteries will not be missed (9). Recorded images then should be evaluated carefully for the presence of occlusive arterial disease. Although the femoral artery has been used to perform arteriography, this test can be performed easily by cannulating the access in a retrograde direction and advancing a diagnostic catheter into the aortic arch area.

In addition to DSA, other, less invasive techniques, such as magnetic resonance and computed tomographic (CT) angiography also are important imaging tools that may be used in vascular evaluation (16,37–43). Indeed, recent studies have found magnetic resonance angiography to be a useful method for quantifying the severity of peripheral vascular disease as well as detecting stenosis in dysfunctional HD accesses (16,37–39). CT arteriography also is emerging as a promising technique for less invasive imaging of the extremity arteries (40–43). With the introduction of multidetector-row CT (MDCT) technology, CT angiography is making rapid advances in the assessment of the peripheral arteries of the upper and lower extremities (40). MDCT offers a variety of advantages, including fast scan times, high spatial resolution, increased anatomic coverage, and capability to generate high-quality multiplanar reformations and three-dimensional renderings from raw data that can be reprocessed promptly (41). A randomized study that compared radiation exposure and image quality during MDCT angiography and DSA in the evaluation of the infrarenal aorta and lower extremity vessels found the former technique to provide a substantial reduction of the radiation dosage that was delivered to the patient while maintaining optimal diagnostic accuracy (43).

Management

At a conceptual level, the goal for managing DHIS must focus on augmenting blood flow distal to the access to relieve

ischemia while preserving the lifeline of the patient. A variety of both percutaneous and surgical interventions are available to achieve this goal (Table 2). Use of one of these interventions has made access ligation the procedure of last resort for patients with hand ischemia. However, this procedure still might be used when the symptoms are apparent immediately after access creation and for cases that are unresponsive to other treatments and demonstrate advancing ischemia.

Percutaneous Interventions

The presence of an arterial stenosis can have a significant effect on the surgical procedure that is performed to correct distal ischemia. Recognition of these stenoses before planning a surgical procedure is very important. For example, in the presence of a significant arterial stenosis proximal to the anastomosis, a banding procedure that is applied to correct arterial steal can result in a critical decline in access blood flow, culminating in access thrombosis.

Because arterial stenosis is an important cause of distal ischemia, the percutaneous approach is gaining popularity in the management of DHIS. In one study, Valji *et al.* (8) performed arteriography to evaluate patients with symptoms of hand ischemia. The entire arterial tree from the aortic arch to the palmar arch was evaluated. Seven of the 10 patients with hand pain revealed arterial stenoses, whereas three were found to have excessive flow into the access through the anastomosis. Five of the seven patients with arterial stenosis were amenable to angioplasty. Of these, four demonstrated resolution of symptoms after treatment. Of the three patients with excessive flow, two cases with radiocephalic fistulas were treated by coil embolization of the efferent radial artery to abolish the steal. The authors concluded that transcatheter therapy can be very successful in selected cases of hand ischemia. In another report, eight of 10 patients with advanced limb ischemia became symp-

Table 2. Percutaneous and surgical interventions to ameliorate hand ischemia

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Percutaneous interventions
  percutaneous balloon angioplasty
  intravascular stent insertion
  intravascular coil insertion
  MILLER procedure[a]
Surgical interventions
  banding procedure
  plication procedure
  insertion of VCS clips
  tapered graft insertion
  proximalization procedure
  DRIL
  RUDI

DRIL, distal revascularization-interval ligation; MILLER, minimally invasive limited ligation endoluminal-assisted revision; RUDI, revision using distal inflow; VSC, vascular clipping system.
[a]Minimally invasive technique that requires a small 1- to 2-cm skin incision.

tom-free after the application of percutaneous transluminal balloon angioplasty (PTA) (9). In a recent report of 12 patients who presented with DHIS, 10 were found to have arterial stenosis and eight were treated successfully with PTA. No procedure-related complications were reported in any of these studies.

Many reports have focused on the use of surgical interventions, including banding/plication, tapered graft insertion, distal revascularization-interval ligation (DRIL), and revision using a distal inflow procedure to correct steal that results in distal ischemia (44–50). However, a minimally invasive percutaneous technique that was designed to limit excessive flow (true steal) through the anastomosis that causes distal ischemia has been reported (51). This technique is based on the application of a ligature around an inflated angioplasty balloon to create a stenosis of a defined size. According to this technique, the body of the access is punctured and entered in a retrograde direction. A complete arteriography (with and without occlusion) to ascertain the presence of stenosis or aberrant anatomy is performed. Under local anesthesia, a small (1 to 2 cm) incision is made over the access approximately 2 to 3 cm from the arterial anastomosis. At this point, blunt dissection is performed so that a ligature (nylon) can be passed around the access. An angioplasty balloon then is positioned at the inflow. The size of the balloon is based on the size of the artery just distal to the arterial anastomosis (4- to 5-mm balloon for elbow fistulas); the goal is to create a significant stenosis once the ligature has been applied. The balloon then is inflated in the juxta-anastomotic region, and a ligature is applied snugly on the external surface of the access to create a stenotic lesion. The balloon is deflated, and the symptoms are assessed. In the absence of resolution of symptoms, another ligature juxtaposed to the first one to create a segment of high resistance can be applied. All 16 patients who were treated in this manner demonstrated immediate symptomatic and angiographic improvement of flow to the forearm after the procedure. The study did not provide information regarding quantification of the reduction of access flow or augmentation of perfusion to the hand.

The advantages of the percutaneous approach include demonstration of arterial anatomy as well as clarification of the cause of DHIS. Both angioplasty of an occlusive lesion and reduction of flow into the access can be performed using minimally invasive techniques. Other benefits include performance of the procedures on an outpatient basis, use of local anesthesia, and reduced incidence of procedure-related complications. It is important to note, however, that the outcome of these interventions depends strongly on the experience and the persistence of the interventionalist.

Surgical Interventions

Surgical interventions have been aimed at both reducing the excessive flow through the low-resistance arteriovenous access and augmenting distal flow without compromising flow through the arteriovenous access. A variety of procedures, including banding, tapered graft insertion, DRIL, and revision using distal artery as inflow (RUDI) have been applied (44–50).

Banding has been used commonly to treat patients with

DHIS. In a retrospective analysis, DeCaprio *et al.* (44) reported on 18 dialysis patients who presented with symptoms of arterial steal. Eleven (61%) of the 18 patients underwent a banding procedure without a previous arteriography; 6-mo patency was only 9%. Five (28%) of the 18 underwent arteriography and documented an arterial inflow lesion. Of these five patients, two underwent angioplasty and stent insertion with resolution of symptoms and continued patency of the access. One underwent graft ligation as a result of multiple arterial lesions. Of the remaining two, axillary artery stenosis could not be opened successfully in one case and the graft thrombosed. The last patient with arterial inflow lesion underwent a banding procedure without angioplasty. This graft thrombosed 2 d later. One of the 18 patients was lost to follow-up. This study highlights that the presence of unsuspected arterial stenosis might explain at least in part the dismal success (44,45) of a banding procedure that is performed to alleviate hand ischemia in an HD patient.

Although it has been suggested that the insertion of a tapered graft can decrease the risk for ischemia, a recent study showed that insertion of four to seven tapered grafts did not prevent this complication (44). In a prospective, controlled trial, Schaffer (47) studied the role of tapered grafts in the development of hand ischemia in patients who were at high risk for this complication. Patients with diabetes and ESRD ($n = 59$) were randomly assigned to receive either a 6-mm ($n = 32$) or 4- to 7-mm stepped graft ($n = 26$). Demographic characteristics of the patients did not reveal significant differences between the groups. Two (6%) patients with 6-mm grafts and three (12%) with 4- to 7-mm grafts developed symptomatic distal ischemia (NS). There was a significant difference regarding the actuarial primary patency rates at 6 and 12 mo (patency rates at 6 mo for 6 mm 85%, patency rates at 6 mo for 4 to 7 mm 64% [$P = 0.01$]; patency rates at 12 mo for 6 mm 75%, patency rates at 12 mo for 4 to 7 mm 37% [$P = 0.004$]). The author concluded that a 6-mm graft offered superior patency rates compared with the tapered graft. In this study, a 4- to 7-mm stepped graft did not protect against the development of hand ischemia.

Originally introduced by Schanzer *et al.* (48) in 1988, DRIL has been demonstrated to augment flow to the hand while preserving the access system. In this procedure, a bypass is created upstream from the anastomosis to the brachial artery just distal to the arteriovenous anastomosis. The native artery (brachial) then is ligated just distal to the arteriovenous access to prevent retrograde flow into the arteriovenous access. An analysis of 23 patients who were treated with the DRIL procedure (52) reported the resolution of symptoms in 19. One patient had advanced gangrene and eventually required amputation. Bypass patency was 96% at 2 yr, whereas access patency was 73 and 46% at 1 and 2 yr, respectively. Knox *et al.* (53) presented the results of a large DRIL experience ($n = 52$) with a mean follow-up of 16 mo. In this report, 90% of the patients had complete or significant improvement in their symptoms. Primary patency of the access was 93% at 1 yr.

Using an elegant mathematical model, Gradman and Pozrikidis (54) studied the role of various surgical procedures to alleviate hand ischemia. These investigators developed a flow model based on an electrical analogue. A 6-mm prosthetic brachial-axillary access was used as the prototype configuration. The resistive elements of this circuit include the subclavian, axillary, and brachial arteries. The distal circulation to the hand was considered as a single fixed resistance. The theoretical effect of various proximalization as well as distal revascularization procedures on the forearm flow was analyzed. The flow model disclosed that the greatest increase in the flow to the forearm was achieved by the DRIL procedure. This was followed by a 6-mm axillobrachial artery bypass graft without interval ligation, the conversion of the prosthetic brachial-axillary access to an axillary-axillary loop access (proximalization procedure), and the conversion to an axillary-brachial access (proximalization procedure). Major simplifications include the use of Poiseuille's law for estimating arterial resistance and ignoring the contribution of collateral circulation. Limitations of the study include the lack of direct evidence of actual augmentation of flow to the forearm and disregard of the increased resistance in the presence of stenotic lesions.

Although on a physiologic basis the DRIL procedure provides a sound basis of augmentation of distal flow in patients with DHIS (54), it does not seem to be practiced on a large scale. The reasons for this underuse are unclear. It is an extensive procedure, and ligation of the brachial artery and leaving arterial supply of the hand dependent on a bypass graft has been a concern. To address this issue, an alternative procedure was recently reported, the RUDI (50). Instead of the brachial artery, the fistula is ligated at its origin. This is followed by reestablishment of the fistula using a bypass from a more distal artery (radial or ulnar). In the initial report, four patients with ischemia reported resolution of symptoms after the RUDI procedure. All four were undergoing dialysis with the same access with a follow-up of 4 to 14 mo. Although both the DRIL and the RUDI procedures offer a sound basis for augmentation of distal flow, these extensive surgeries require careful selection of patients. Patients with arterial stenoses upstream (brachial, axillary, subclavian, and brachiocephalic arteries) and downstream (ulnar and radial arteries) from the arteriovenous anastomosis should be subjected to these procedures only after careful consideration.

These recent advances in the surgical treatment of patients with hand ischemia have rendered access ligation the last resort. In contrast to percutaneous interventions, surgery is more invasive, is more extensive, and cannot be performed routinely on an outpatient basis.

Management of Generalized Arteriopathy

Patients with severe distal arteriopathy as a result of vascular calcification and diabetes are not good candidates for either surgical or percutaneous interventions. Vascular calcification affects both the intimal and medial layers (12). Unfortunately, there is no definitive therapy for patients with vascular calcification and distal arteriopathy. Avoidance of treatment modalities that lead to calcium overload, achievement of good mineral metabolic balance, and optimal dialysis are the mainstays of treatment. The progression of coronary calcification has been shown to progress more rapidly with the use of calcium-con-

taining phosphate binders compared with a noncalcium phosphate binder (sevelamer) (55). Although etidronate disodium was demonstrated recently to ameliorate calcific uremic arteriolopathy and result in healing of skin ulcers (56), further studies are needed to evaluate properly the role of this agent in the management of vascular calcification.

Management Proposal for DHIS

The primary goal in treating an HD patient with hand ischemia is preservation of the digits and hand and to do so without sacrificing the access. Because distal hypoperfusion can develop in the presence or absence of stenotic arterial lesions, a complete arteriogram of the extremity must be an integral part of the patient's initial evaluation. The choice of modality and the procedure to be performed can be made only after analysis of the results from this study. An algorithm for the management of DHIS is presented in Figure 2.

The choice for treatment, either surgery or percutaneous, must be individualized to obtain optimal results. Decisions should be based on the arteriogram. The value of this approach was demonstrated clearly in a recent report that was based on 12 cases that presented with DHIS (10). Basing management decisions on an initial radiologic evaluation of the arterial pathology, it was possible to obtain a resolution of symptoms in 100% of patients and preservation of access function in >90%. In this study, angiography showed arterial stenotic lesions in 10 (83%) of 12 patients. Eight (80%) patients with stenotic lesions underwent PTA successfully. The degree of stenosis before and after PTA was $66 \pm 14\%$ (SD) and $13 \pm 10\%$. The remaining two patients were not considered candidates for PTA and were referred to surgery with arteriography images. At the surgeon's discretion, one patient underwent access ligation, and the other

patient (Figure 1) with stenosis required an axillary loop fistula using the same outflow vein. The two patients without stenoses showed excessive steal through the anastomosis and underwent lengthening procedures by insertion of a vein segment. All 12 patients are symptom-free with a mean follow-up of 8.3 ± 4 mo, and 11 (92%) of 12 patients are undergoing dialysis using the same access. There were no procedure-related complications.

Good medical management of comorbidities and complicating factors also is important. Symptoms of DHIS are common in patients with diabetes (52,53). Careful control and the application of appropriate diabetic care principles are beneficial in these cases. Both current and former smoking is associated with peripheral arterial disease (17,18). In addition, smoking increases the risk for amputation in patients with claudication (19) and decreases patency rates after lower extremity bypass (20). It has been demonstrated that in dialysis patients, current smoking is predictive of peripheral arterial disease and future cardiovascular events (21). In one series of patients who presented with hand ischemia, >90% gave a history of smoking (current smokers 58%; former smokers 34%) (10). Smoking cessation is beneficial (57) and should be strongly encouraged in these cases.

Conclusion

DHIS has multiple causes: Arterial stenosis, vascular steal, and distal arteriopathy as well as combinations of these three. The approach to therapy must be individualized on the basis of a thorough evaluation of the patient. This evaluation should include a complete imaging of the arterial circulation of the extremity. The decision on modality, surgical or percutaneous, and the type of procedure performed should be based on the findings demonstrated in this study. The goal of treatment should be preservation of the digits and hand and to do so without sacrificing the access. Because of the complexity of these cases, a team approach involving nephrologists, interventionalists, and surgeons would be beneficial and serve to improve patient care.

Acknowledgments

References

1. Duncan H, Ferguson L, Faris I: Incidence of the radial steal syndrome in patients with Brescia fistula for hemodialysis: Its clinical significance. *J Vasc Surg* 4: 144–147, 1986
2. Kwun KB, Schanzer H, Finkler N, Haimov M, Burrows L: Hemodynamic evaluation of angioaccess procedures for hemodialysis. *Vasc Surg* 13: 170–177, 1979
3. DeMasi RJ, Gregory RT, Sorrell KA, Wheeler JR, Snyder SO, Gayle RG, Parent FN, Gandhi RH: Intraoperative noninvasive evaluation of arteriovenous fistulae and grafts. The steal study [Abstract]. *J Vasc Tech* 18: 192, 1994
4. Morsy A, Kulbaski M, Chen C, Isiklar H, Lumsden AB: Incidence and characteristics of patients with hand ischemia after a hemodialysis access procedure. *J Surg Res* 74: 8–10, 1998
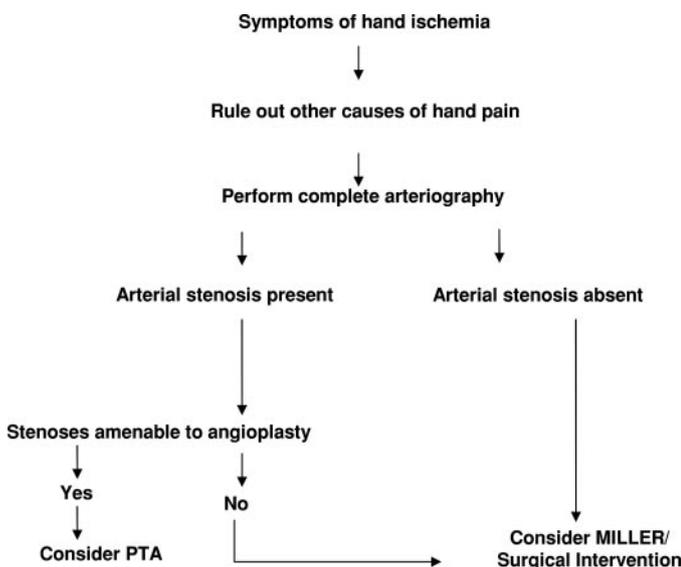

Figure 2. A simple algorithm to treat patients with symptoms of distal hypoperfusion ischemic syndrome. PTA, percutaneous transluminal balloon angioplasty; MILLER, minimally invasive limited ligation endoluminal-assisted revision. Reprinted from reference (10), with permission.

5. Tordoir JHM, Dammers R, van der Sande FM: Upper extremity ischemia and hemodialysis vascular access. *Eur J Vasc Endovasc Surg* 27: 1–5, 2004

6. Haimov M, Baez A, Neff M, Sliftin R: Complications of arteriovenous fistulae for hemodialysis. *Arch Surg* 110: 708–712, 1975

7. Rinnaert P, Struyvan J, Mathieu J: Intermittent claudication of the hand after creation of an arteriovenous fistula in the forearm. *Am J Surg* 139: 838–843, 1980

8. Valji K, Hye RJ, Roberts AC, Oglevie SB, Ziegler T, Bookstein JJ: Hand ischemia in patients with hemodialysis access grafts: Angiographic diagnosis and treatment. *Radiology* 196: 697–701, 1995

9. Guerra A, Raynaud A, Beyssen B, Pagny JY, Sapoval M, Angel C: Arterial percutaneous angioplasty in upper limbs with vascular access devices for haemodialysis. *Nephrol Dial Transplant* 17: 843–851, 2002

10. Asif A, Leon C, Merrill D, Bhimani B, Ellis R, Ladino M, Gadalean FN: Arterial steal syndrome: A modest proposal for an old paradigm. *Am J Kidney Dis* 48: 88–97, 2006

11. Derici U, El Nahas AM: Vascular calcifications in uremia: Old concepts and new insights. *Semin Dial* 19: 60–68, 2006

12. Goldsmith DJ, Covic A, Sambrook PA, Ackrill P: Vascular calcification in long-term haemodialysis patients in a single unit: A retrospective analysis. *Nephron* 77: 37–43, 1997

13. Asif A, Gadalean FN, Merrill D, Cherla G, Cipleu CD, Epstein DL, Roth D: Inflow stenosis in arteriovenous fistulas and grafts: A multicenter, prospective study. *Kidney Int* 67: 1986–1992, 2005

14. Khan FA, Vesely TM: Arterial problems associated with dysfunctional hemodialysis grafts: Evaluation of patients at high risk for arterial disease. *J Vasc Interv Radiol* 13: 1109–1114, 2002

15. Lockhart ME, Robbin ML, McNamara MM, Allon M: Association of pelvic arterial calcification with arteriovenous thigh graft failure in haemodialysis patients. *Nephrol Dial Transplant* 9: 2564–2569, 2004

16. Duijm LEM, Liem YS, van der Rijt RHH, Nobrega FJ, van den Bosch HC, Douwes-Draaijer P, Cuypers PW, Tielbeek AV: Inflow stenosis in dysfunctional hemodialysis access fistulae and grafts. *Am J Kidney Dis* 48: 98–105, 2006

17. Murabito JM, Evans JC, Nieto K, Larson MG, Levy D, Wilson PW: Prevalence and clinical correlates of peripheral arterial disease in the Framingham Offspring Study. *Am Heart J* 143: 961–965, 2002

18. Newman AB, Siscovick DS, Manolio TA, Polak J, Fried LP, Borhani NO, Wolfson SK: Ankle-arm index as a marker of atherosclerosis in the Cardiovascular Health Study. Cardiovascular Heart Study (CHS) Collaborative Research Group. *Circulation* 88: 837–845, 1993

19. Juergens JL, Barker NW, Hines EA Jr: Arteriosclerosis obliterans: Review of 520 cases with special reference to pathogenic and prognostic factors. *Circulation* 21: 188–195, 1960

20. Myers KA, King RB, Scott DF, Johnson N, Morris PJ: The effect of smoking on the late patency of arterial reconstructions in the legs. *Br J Surg* 65: 267–271, 1978

21. Foley RN, Herzog CA, Collins AJ: Smoking and cardiovascular outcomes in dialysis patients: The United States Renal Data System Wave 2 study. *Kidney Int* 63: 1462–1467, 2003

22. Wixon CL, Hughes JD, Mills JL: Understanding strategies for the treatment of ischemic steal syndrome after hemodialysis access. *J Am Coll Surg* 191: 301–310, 2000

23. Vellani G, Dallari D, Fatone F, Martella D, Bonomini V, Gualtieri G: Carpal tunnel syndrome in hemodialyzed patients. *Chir Organi Mov* 78: 15–18, 1993

24. Bartova V, Zima T: Diagnosis and treatment of carpal tunnel syndrome. *Ren Fail* 15: 533–537, 1993

25. Asencio G, Rigout C, Ramperez P, Branger B, Oules R, Bertin R, Megy B, Leonardi C: Hemodialysis-related lesions of the hand. *Rev Rhum Engl Ed* 62: 233–240, 1995

26. Flipo RM, Le Loet X, Siame JL, Benoit J, Goutallier D, Duquesnoy B, Bardin T: Destructive arthropathy of the hands in chronic hemodialysis patients. A report of seven cases with pathologic documentation. *Rev Rhum Engl Ed* 62: 241–247, 1995

27. Weise WJ, Bernard DB: Reflex sympathetic dystrophy syndrome of the hand after placement of an arteriovenous graft for hemodialysis. *Am J Kidney Dis* 18: 406–408, 1991

28. Bansal V, Kalita J, Misra UK: Diabetic neuropathy. *Postgrad Med J* 82: 95–100, 2006

29. Riggs JE, Moss AH, Labosky DA, Liput JH, Morgan JJ, Gutmann L: Upper extremity ischemic monomelic neuropathy: A complication of vascular access procedures in uremic diabetic patients. *Neurology* 39: 997–998, 1989

30. Miles AM: Vascular steal syndrome and ischaemic monomelic neuropathy: Two variants of upper limb ischaemia after haemodialysis vascular access surgery. *Nephrol Dial Transplant* 14: 297–300, 1997

31. Papasavas PK, Reifsnyder T, Birdas TJ, Caushaj PF, Leers S: Prediction of arteriovenous access steal syndrome utilizing digital pressure measurements. *Vasc Endovascular Surg* 37: 179–184, 2003

32. Goff CD, Sato DT, Bloch PH, DeMasi RJ, Gregory RT, Gayle RG, Parent FN, Meier GH, Wheeler JR: Steal syndrome complicating hemodialysis access procedures: Can it be predicted? *Ann Vasc Surg* 14: 138–144, 2000

33. Valentine RJ, Bouch CW, Scott DJ, Li S, Jackson MR, Modrall JG, Clagett GP: Do preoperative finger pressures predict early arterial steal in hemodialysis access patients? A prospective analysis. *J Vasc Surg* 36: 351–356, 2002

34. Halevy A, Halpern Z, Negri M, Hod G, Weissgarten J, Averbukh Z, Modai D: Pulse oximetry in the evaluation of the painful hand after arteriovenous fistula creation. *J Vasc Surg* 14: 537–539, 1991

35. Lazarides MK, Staramos DN, Panagopoulos GN, Tzilalis VD, Eleftheriou GJ, Dayantas JN: Indications for surgical treatment of angioaccess-induced arterial "steal." *J Am Coll Surg* 187: 422–426, 1998

36. Sumner DS: Noninvasive vascular laboratory assessment. In: *Vascular disorders of upper Extremity*, 2nd rev. ed., edited by Machleder HI, Mount Kisco, New York, Futura Publishing Company, 1989, pp 9–57

37. Pavlovic C, Futamatsu H, Angiolillo DJ, Guzman LA, Wilke N, Siragusa D, Wludyka P, Percy R, Northrup M, Bass TA, Costa MA: Quantitative contrast enhanced magnetic resonance imaging for the evaluation of peripheral arterial disease: A comparative study versus standard digital angiography. *Int J Cardiovasc Imaging* July 27, 2006 [epub ahead of print]

38. Planken RN, Tordoir JH, Dammers R, de Haan MW, Oei TK, van der Sande FM, van Engelshoven JM, Leiner T: Stenosis detection in forearm hemodialysis arteriovenous

fistulae by multiphase contrast-enhanced magnetic resonance angiography: Preliminary experience. *J Magn Reson Imaging* 17: 54–64, 2003

39. Smits JH, Bos C, Elgersma OE, van der Mark WA, Blankestijn PJ, Bakker CJ, Zijlstra JJ, Kalmijn S, Mali WP: Hemodialysis access imaging: Comparison of flow-interrupted contrast-enhanced MR angiography and digital subtraction angiography. *Radiology* 225: 829–834, 2002
40. Willmann JK, Wildermuth S: Multidetector-row CT angiography of upper- and lower-extremity peripheral arteries. *Eur Radiol* 15: D3–D9, 2005
41. Hiatt MD, Fleischmann D, Hellinger JC, Rubin GD: Angiographic imaging of the lower extremities with multidetector CT. *Radiol Clin North Am* 43: 1119–1127, 2005
42. Ouwendijk R, de Vries M, Pattynama PM, van Sambeek MR, de Haan MW, Stijnen T, van Engelshoven JM, Hunink MG: Imaging peripheral arterial disease: A randomized controlled trial comparing contrast-enhanced MR angiography and multi-detector row CT angiography. *Radiology* 1094–1103, 2005
43. Fraioli F, Catalano C, Napoli A, Francone M, Venditti F, Danti M, Pediconi F, Passariello R: Low-dose multidetector-row CT angiography of the infra-renal aorta and lower extremity vessels: Image quality and diagnostic accuracy in comparison with standard DSA. *Eur Radiol* 16: 137–146, 2006
44. DeCaprio JD, Valentine RJ, Kakish HB, Awad R, Hagino RT, Claggett GP: Steal syndrome complicating hemodialysis access. *Cardiovasc Surg* 5: 648–653, 1997
45. Odland MD, Kelly PH, Ney AL, Andersen RC, Bubrick MP: Management of dialysis-associated steal syndrome complicating upper extremity arteriovenous fistulas: Use of intraoperative digital photoplethysmography. *Surgery* 110: 664–669, 1991
46. Schild AF, Pruett CS, Newman MI, Raines J, Petersen F, Konkin T, Kim P, Dickson C, Kirsch WM: The utility of the VCS clip for creation of vascular access for hemodialysis: Long-term results and intraoperative benefits. 9: 526–530, 2001
47. Schaffer D: Schaffer D: A prospective, randomized trial of 6-mm versus 4–7-mm PTFE grafts for hemodialysis access

in diabetic patients. In: *Vascular Access for Hemodialysis*, 5th ed., edited by Henry ML, Ferguson RM, Tucson, W.L. Gore and Associates, Inc., and Precept Press, 1997, pp 91–94
48. Schanzer H, Schwartz M, Harrington E, Haimov M: Treatment of ischemia due to "steal" by arteriovenous fistula with distal artery ligation and revascularization. *J Vasc Surg* 7: 770–773, 1988
49. Berman SS, Gentile AT, Glickman MH, Mills JL, Hurwitz RL, Westerband A, Marek JM, Hunter GC, McEnroe CS, Fogle MA, Stokes GK: Distal revascularization-interval ligation for limb salvage and maintenance of dialysis access in ischemia steal syndrome. *J Vasc Surg* 26: 393–404, 1997
50. Minion DJ, Moore E, Endean E: Revision using distal inflow: A novel approach to dialysis-associated steal syndrome. *Ann Vasc Surg* 19: 625–628, 2005
51. Goel N, Miller GA, Jotwani MC, Licht J, Schur I, Arnold WP: Minimally invasive limited ligation endoluminal-assisted revision (MILLER) for treatment of dialysis access-associated steal syndrome. *Kidney Int* 70: 765–770, 2006
52. Haimov M, Schanzer H, Skladani M: Pathogenesis and management of upper-extremity ischemia following angioaccess surgery. *Blood Purif* 14: 350–354, 1996
53. Knox RC, Berman SS, Hughes JD, Gentile AT, Mills JL: Distal revascularization-interval ligation: A durable and effective treatment for ischemic steal syndrome after hemodialysis access. *J Vasc Surg* 36: 250–255, 2002
54. Gradman WS, Pozrikidis C: Analysis of options for mitigating hemodialysis access-related ischemic steal phenomena. *Ann Vasc Surg* 18: 59–65, 2004
55. Block GA, Spiegel DM, Ehrlich J, Mehta R, Lindbergh J, Dreisbach A, Raggi P: Effects of sevelamer and calcium on coronary artery calcification in patients new to hemodialysis. *Kidney Int* 68: 1815–1824, 2005
56. Izzedine H, Brocheriou I, Eymard B, Le Charpentier M, Romero NB, Lenaour G, Bourry E, Deray G: Successful treatment of a patient with severe calcific uremic arteriolopathy (calciphylaxis) by etidronate disodium. *Am J Kidney Dis* 48: 151–154, 2006
57. Quick CR, Cotton LT: The measured effect of stopping smoking on intermittent claudication. *Br J Surg* 69: 24–26, 1982