The Journal of Vascular Access 2008; 9: 155-166

Understanding the dialysis access steal syndrome. A review of the etiologies, diagnosis, prevention and treatment strategies

J. MALIK[1], V. TUKA[1], Z. KASALOVA[1], E. CHYTILOVA[1], M. SLAVIKOVA[2], P. CLAGETT[3], I. DAVIDSON[3], B. DOLMATCH[4], D. NICHOLS[3], M. GALLIENI[5]

[1]Third Department of Internal Medicine, General University Hospital and 1st School of Medicine, Charles University, Prague - Czech Republic
[2]Department of Cardiovascular Surgery, General University Hospital and 1st School of Medicine, Charles University, Prague - Czech Republic
[3]Division of Transplant, Department of Surgery, Parkland Memorial Hospital University of Texas Southwestern Medical Center, Dallas - USA
[4]Division of Interventional Radiology, Parkland Memorial Hospital University of Texas Southwestern Medical Center, Dallas - USA
[5]Renal Unit, San Paolo Hospital, University of Milan, Milan - Italy

Abstract: Distal hypoperfusion ischemic syndrome (DHIS), commonly referred to as hand ischemia or "steal" after dialysis access placement, occurs in 5-10% of cases when the brachial artery is used, or 10 times that of wrist arteriovenous fistulas (AVFs) using the radial artery. It is typically seen in elderly women with diabetes, and may carry severe morbidity including tissue or limb loss if not recognized and treated. Three distinct etiologies include (1) blood flow restriction to the hand from arterial occlusive disease either proximal or distal to the AV access anastomosis, (2) excess blood flow through the AV fistula conduit (true steal), and (3) lack of vascular (arterial) adaptation or collateral flow reserve (ie atherosclerosis) to the increased flow demand from the AV conduit. These three causes of steal may occur alone or in concert. The diagnosis of steal is based on an accurate history and physical examination and confirmed with tests including an arteriogram, duplex Doppler ultrasound (DDU) evaluation with finger pressures and waveform analysis. Treatment of steal includes observation of developing symptoms in mild cases. Balloon angioplasty is the appropriate intervention for an arterial stenosis. At least three distinct surgical corrective procedures exist to counteract the pathophysiology of steal. The ultimate treatment strategy depends on severity of symptoms, the extent of patient co-morbidity, and the local dialysis access technical team support and skills available. (J Vasc Access 2008; 9: 155-66)

Key words: *Hemodialysis, Duplex Doppler ultrasonography, Dialysis access, Hand ischemia, DRIL, Banding, PAI, "Steal" syndrome*

Definition and incidence

Distal hypoperfusion ischemic syndrome (DHIS) is an infrequent, but disabling complication after hemodialysis (HD) access creation with and incidence of 1-8% (1). Terms such as "steal", or "arterial steal syndrome", or hand "ischemia", describe the same entity and are used interchangeably in this article.
Although the incidence of end-stage renal disease (ESRD) varies markedly between countries, there has been a steady increase worldwide in the last 20 yrs. The number of patients treated by HD in the USA was 1569 patient/million in 2005, which is 1.4 times more than in 1995 and approximately 3 times more than in 1985 (2). The severity and complexity of associated complications increases similarly. The management of DHIS has become more challenging, as the dialysis patients are older and with increasing severity of co-morbid, mainly cardiovascular, conditions.
Individuals at risk for DHIS include female gender, age greater than 60 yrs, diabetes mellitus, previous operations on the same limb, and the use of the brachial artery as the access donor vessel (1, 3-6). Type 2 diabetes mellitus associated with obesity, hypertension, and arterial occlusive disease has be-

 1129-7298/155-12$25.00/0

come the leading cause of adult chronic kidney failure. Uremia itself contributes to both accelerated atherosclerosis and medial calcinosis, predominantly present distally in the arterial tree (7). Medial calcinosis in particular prevents arterial dilation in response to high (dialysis access) blood flow, and limits blood flow to the hand and digits. Diabetic micro-angiopathy when present further worsens DHIS.

Normal upper extremity vascular anatomy and blood flow

Resting blood volume flow in the brachial artery varies between 30-120 ml/min, being at the lower range in patients with ESRD (JM, unpublished data). After HD access placement, blood flow increases by more than 10-fold within hours to a few weeks (8). The diameter of the inflow artery and outflow fistula vein may dilate 2-4 times. Arteriovenous (AV) access flow rates of 500-800 mL/min will meet the need of the dialysis machine blood flow rates, usually set at 250-500 mL/min (9). In cases where this vascular adaptation does not occur, symptoms of steal may occur. Physiologic steal phenomenon occurs and can be measured after every successful dialysis access creation (ie retrograde radial artery flow distal to the anastomosis). Symptomatic, clinical steal (Tab. I) is rare after wrist AVFs (less than 1%), but is more commonly seen (in 5-8% of cases) when the brachial artery is used at the antecubital fossa level (6).
Brachial artery bifurcation can occur at any point from the axilla to a level below the antecubital fossa. When preoperative vascular mapping is NOT performed or the surgeon is not actively involved in the interpretation and planning of findings, the superficial and uniformly smaller (radial) artery is the artery likely to be chosen for anastomosis when the antecubital fossa is the site of anastomosis. The dual artery anatomy brings two important dialysis issues to light. First, if the smaller (radial) artery is used, the access is more likely to fail from poor inflow, or lack of maturation (10). Secondly, with two arteries the collateral flow from the artery not used constitutes a partial DRIL procedure (without the distal artery ligation), a situation likely to prevent steal occurring.

TABLE I - STEAL SYMPTOMS IN ORDER OF INCREASING SEVERITY

- Nail changes
- Occasional tingling
- Extremity coolness
- Tingling and numbness in hand and fingers
- Muscle weakness
- Pale to whitish or cyanotic fingernail beds
- Rest-pain
- Sensory and motor function deficit
- Fingertip ulcerations
- Tissue loss

Clinical presentation of steal

DHIS presents in a variety of clinical manifestations. It may be present immediately after access surgery as a cold white or bluish painful hand requiring immediate correction (Tab. I). This acute form of ischemia commonly appears after hours to days and may worsen or subside over time (Fig. 1). Depending on test outcomes and severity of clinical symptoms, the decision of surgical intervention becomes one of judgment and common sense. The chronic form of DHIS is more subtle and appears later, weeks to months after the placement, and is often progressive. Acute and chronic DHIS symptoms vary from mild to severe. The patient may have minor nail changes, or symptoms, ie pain, tingling, numbness only during dialysis sessions, associated with blood pressure (BP) drop and lower cardiac output, to more distinct symptoms with pain and dry ulcerations on the fingertips (Fig. 2). Although steal is most commonly seen in older diabetic women, it must not be incorrectly diagnosed as neuropathy, which may also be present, confounding the clinical picture. Chronic steal may become evident after an unrelated minor trauma, when a fingernail or fingertip becomes a non-healing infection (Fig. 1). Most steal symptoms that appear early are mild and self-limiting, while late developing access associated ischemia tends to be progressive requiring surgical attention.

Etiologies of steal

There are three distinct etiologic entities of DHIS. First, in up to one-third of cases an arterial stenosis is present that will induce low arterial inflow, located above or below the access arterial anastomosis. Secondly, a large AV anastomosis producing a high fistula flow with distal ischemic symptoms constitutes true steal. Thirdly, the lack of vascular adaptation or collateral flow to the forearm will prevent compensation for the flow going into the fistula. The lack of blood flow adaptation results from atherosclerosis, medial calcinosis and inadequate collateral circulation around the fistula. Appreciating the different causes of clinical steal will also explain the different available strategies to correct and prevent it.

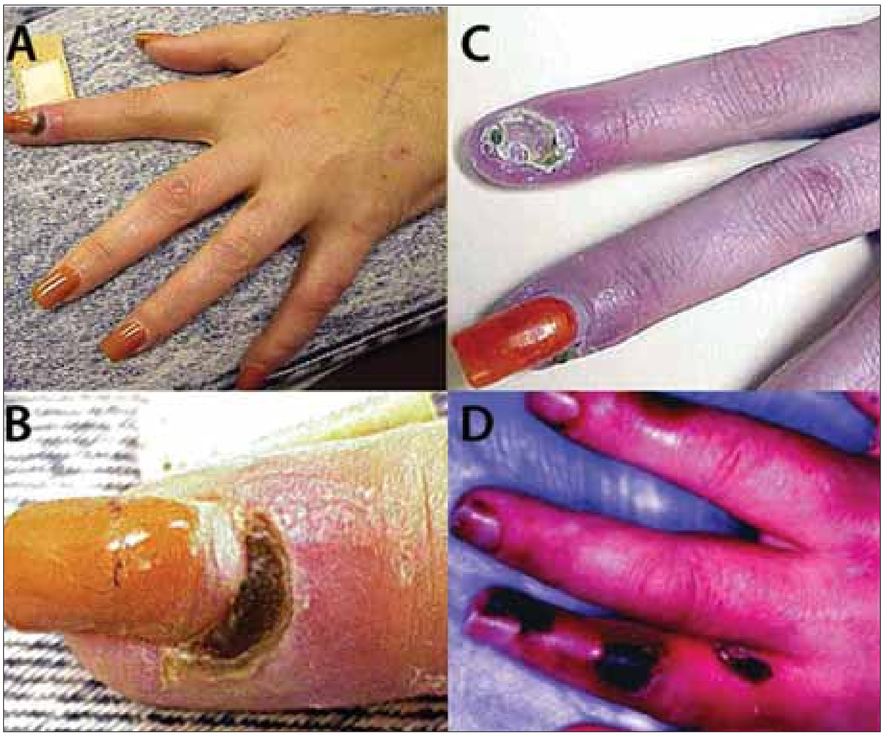

Fig. 1 - *Acute DHIS is seen in various degrees of severity. Sometimes, it is associated with infection and diabetes. Finger-nail infection from minor trauma (A, with a close up image depicted in B). The finger heals rapidly after removal of the nail and controlled banding of the access (C). Fig. D shows a non-treated infected hand in a young non-compliant diabetic man with steal.*

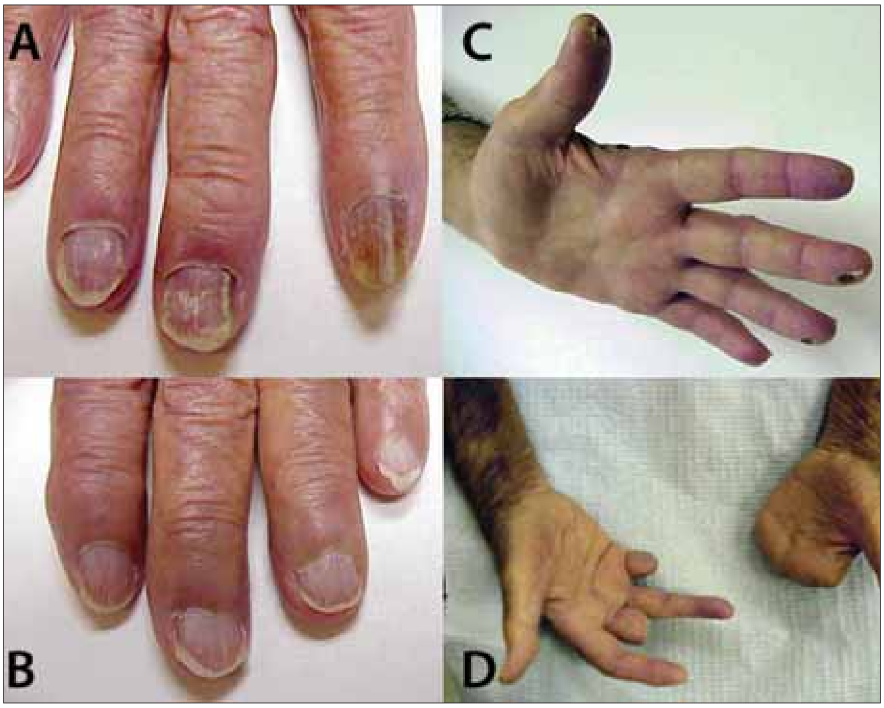

Fig. 2 - *Chronic DHIS also presents in many forms, such as minor ischemic nail changes in a 90 year old man (A), compared to his non-fistula hand (B). Typical chronic distal digit dry ulcerations are depicted in (C), which responded to controlled banding of an upper arm brachio-cephalic AVF. Image D shows the hands of a heart transplant patient undergoing dialysis, with massive tissue loss from multiple access procedures and severe distal arterial occlusive disease.*

Understanding the physiology of the steal syndrome

An HD access must have enough blood flow to supply the dialysis machine of 250-500 mL/min, and at the same time limit flow to avoid distal limb ischemia and/or heart failure. These seemingly opposite goals require some hemodynamic engineering understanding. The outflow vein of a native vascular access typically requires 4-6 weeks to mature into a useable conduit for HD. The feeding artery dilation may continue months to years after access creation (11). High blood flow (velocity) signals the endothelium of the arteries to release nitric oxide, the most potent endogenous arterio-dilating molecule (12). The arterial wall adaptations in response to the chronic increase of blood flow require structural adaptation associated with modification of the vessel wall matrix by metallo-proteinases (13).

Arterial flow is regulated by the perfusion pressure (PP) and by the peripheral vascular resistance (PVR) of the arterial tree. The PP is determined by the cardiac output and by the elastic properties of arteries. In vascular access induced tissue ischemia, maximal vasodilatation occurs with increased blood flow from lowering PVR. Diabetic micro-angiopathy and/or endothelial dysfunction restrict this physiologic adaptation promoting DHIS. Furthermore, a network of collaterals develops, some of them with antegrade, others with retrograde flow. Using the principle of Wheatstone bridge of electrical current and resistance helps explain and understand these complicated hemodynamic interactions (3).

The blood flow volume through an AV access (conduit) is related to the diameter of the fistula (anastomosis) and the inflow artery. In small AV conduits where the fistula diameter is less than 3/4 of the inflow artery, the flow is regulated by the fourth power of fistula radius. In large AV conduits, where the diameter of the anastomosis and outflow circuit is equal or greater than that of the donor artery, volume blood flow is regulated by the summary resistances of the peripheral vascular bed, the donor artery and the collateral circulation, similar to that of an electric model consisting of high and low resistance circuits (3). Because of the complex interaction between the basic components each case of steal requires investigative diagnostic steps to determine the therapeutic choices. While the direction of flow in the artery proximal to the anastomosis is always antegrade (forward), the flow in the artery distal to the anastomosis is variable and unpredictable and may be antegrade retrograde, or bi-directional, i.e. retrograde only during diastole. The direction of the blood flow is the result of a complex relationship between the inflow artery, the collateral arteries, the fistula itself and the peripheral vascular bed (14).

Physical examination and testing for diagnosis of DHIS

Table I lists the most common symptoms associated with steal for mild and severe disease stages. In most instances of DHIS the diagnosis and the course of action are evident based on history and physical examination. As the patient's symptoms become worse so do the findings at physical examination and the test results (Tab. II). Testing for accurate anatomical diagnosis and intervention is done in an incremental fashion starting with physical examination to more invasive and costly interventions guided by clinical severity and available expertise and equipment.

Determined by physical examination, all patients with significant clinical steal symptoms will undergo duplex Doppler ultrasonography (DDU) with access blood flow determination and finger pressures with and without compression of the access (Tab. II). The relief of symptoms and restoration of finger pressures upon compressing the access is the most compelling sign supporting the diagnosis of DHIS or "steal". Patients with symptoms severe enough deemed to require intervention must undergo an arteriogram to diagnose, and in the same setting treat vascular obstructive lesions with balloon angioplasty, present above or below the access anastomosis.

In contrast, late steal (>30 days) onset are often progressive requiring diagnostic and invasive treatment. Because symptoms may be non-specific, especially in diabetics with neuropathy, a high index of suspicion will lead to definitive testing.

Acute steal symptoms typically include coolness, pain, tingling and numbness, motor function deficits and muscle weakness. Chronic steal may include all the same but also nail changes, distal digit dry ulcerations and in severe cases tissue loss.

Other causes of hand pain, such as carpal tunnel syndrome, destructive arthropathy or ischemic monomelic neuropathy, should be excluded (1, 15).

Treatment options of DHIS

Instead of advocating one treatment option fits all, the authors favor the thoughtful consideration of the available options (Tab. III). The indication for each vary depending on fistula characteristics, patient comorbidity and surgical risk, the access team skill set and technical support; indeed, this approach is supported by each strong treatment option proponent, as variations and limitations of each procedure are described (3, 16, 17).

Choosing the appropriate treatment for different DHIS is based on the understanding of the local ex-

TABLE II - PHYSICAL FINDINGS ASSOCIATED WITH DHIS

- Diminished or absent radial and ulnar pulses
- Relieve of (acute) symptoms when compressing AV access
- Ischemic changes (ie nails, ulcerations, necrosis, and non-healing ulcers)
- Brachial artery digital index (DBI) of 0.6 or less
- Digital pressures below 50 mmHg or non-recordable
- Abnormal waveform suggestive of steal

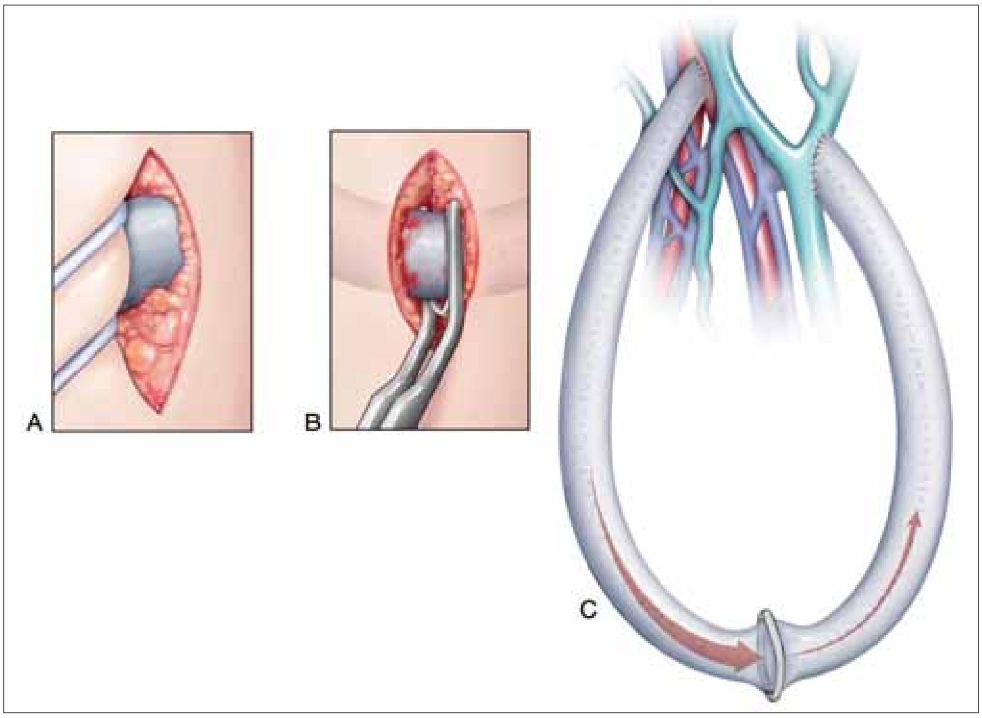

Fig. 3 - *The artist's view of the banding procedure of an access at the mid-portion preserves the dialysis functionality, in this case a forearm loop graft. Access flow restriction is achieved by surgical exposure of the graft surrounded with a vesi-loop (A) under local anaesthesia, followed by graded partial clamping of the access with a large hemo-clip (B) that is left in place. The authors use the Weck Hemoclip® 10 large Titanium Ligating Clip, which while being clamped forms a smooth semi-circular pattern allowing graded partial restriction of blood flow (C). Intra-operative DDU and finger pressure measurements guiding the procedure (Fig. 7) assures optimal outcome.*

tremity hemodynamics of the patient, diagnostic testing equipment availability, the local team and surgeon's experience, as well as the patient's co-morbid conditions. The authors realize the wide variation of treatment practices and differences in opinions, practice patterns, experience, as well as institutional technical skill supports. The paragraphs below are aimed to highlight different options related to the overall findings in the DHIS patient.

Table III lists the therapeutic options, which include:
1. Observation. Most cases of early steal are mild and may be followed by observing worsening of symptoms, based on clinical judgment. With increased team experience this choice becomes more prevalent, but it also requires frequent follow-ups. Most DHIS patients undergo a brief time of "observation" while undergoing diagnostic testing (ie arteriogram and finger pressure determination) to assess the severity and need for intervention (Tab. IV). Vasodilating drugs, ie pentoxyphyllin, naftidrofuryl, cilostazol and calcium antagonists may help but none of these treatments has been properly tested in a randomized trial. Severe rest pain, with blue or white digits and motor function deficit requires urgent surgical intervention.
2. Angioplasty. The authors recommend a diagnostic arteriogram in cases of DHIS severe enough to require corrective intervention. The treatment of choice for an arterial stenosis is balloon angioplasty, performed in the same setting as the diagnostic arteriogram. Angiographic imaging must include all vessels that carry blood flow to and from the AV access, i.e. from origin of the subclavian artery at the aorta, the AV access conduit itself, the outflow veins as well as the central veins back to the right atrium. Also in order to evaluate the distal forearm for occlusive disease, images must be obtained while compressing the access, directing the radiographic contrast to bypass the AV access anastomosis. Forearm occlusive disease is easily missed when this compression step is not performed. These images also will assess the runoff vascular artery suitability for the DRIL procedure.
3. "Banding" of the access is an attractive method because of the benign nature of the procedure (18, 19). The surgery is carried out under local anesthesia with no sedation to facilitate communication with the patient since immediate improvement in symptoms is expected. For optimal outcome finger pressures and waveform analysis and ideally access flow measurement are performed in the operating suite using DDU (20). Correctly done, banding represents a controlled, gradual, restriction of blood flow through the access (Fig. 3). It is applied at the mid-section of the access in order to preserve the effectiveness of

TABLE III - TREATMENT OPTIONS OF STEAL

- Observation
- Partial banding of the access conduit at its mid-point
- Distal revascularization and interval ligation (DRIL)
- Proximalization of the arterial inflow (PAI)
- Ligation of the AV access

dialysis treatment with the two-needle cannulation sites located on either side of the surgical banding clip. Under certain circumstances banding may be applied close to the arterial anastomosis. The authors prefer banding with a large hemo-clip that can be sequentially tightened as the intended finger pressures are attained. Prior to banding finger pressures are typically below 50 mmHg or not recordable. There is no uniformly agreed upon level to which pressures should reach after banding. First, the patient's symptoms should be relieved, then the degree of obstruction can be at least 50%, at which point the pressures may have risen to 70-100 mmHg, but less than that of the contra-lateral "normal" hand digits. One may allow 10-15 min after banding before improved symptoms can be reliably assessed. Hemodynamic monitoring during the banding procedure may not be available in some centers; however, a high agreement between the surgeon's experience and hemodynamic outcome has been reported (18). Figure 3 outlines the banding procedure for a forearm loop graft. Banding is an appropriate procedure for DHIS with (very) high blood flow (true steal), or access flow above 800 mL / min in AVFs and 1000 mL / min in grafts. Banding is preferred when access flow is exceeding 2000 mL / min. It is, therefore, also performed in subjects with either hyperkinetic heart failure or decompensation of congestive heart failure (21). In addition, regardless of blood flow level, and because of its benign nature, the authors prefer the banding procedure in the very fragile patient with co-morbid conditions of cardiovascular nature. In cases with severe or complete arterial occlusive distal arterial disease banding is the only option short of ligating the access. This is the setting where a DRIL procedure cannot be performed for lack of patent artery for the distal revascularization anastomosis. Strict adherence to local anesthesia without sedation, intra-operative finger pressure monitoring and DDU flow monitoring, will assure optimal outcome in the critically ill individuals. Banding is reported to have a high incidence of failure, ie thrombosis (6, 17, 22). The reasons for banding failure include missed inflow artery stenosis (6), poor patient selection with access blood flow less than 600-800 mL / min. Finally, the lack of intra-operative finger pressure monitoring for accurate and gradual flow restriction through the access predict failure.

4. The **DRIL** (distal revascularization and interval ligation) procedure is the preferred treatment from a physiologic standpoint (23-25). It represents a low resistance collateral conduit resulting in artery shunt fraction from the fistula and a greater proportion of blood flow to the periphery (hand). To prevent retrograde blood flowing into the fistula conduit, the distal artery it is ligated close to the access anastomosis. The multistep DRIL procedure requires general anesthesia and is detailed in Figure 4. First a vascular graft (i.e. the reversed saphenous vein, excised from the leg or a 4-6 mm polytetrafluoroethylene (PTFE)) is used as a bypass graft. The proximal anastomosis is placed 4-5 cm above the fistula anastomosis (above the pressure sink) (23) to an outflow artery below the anastomosis. These distances also avoid operating through scarred tissue from the fistula placement surgery. Ligation of the artery below the AVF anastomosis completes the procedure. The ligation step may be omitted when severe atherosclerotic occlusive disease is present (ie no retrograde flow present) between the access anastomosis and the distal bypass anastomosis. Patients selected to undergo the DRIL procedure must be able to tolerate major vascular surgery with general anesthesia. DRIL is appropriate for patients with access flow of 800 mL / min or less, since banding in these cases likely results in thrombosis from stagnant flow. In cases of arterial occlusive disease below the access anastomosis, a partial DRIL without ligation may be considered. DRIL may not be technically feasible for lack of useable artery anastomosis anatomy.

In a subset of patients carrying a forearm AV fistula, a "palmar arch shunt steal" can be observed, which is characterized as hypertrophy of the palmar arch and reduced flow to the arteries of the digits (26). When this phenomenon occurs, blood flow travels according to the pathway of least resistance, which is towards the fistula from both the radial and ulnar directions. Interruption of retrograde flow into the distal radial artery can be achieved by ligation or coil embolization of the radial artery, distal to the AV fistula (26).

5. The **PAI** (proximalization of the arterial inflow anastomosis) was developed as ligation of the distal outflow artery as part of the DRIL procedure by some was considered undesirable (16). The PAI procedure preserves the distal natural artery and may reduce access flow by increased resistance from the added proximal inflow segment, by using a smaller caliber (4 mm) PTFE grafts as proximalization inflow segment (16) (Fig. 5). More importantly, and because of the now more proximal anastomosis, collateral arterial flow is increased, which will help improve distal BP and flow to the hand. When using a PTFE graft, the PAI procedure is less invasive than the DRIL as the native (saphenous) vein is preserved. In contrast to the DRIL, the PAI procedure does not interfere with or worsen forearm pre-existing arterial disease. In cases when an additional access cannulation length is desired a 4-7 mm tapered proximalization PTFE graft can be used. The PAI procedure is best suited for DHIS in the upper arm access, when the arterial anastomosis is above the antecubital fossa. Results are likely improved in cases with access flow exceeding 800 mL / min in AVFs and

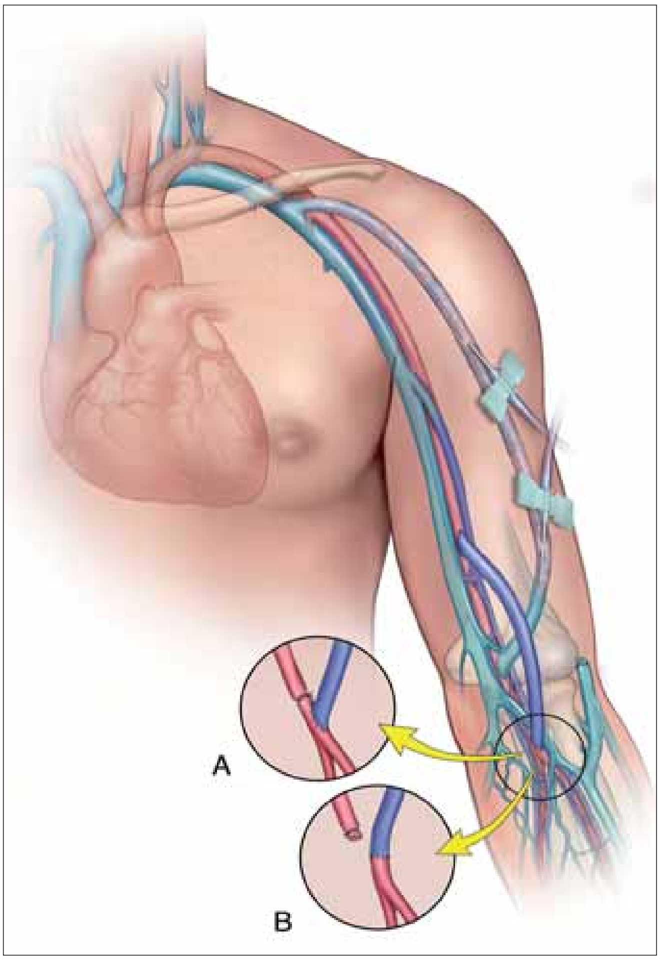

Fig. 4 - *The DRIL procedure involves the following steps and variations. First, a bypass (Distal Revascularization) graft (such as the reversed saphenous vein) is placed between the brachial artery, 5-6 cm proximal to the access anastomosis, and an artery distal to the access anatomosis. Second, the artery distal to the access is Ligated to prevent reversal of blood flow from the bypass. The distal anastomosis can be placed in an end-vein to side- artery fashion (A) or as an end-vein to end-artery after ligating and dividing the artery (B). Lacking suitable vein graft, a 4 or 6 mm PTFE graft may be used as the bypass conduit.*

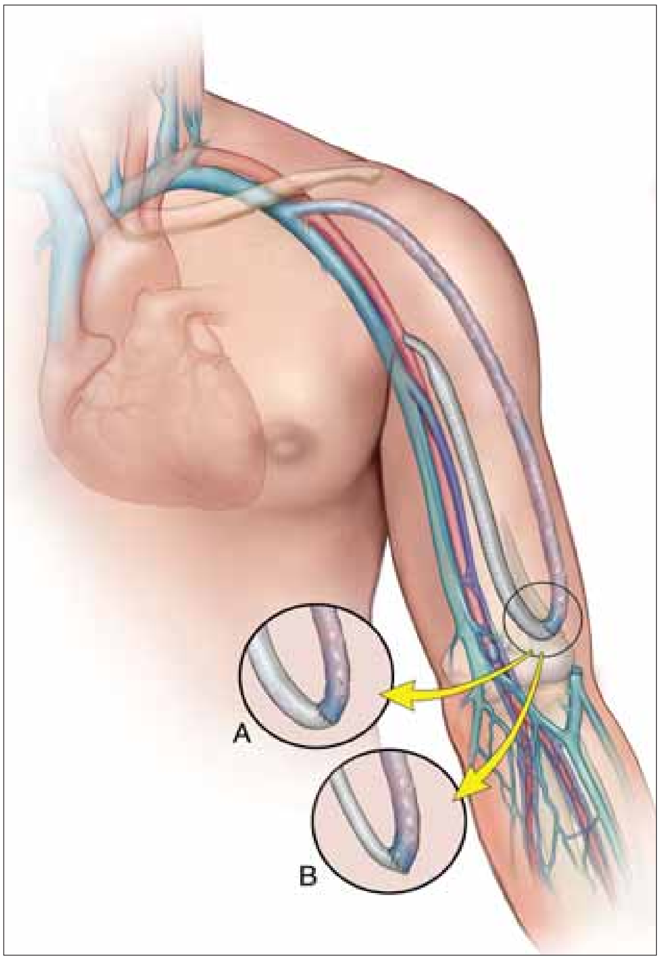

Fig. 5 - *The PAI (Proximalization of the Arterial Inflow) procedure is mostly applicable in the upper arm access, where the access anastomosis is moved up towards the upper brachial or axillary artery. When a longer cannulation segment is needed a 4-7 mm tapered PTFE graft is recommended (A). A 4 mm PTFE graft usually creates a slight anastomosis size discrepancy when a larger fistula vein is present (B).*

1000 mL/min in PTFE grafts. The decision between DRIL, PAI and banding becomes a matter of preference and experience (3, 6, 16).

6. Ligating the access represents the extreme case of banding and abandoning the access in order to prevent tissue loss and avoid severe chronic disability. Ligation of the access invariably removes the ischemic symptoms. However, it leaves the patient and the dialysis team with no access and the challenge of finding another access site, which again carries the risk of developing ischemic symptoms. Ligation should be restricted only as a measure to save an extremity in an acutely and critically sick patient often in shock in the ICU setting. The ligation procedure as is the case with banding should be accomplished under local anesthesia without sedation.

Role of duplex Doppler ultrasonography in DHIS

After the DHIS diagnosis is confirmed, DDU is also used to clarify its etiology and guide the selection of treatment options from volume flow determination, directions of flow, and the AV access anatomic features, ie stenosis, aneurysms, branching. The authors' protocol is summarized in the following paragraphs (9, 27, 28).

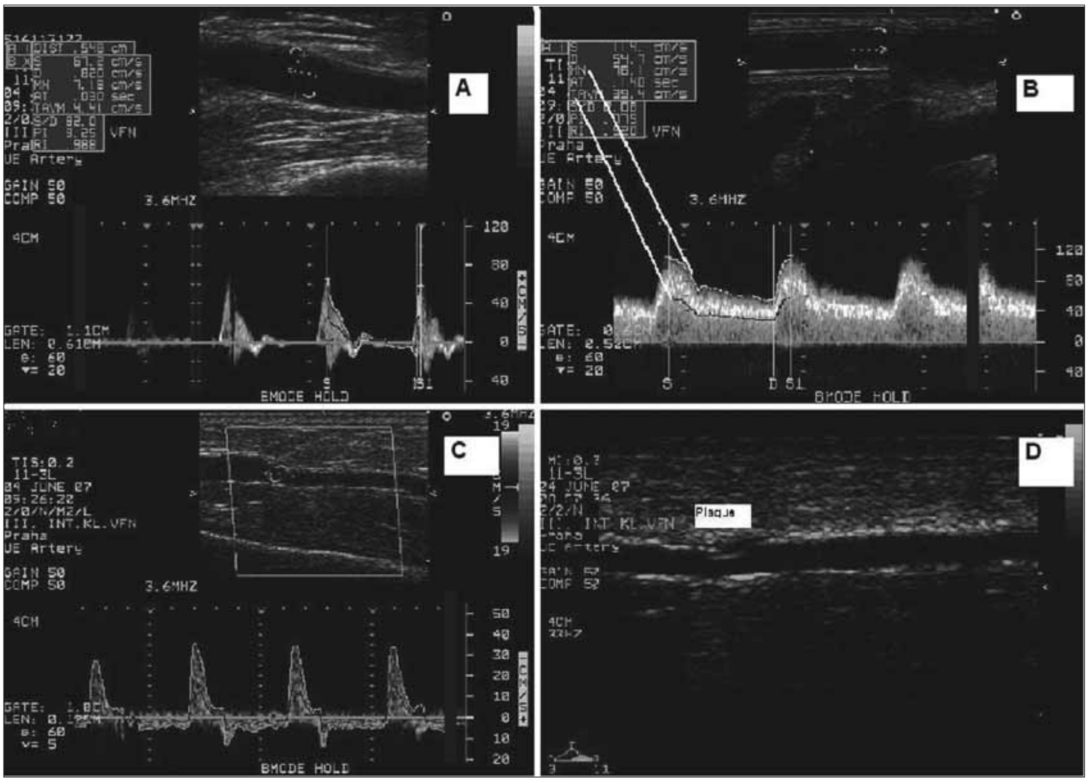

Fig. 6 - ***The intima/media complex is depicted in panel A for a normal brachial artery. The lower aspect exemplifies the Spectral Doppler for this high resistant flow situation i.e. fast during systole and near-to-zero during end-diastole, referred to as being tri-phasic. When this type of flow is recorded in the feeding artery of an established access, the access is usually completely obliterated. Panel B represents a low-resistant spectral Doppler curve at the venous anastomosis of a PTFE graft, with little difference between systolic and diastolic velocity and mono-directional flow during the whole cardiac cycle, which is typical for the low resistant flow seen in the feeding artery, graft and outflow vein of a normal dialysis access.***
Panel C illustrates bi-directional flow that is ante-grade during the systolic and retro-grade in the diastolic phase. This pattern is typical for the radial artery distal to the anastomosis in case of incomplete palmar arches. It is also present when an old abandoned fistula acts as pseudo-aneurysm. Panel D. Using B-mode spectral Doppler, the calcified arterial wall is shown hyper-echoic, which sometimes prevents detailed examination of the arterial lumen. Although usually diffuse, a focal significant stenosis is seen as sudden increase in blood velocity. Also medial calcinosis is often combined with intra-luminal atherosclerotic plaques.

Practical use of duplex Doppler ultrasonography

Abundant ultrasound gel allows minimum pressure to avoid compression of the examined veins, with erroneous access flow calculation. The entire length of the upper extremity arteries, beginning at the subclavian artery to the wrist, is examined by a high frequency (5-15 MHz) B-mode linear probe and by color Doppler mapping. Pulsed color Doppler spectral depicts the direction of flow (i.e. antegrade, retrograde or bi-directional) as well as areas with increased blood velocities suggestive of stenosis. Velocities in stenotic sites are compared with that in adjacent, unaffected segments. The Doppler spectral curve is also used for volume flow calculation and for estimation of the peripheral resistance of the examined artery. The Doppler (co-sinus) angle between the axis of blood flow and the direction of the ultrasound beam affects the Doppler frequency shift, ideally set to 60 degrees or less.

Normal DDU findings

The feeding (inflow) artery of a vascular access is usually dilated, displaying a thin two-layered wall, similar to that seen in the carotid arteries (Fig. 6A). Color Doppler depicts homogenously the arterial lumen. The exception is in the arches or in the serpentine direction of the arteries, where the color (and spectral) Doppler may show up to a 2-fold velocity increase compared to a straight vessel segment, since the blood flows faster along the outer wall of the arch (similar to that in a river meander). In the feeding artery of a vascular access, the spectral Doppler curve is low-resistant with continuously antegrade flow (during the entire cardiac cycle) with little variation between the systolic and diastolic phases (Fig. 6B). Forearm accesses uniformly receive flow from both radial and ulnar arteries. In the case of a radio-cephalic fistula at the wrist, there is low-resistant antegrade flow in the ulnar artery as well as retrograde low-resistant flow in the distal segment of the radial artery (distal to anastomosis). In brachial artery accesses, bi-directional or even retrograde flow is commonly found in the arteries distal to the anastomosis, due to collaterals. The bi-directional flow patterns are antegrade in the systolic phase and retrograde during diastole (Fig. 6C). With the current Doppler technique, DDU evaluation of the hand, the palmar arches and the digital arteries is technically difficult and rarely yields useful information. Likewise, the Allen test, in the authors' opinion, is of little practical value.

Severe arterial calcification (such as in medial calcinosis) limits the diagnostic power of DDU (Fig. 6D).

Assessment of the palmar arches in the prevention of steal

There is no uniformly accepted objective testing to predict and prevent DHIS. Finger pressures and analysis of three Doppler waveform characteristics (pulsatility, diastolic flow directions and oscillations) offer the best assessment (29) (Fig. 7). Currently, this test battery is being used to determine whether the radial artery can safely be excised and used for grafting in a coronary artery bypass procedure. The digit pressure, in this case mainly the thumb, is obtained before and during manual occlusion of the radial and ulnar arteries at the wrist (Fig. 7 C-E). A thumb systolic pressure that drops to half or below 50 mmHg with a digital / brachial artery index (DBI) of <0.65 while occluding the radial suggests incomplete palmar arches and a high likelihood of DHIS after access placement (30-32) (Tab. V). Digital waveform analysis is an integral part of this assessment. Diminished or lack of pulsatility suggests severe arterial stenosis or, in case of dialysis access, significant DHIS (Fig. 7D). Similar criteria likely apply for a dialysis access. Patients being evaluated for HD access placement greatly benefit from digital pressures and waveform analysis to assess the risk for developing DHIS. Likewise, patients with symptoms of steal should undergo finger pressures and waveform morphology evaluation, with and without manual compression of the access (Fig. 7E). All fingers should be examined for pressures and flow curve patterns and compared to non access side.

Current data suggest that a DBI of <0.6 identifies a patient at risk for DHIS. Therefore, a patient with clinical steal should have a post procedural DBI restored to >0.6.

Access flow calculation by ultrasonography. Correctly done, the dialysis access volume flow determination by DDU correlates well with the thermo-dilution technique with less than 10% variation (33). The measurement is ideally obtained in a straight segment with laminar flow characteristics or at least 5 cm away from aneurysms, stenotic lesions, and anastomosis sites. Such segments are usually present in PTFE grafts. Native vein fistula flow is less reliable because of the often abrupt luminal size variations from aneurysmatic formations, and from side branches. These limitations are overcome by measuring the blood flow in the brachial artery above the arterial fistula anastomosis, since only a small portion (likely within the error of measurement) or 50-100 ml / min of blood flow is distributed to the distal limb.

The calculation of flow volume is based on the equation:

$$Q = \pi.r^2 \times TAVM$$

where r = vessel radius and TAVM = time averaged velocity integral of the mean velocity of the parabolic profile layers, as the velocity is higher in the middle of the vessel and slower towards the vessel walls because of friction. $\pi.r^2$ is the transactional lumen area in cm^2. Time averaged mean velocity averages velocity changes during the cardiac cycle (Fig. 6B). Most ultrasound machines have software that automati-

TABLE IV - TESTS TO ASSESS SEVERITY OF DHIS, GUIDING INTERVENTION

- Physical exam (ie inspection, sequential blood pressure, palpable bruit)
- Finger pressures and waveform analysis with and without manual artery and access compression
- Duplex Doppler ultrasonography with blood volume flow estimation in mL / min
- Upper extremity arteriography and fistulogram with simultaneous intervention (i.e. balloon angioplasty of arterial stenosis)
- MRI or CT angiogram to evaluate cases with complex vascular anatomy

TABLE V - PATIENTS AT RISK FOR STEAL

- Female
- Elderly (over 60 years of age)
- Diabetes
- Previous access surgeries in affected limb
- Use of distal brachial artery as anastomosis site
- Thumb pressures of 50 mmHg or less and pathological waveform, when occluding the ulnar artery

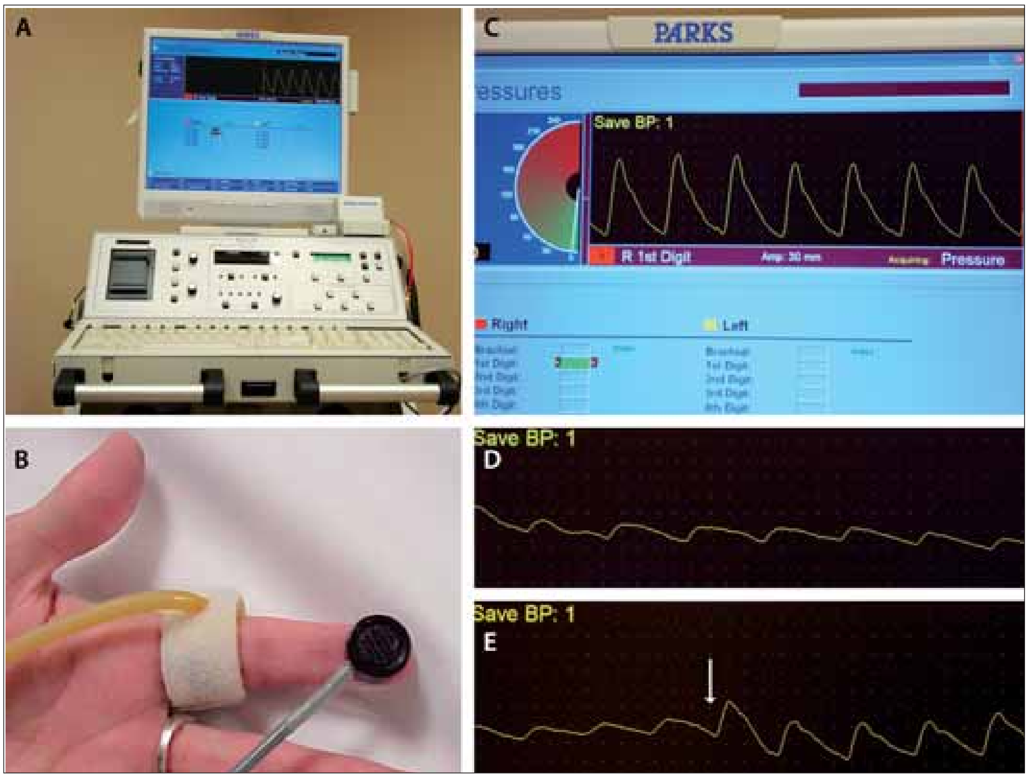

Fig. 7 - *Finger pressure measurements and waveform evaluations are critical components for evaluation of DHIS with recording equipment in the left upper panel (A). A small blood pressure cuff designed for digits and the photopletysmographic sensor are applied to each finger sequentially (B). Panel C depicts normal digit waveforms. The digit pressures and waveforms on the dialysis access side are uniformly lower (D) compared to the non-access extremity or below 50 mmHg or even non-recordable or flat in cases of severe steal. Compression of the dialysis access (at arrow in panel E) of the access will improve the waveform (E) or return it to that similar of the non access extremity.*

cally calculates blood flow after the input of vessel diameter and TAVM. It is customary to average access flow from three separate measurements. The determination of the vessel diameter is the most critical factor for the calculation of access flow. Consistent technique is essential for quality determination.

DHIS caused by arterial occlusive lesions. Arterial flow is directly related to the PP and indirectly to the PVR. This mechanism is maintained in conduit arteries, which supply tissues of the extremity with access. A significant stenosis will cause PP to drop.

Both atherosclerosis and medial calcinosis are associated with stenoses and may be present simultaneously. Atherosclerotic lesions are usually focal and may be present in any part of the extremity arterial tree, with predilection in the subclavian, axillary and brachial arteries. Stenotic lesions are treated by percutanous transluminal angioplasty (PTA). Diffuse medial calcinosis associated with diabetes mellitus affects predominantly distal arteries in the forearm, and prevents physiological arterial dilatation after access creation. PTA is usually technically unsuccessful in treating medial calcinosis. A significant stenotic lesion proximal to the access anastomosis usually causes low access flow (with or without DHIS), while distal occlusive arteries is more likely associated with DHIS.

In B-mode, atherosclerotic plaques are visible as intraluminal masses adjacent to the arterial wall. Their echo-genicity varies. Hypo-echoic plaques are formed mainly from cholesterol and other lipids and have a thin fibrous cap. They are clinically unstable because of the high risk of fibrous cap rupture with subsequent intra-plaque bleeding and sudden increase in the significance of stenosis or even arterial obliteration. Plaques with high echo-genicity contain more fibrous tissue and calcium, cause acoustic shadow below the plaque and are thought to be more stable. Arteries with medial calcinosis are characterized by a diffusely hyper-echoic vessel wall with a thin lumen (Fig. 6D). Acoustic shadows tend to limit the evaluation of the vessel lumen, as is also the case with color Doppler. Focal, significant stenotic lesions within the diffusely thin artery are commonly found (Fig. 6D).

The ultrasound criterion of an hemodynamically significan stenosis is the combination of greater than 50% stenosis in the B-mode and a 2- to 3-fold increase of peak systolic velocity in comparison to a nearby unaffected laminar flow segment. A laminar flow arterial segment is chosen proximal to the stenosis or at least 5 cm distal to the stenosis.

It is recommended to obtain spectral Doppler curves for all examined arteries. In the feeding arteries of a well functioning access, the spectral Doppler reflects low resistance while non-access arteries show high-resistance.

DHIS caused by high access flow. This type of DHIS steal could be explained as disequilibrium between the sum of perfusion arterioles lumina and the arterial anastomosis. In other words, the dilatation of tissue arterioles is not sufficient to compensate for a large anastomosis. By DDU examination, these types of DHIS show near normal anatomic findings of all examined arteries. Dialysis access flow exceeding 2000 mL / min are commonly seen, but only rarely associated with DHIS or congestive (or high output) failure. The authors suggest to obtain an echocardiogram every 6 months in dialysis patients with volume flow of 2000 mL / min or more. If left ventricular dilatation exceeding 60 mm, or a decline in the ejection fraction are present, not responding to medical treatment (such as dry weight correction, diuretics), banding of the hemo-access should be considered.

Special clinical DHIS situations

1. Non-thrombosed aneurysmatic remnants of the old access communicating with the anastomosis may contribute to DHIS, even with no or minimal remaining blood flow. This is prone to happen when severe forearm and hand arteries occlusive disease is present (ie medial calcinosis). Blood flows in during systole and out during diastole resulting in decreased pressure and flow to the hand. DDU with finger pressures and waveform analysis will define this condition. Treatment consists of excising, and excluding the aneurysm.
2. Retrograde flow in the artery distal to the fistula anastomosis is commonly seen with wrist radiocephalic AVFs. This retrograde flow significantly contributes to the fistula flow when true steal exists. In cases with steal symptoms requiring correction, ligation of the (radial) artery distal to the anastomosis is the appropriate intervention, after having confirmed a patent ulnar artery and palmar arches (ie thumb Allen digit pressure) as well as the absence of inflow arterial occlusive disease.
3. In cases with severe arterial occlusive disease distal to the fistula anastomosis the ligation step may not be necessary as part of the DRIL procedure, making surgery less invasive. The native artery continuity distal to the fistula anastomosis is already lost, and the ligation step therefore accomplished by the disease process. In fact the DRIL procedure may not be technically possible because of no usable artery for anastomosis, a circumstance becoming more common in the elderly and diabetic ESRD population.
4. In cases where steal is expected or predicted (Tab. V) a "preemptive" proximalization (PAI) may be advised by using brachial artery as access inflow close to the axilla.
5. Patients who exhibit steal symptoms only during dialysis treatment represent a subgroup of DHIS that may not require surgical intervention but rather BP medication modification. The etiology is likely related to dialysis induced BP drop and a decrease in cardiac output resulting in temporary hypoperfusion. Omitting or decreasing BP medication in the morning of dialysis treatments usually improves symptoms.
6. Balloon angioplasty sometimes induces steal symptoms after successful dilatation of a severe access stenosis resulting in markedly increased flow. After excluding distal embolization with DDU and finger pressures, these rare cases are managed as any other patient with DHIS.
7. Cases of dual upper arm arteries, which represents a high brachial artery bifurcation, brings two important dialysis issues to light. First, if the smaller (radial) artery is used, the access is more likely to fail from poor inflow, or lack of maturation (10). Secondly, with two arteries the collateral flow from the artery not used constitutes a "partial" DRIL procedure (without the distal artery ligation), a situation likely to prevent steal to occur.

ACKNOWLEDGEMENT

J.M., V.T., M.S. and Z.K. are supported by the Grant NR 8334 of the Internal Grant Agency, Ministry of Health, Czech Republic.

Conflict of interest statement: none declared.

Address for correspondence:
Jan Malik, MD, PhD
3rd Dept of Internal Medicine, VFN
U nemocnice 1
12808 Prague 2
Czech Republic
malik.jan@vfn.cz

REFERENCES

1. Tordoir JHM, Dammers R, van der Sande FM. Upper extremity ischemia and hemodialysis vascular access. Eur J Vasc Endovasc Surg 2004; 27: 1-5.
2. 2007 USRDS Annual Data Report. http://www. usrds.org.
3. Wixon CL, Hughes JD, Mills JL. Understanding strategies for the treatment of ischemic steal syndrome after hemodialysis access. J Am Coll Surg 2000; 191: 301-10.
4. Berman SS, Gentile AT, Glickman MH, et al. Distal revascularization-interval ligation for limb salvage and maintenance of dialysis access in ischemic steal syndrome. J Vasc Surg 1997; 26: 393-404.
5. Morsy AH, Kulbaski M, Chen C, Isiklar H, Lumsden AB. Incidence and characteristics of patients with ischemia after hemodialysis access procedure. J Surg Res 1998; 74: 8-10.
6. DeCaprio JD, Valentine RJ, Kakish J, Awad R, Hagino RT, Clagett GP. Steal syndrome complicating hemodialysis access. Cardiovasc Res 1997; 5: 648-53.
7. Moe SM, Chen NX. Pathophysiology of vascular calcification in chronic kidney disease. Circ Res 2004; 95: 560-7.
8. Wedgewood KR, Wiggins PA, Guillou PJ. A prospective study of end-to-side vs. side-to-side arteriovenous fistulas for haemodialysis. Brit J Surg 1984; 71: 640-2.
9. Davidson IJ, Chan D, Dolmatch B, et al. Duplex ultrasound evaluation for dialysis access selection and maintenance: a practical guide. J Vasc Access 2008; 9: 1-9.
10. Dember LM, Beck GJ, Allon M, et al. Dialysis Access Consortium Study Group. Effect of clopidogrel on early failure of arteriovenous fistulas for hemodialysis: a randomized controlled trial. JAMA 2008; 299: 2164-71.
11. Tuka V, Slavikova M, Svobodova J, Malik J. Diabetes and distal access location are associated with higher wall shear rate in feeding artery of PTFE grafts. Nephrol Dial Transplant 2006; 21: 2821-4.
12. Furchgott RF, Zawadzki JV. The obligatory role of endothelial cells in the relaxation of arterial smooth muscle by acetylcholine. Nature 1980; 288: 373-6.
13. Tronc F, Mallat Z, Lehoux S, Wassef M, Esposito B, Tedgui A. Role of matrix metalloproteinases in blood flow-induced arterial enlargement: interaction with NO. Arterioscler Thromb Vasc Biol 2000; 20: e120-6.
14. Kwun KB, Schanzer H, Finkler N, et al. Hemodynamic evaluation of vascular angioaccess procedures for hemodialysis. Vasc Surg 1997; 13: 170-7.
15. Leon C, Asif A. Arteriovenous access and hand pain: the distal hypoperfusion ischemic syndrome. Clin J Am Soc Nephrol 2007; 2: 175-83.
16. Zanow J, Kruger U, Scholz H. Proximalization of the arterial inflow: a new technique to treat access-related ischemia J Vasc Surg 2006; 43: 1216-21.
17. Odland MD, Kelley PH, Ney AL, Andersen RC, Bubrick MP. Management of dialysis associated steal syndrome complicating upper extremity arteriovenous fistulas: use of intraoperative digital photoplethysmography. Surgery 1991; 110: 664-9.
18. Murray BM, Rajczak S, Herman A, Leary D. Effect of surgical banding of a high-flow fistula on access flow and cardiac output: intraoperative and long-term measurements. Am J Kidney Dis 2004; 44: 1090-6.
19. Mattson WJ. Recognition and treatment of vascular steal secondary to hemodialysis prostheses. Am J Surg 1987; 154: 198-201.
20. Shemesh D, Mabjeesh NJ, Abramowitz HB. Management of dialysis access-associated steal syndrome: use of intraoperative duplex scanning for optimal flow reduction. J Vasc Surg 1999; 30: 193-5.
21. Chemla ES, Morsy M, Anderson L, Whitemore A. Inflow reduction by distalization of anastomosis treats efficiently high-inflow high-cardiac output vascular access for hemodialysis. Semin Dial 2007; 20: 68-72.
22. Ebeid A, Saranchak HJ. Banding of a PTFE hemodialysis fistula in the treatment of steal syndrome. Clin Exp Dial Apheresis 1981; 5: 251-7.
23. Knoz RC, Berman SS, Huges JD, Gentile AT, Mills JL. Distal revascularization - interval ligation: a durable and effective treatment for ischemic steal syndrome after hemodialysis access. J Vasc Surg 2002; 36: 250-6.
24. Berman SS, Gentile AT, Glickman MH, et al. Distal revascularization-interval ligation for limb salvage and maintenance if dialysis access in ischemic steal syndrome. J Vasc Surg 1997; 26: 393-404.
25. 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 1988; 7: 770-3.
26. Miller GA, Khariton K, Kardos SV, Koh E, Goel N, Khariton A. Flow interruption of the distal radial artery: treatment for finger ischemia in a matured radiocephalic AVF. J Vasc Access 2008; 9: 58-63.
27. Davidson IJA. Access for dialysis: surgical and radiologic procedures, 2nd edn. Georgetown, Tx, USA: Landes Bioscience, 2002.
28. Malik J, Slavikova M, Maskova J. Dialysis access-associated steal syndrome: the role of ultrasonography. J Nephrol 2003:15: 903-7.
29. Goff CD, Sato DT, Bloch PH, et al. Steal syndrome complicating hemodialysis access procedures: can it be predicted? Ann Vasc Surg 2000; 14: 138-44.
30. Valentine RJ, Bouch CW, Scott DJ, et al. Do preoperative finger pressures predict early arterial steal in hemodialysis access patients? A prospective analysis. J Vasc Surg 2002; 2: 351-6.
31. Papasavas PK, Reifsnyder T, Birdas TJ, Caushaj PF, Leers S. Prediction of arteriovenous access steal syndrome utilizing digital pressure measurements. Vasc Endovasc Surg 2003; 37:179-84.
32. Nguyen LL, Owens CD. Use of digital pressure measurements for the diagnosis of AV access-induced hand ischemia. Vasc Med 2006;.11: 227-31.
33. Malik J, Slavikova M, Malikova H, Maskova J. Many 0clinically silent access stenoses can be identified by ultrasonography. J Nephrol 2002; 15: 661-5.