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Arteriovenous Access: Infection, Neuropathy, and Other Complications

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Abstract

Complications of vascular access lead to morbidity and may reduce quality of life. In this module, we review both infectious and noninfectious arteriovenous access complications including neuropathy, aneurysm, and high-output access. For the challenging patients who have developed many complications and are now nearing their last vascular access, we highlight some potentially novel approaches.

Abrégé

Les complications encourues après la création d'un accès vasculaire entraînent de la morbidité article pour le patient et peuvent contribuer à la diminution de sa qualité de vie. Dans ce chapitre, nous examinons les possibles complications artérioveineuses infectieuses et non infectieuses liées à l'accès vasculaire. La neuropathie, la rupture d'anévrisme et le débit sanguin élevé dans l'accès vasculaire sont notamment abordés. De plus, nous mettons l'accent sur des approches innovantes qui pourraient être utilisées pour les cas complexes de patients ayant développé plusieurs complications, et qui ont peu de sites potentiels pour la création de nouveaux abords vasculaires.

Keywords

arteriovenous access infection, neuropathy, carpal tunnel, ischemic monomelic neuropathy, ischemic steal, aneurysm, pseudoaneurysm, high-flow access, high-output cardiac failure

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In this, we review both infectious and noninfectious arteriovenous (AV) access complications including neuropathy, aneurysm, and high-output access. For the challenging patients who have developed many complications and are now nearing their last vascular access, we highlight some potentially novel approaches.

Arteriovenous Access Infection

Definitions

Systemic infection involves presence of bacteremia in association with evidence of infected AV access.

Localized infection refers to cellulitis (without bacteremia), postoperative incision infection, and abscess or infected exudate associated with the AV access.

Incidence of Arteriovenous Access Infection

Fistula tend to have a low incidence of infection at a rate of 0.2 to 0.4 per 1000 fistula days, compared with grafts, which are typically 10-fold higher (1-2 per 1000 fistula days[1,2]). Risk factors for fistula infection include poor patient hygiene, diabetes, skin excoriations, and buttonhole cannulation (See Access Cannulation section in MacRae et al ref) from arteriovenous vascular access selection and evaluation. The main bacterial organisms for fistula infection are *Staphylococcus aureus* and *Staphylococcus epidermidis.*[2]

Risk factors for graft infection include poor patient hygiene, diabetes, older age, femoral site of placement, and history of bacteremia.[1] Graft infections can occur at any time, but the majority of them occur within 1 month after placement.[1] Common bacterial organisms for graft include *S*

aureus, *S epidermidis*, *Streptococcus viridans*, and *Pseudomonas aeruginosa*.

Graft infections and fistula buttonhole infections have grave manifestations including septic complications.[3] Furthermore, infection associated with a graft is difficult to eradicate and usually leads to loss of the access.

i. Symptoms: Fever, chills, rigors, malaise. Occult buttonhole infections in fistula or occult graft infections (even in abandoned grafts) should be considered in patients who present with fever of unknown origin.
ii. Signs: Patients may present with a localized cellulitis or erythema at the access site. An abscess at the needle site can occur with buttonhole cannulation in a fistula. If the skin integrity appears compromised (necrotic patch or shiny, thin skin) at a buttonhole site, then a surgical consult is required. Signs of graft tenderness or exudate, even in the absence of fever, could indicate an underlying access infection. The most common presentation of an infected graft is that of a draining sinus tract (45% of all graft infections) followed by purulent drainage (12%).[3] A surgical consult is also necessary for any suspected graft infection.
iii. Special tests: Two sets of blood cultures should be drawn; if there is any exudate at the access site (especially at a buttonhole site), then a swab for culture and sensitivity should be sent. A white blood cell scan could be ordered for individuals with a suspected occult AV access infection.

Treatment

i. Antibiotics: The recommended treatment for an infected fistula without fever or bacteremia is 2 weeks. The treatment duration for an infected fistula with bacteremia is a minimum of 4 weeks with an extension to 6 weeks in the case of *S aureus*. Blood cultures and sensitivities should always be reviewed in order to guide antibiotic choice. An infected buttonhole site should be treated for a minimum of 4 weeks even in the absence of any bacteremia given the high risk of *S aureus* bacteremia. There should be a low threshold for investigation for septic emboli or complications in any *S aureus* bacteremia, including a transthoracic 2-dimensional cardiac echo to rule out endocarditis.
ii. The recommended treatment for graft infection is for 4 to 6 weeks of antibiotics after the whole or the infected portion of the graft has been removed. Double coverage for both gram-positive and gram-negative organisms is suggested until confirmation of organism occurs.
iii. Surgery: Surgical revision or excision of a fistula may be required if the access fails to respond to medical management. However, a surgical consult is mandatory when dealing with graft infections. Depending on the extent of infection, the surgeon may choose to resect either the entire graft or a portion of the graft. An infection involving the anastomosis is an indication for the complete excision of the graft.[4]

Prevention of Arteriovenous Access Infection

All patients should be instructed to wash their access arm upon entry into the hemodialysis unit. In addition, clean gloves and antiseptic solution such as chlorhexidine with 70% alcohol is used to disinfect the skin prior to needling. For patients with buttonhole cannulation, extra precautions should be taken including the use of a face mask for needling and the use of topical antibiotics after needle removal.[5] It is critical for nurses to follow strict infection-prevention protocols, and routine audits should be carried out.

Neuropathy

Temporary digital and hand numbness and tingling can occur following AV access surgery due to soft tissue swelling or hematomas compressing on nerves. This typically resolves within 4 weeks. If not, the following neuropathies should be considered.

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Carpal Tunnel

The most common neuropathy is due to median nerve compression at the wrist from carpal tunnel syndrome. Clinical features of median nerve entrapment consist of pain, numbness, and tingling in the median nerve distribution to the palm. The pain component is often greatest in the nocturnal hours and usually worsens during dialysis. Atrophy and weakness of the ulnar muscles clinically manifest as inability to pinch between the thumb and index finger. Motor dysfunction is a late but more specific finding and suggests a less complete or prolonged recovery.

Access creation may worsen preexisting neuropathy, and in fact, Carpal tunnel syndrome is more common among hemodialysis patients (in up to 9%[6]) than among the general population. Reasons include increased number of patients with diabetes, uremia, beta-2 microglobulin accumulation, and the presence of an AV access. The risk of carpal tunnel is higher on the side of the AV access than in the non-AV access arm.[7] AV access can increase the risk of carpal tunnel via the presence of hematoma, pseudoaneurysm, edema, venous hypertension in the flexor retinaculum, or steal.

An important and immediate distinction to be made is whether the symptoms are due to ischemic steal or a compression neuropathy.

i. Symptoms: Symptoms can include pain or numbness of the hand (usually the thumb and first 2 fingers), pain in the forearm or shoulder, or weakness of the thumb. Carpal tunnel symptoms should be differentiated from other causes of neuropathy in patients with AV access such as steal or ischemic monomelic neuropathy (IMN) as the treatment approach is widely different.
ii. Signs: Rarely a positive Tinel's or Phalen's sign is present. There may be muscle wasting in the hand or forearm if the syndrome is present for long periods of time.
iii. Special tests: Nerve conduction testing can be organized to confirm the diagnosis.

Treatment. A conservative approach is recommended for patients with mild symptoms. Elimination of the activities that worsen the symptoms is recommended along with wearing a wrist splint when symptoms are the worst, eg, at nighttime or on hemodialysis. If the symptoms progress despite the conservative approach, then a referral for surgical decompression is recommended. Ligation of the AV access may or may not be associated with improved symptoms.

Ischemic Monomelic Neuropathy

IMN is caused by infarction of the vasa nervosa and generally occurs very quickly after access creation.[8]

i. Symptoms: IMN is characterized by its involvement of all 3 forearm nerves leading to pain, weakness, and sensory changes in an otherwise warm hand. Patients note a deep, burning discomfort in the hand which is continuous and persistent. Sensory impairment is most prominent distally, with pain, paresthesias, and numbness in the distribution of all 3 forearm nerves.
ii. Signs: The motor features include weakness or paralysis of the muscles innervated by the 3 forearm nerves: radial, median, and ulnar nerves. Thus, patients may have a wrist drop or have difficulty with wrist and finger extension (radial nerve), or difficulty with abduction and adduction of the extended fingers (ulnar nerve) or difficulty with thumb opposition, flexion, and abduction (median nerve). The end result is a claw-hand deformity with profound loss of function and severe neuropathic pain.

Treatment. Once IMN is suspected, the AV access should be sacrificed immediately in order to improve the chance of neurologic recovery.

Steal

Ischemic steal syndrome or dialysis-associated ischemic steal syndrome is defined as hand or finger pain caused by the hypoperfusion of the hand distal to the AV access. The prevalence of symptomatic steal varies from 0.25% to 20% and appears to depend on the location of the anastamosis.[9,10] Forearm AV accesses have a low incidence of symptomatic steal, ranging from 0.25% to 1.8%. Severe symptomatic arterial steal syndrome is most frequently associated with a brachial arterial source (high flow), with a frequency of 4% to 9%.[9] Most recent large retrospective studies indicate that an operative intervention for steal occurs in about 4% of all patients after vascular access surgery.[10]

Risk factors for steal overall include diabetes, female gender, smoking, upper arm fistula, peripheral arterial disease, prior AV access in same limb, and advanced age.

The diagnosis of ischemic steal syndrome is predominantly clinical and is based on history and physical exam. It is important to consider that there is a differential diagnosis of the patient presenting with numbness or pain of the hand including IMN, focal neuropathy, and generalized neuropathy.

There are 3 stages of steal, ranging from mild (stage 1) to severe (stage 3).[11]

- Stage 1 is associated with a cold, pale or blue hand.
- Stage 2 has pain with exercise or on hemodialysis.
- Stage 3 is complicated by rest pain and/or ulcers, necrosis, or gangrene of the fingertips or hand. Individuals with rest pain should also be investigated

for possible carpal tunnel as there can be significant overlap.

i. Symptoms: Pain, duskiness of hand, coolness, paresthesias, and paralysis of hand. Symptoms may be present all the time, or just occur/worsen with dialysis. The onset can occur acutely (ie, immediately after access creation) or be more insidious—occurring over subsequent days to weeks to months.
ii. Signs: Pallor, abnormal sensory or motor function, cool to touch, and decreased or absent radial pulse. There may be a relative decrease in oxygen saturation on affected hand. If advanced, digital ulceration or gangrene can occur.
iii. Special tests: An early referral to surgery is recommended for patients with suspected steal. The appearance of a radial pulse upon occlusion of the AV access during the physical exam may indicate that the AV access is stealing too much blood away from the distal circulation.[11] Noninvasive vascular laboratory studies such as digital blood pressures, digital-brachial index, duplex ultrasonography, and transcutaneous oxygen saturation are helpful to evaluate the patient with potential arterial steal.[12-14]

Treatment of steal. Mild, stage 1, steal can often be managed with conservative measures including keeping the hand warm. For moderate-to-severe steal, stages 2 and 3, an underlying arterial inflow lesion should be ruled out, as these can contribute to the steal syndrome. Patients with distal severe small vessel disease can experience steal in the absence of excessive access flow. In such patients, digital pressures do not normalize with compression of the access. Surgery should be considered for patients with stage 3 steal.

Surgical options. There are several surgical options for the treatment of ischemic steal which include the following:

i. Distal revascularizations–interval ligation (DRIL)

The procedure includes ligation of the artery distal to the AV access anastomosis to eliminate flow reversal. An antegrade bypass is also created originating 7 to 10 cm proximal to the arterial anastomosis, in a more normal section of artery, with the distal anastomosis distal to the ligated artery.[15] In a study of 134 DRIL procedures,[14] there was an 85% success rate, measured by continued access use, and 82% of patients achieved symptom resolution.

ii. Revision using distal inflow (RUDI)

The RUDI technique is preferred to the DRIL procedure because the artery is not disrupted. It involves the relocation of the access anastomosis to a smaller, more distal artery (eg, from the brachial to the proximal radial artery), thereby theoretically allowing antegrade flow in the ulnar artery and decreasing the size of the AV anastomosis.[14-16] This procedure results in a 50% reduction in access flow.[17]

iii. Proximalization of arterial inflow

Proximalization of the arterial inflow (PAI) is a useful alternative for both low-flow and high-flow steal.[15,18] The procedure involves ligation of the cephalic (fistula) vein near the preexisting AV access anastomosis. A graft is then placed from the proximal artery (axillary artery for a brachiocephalic fistula and brachial artery for a radiocephalic fistula) to the cephalic vein. Blood flow to the original AV access is restored through an interposition vein graft or small-diameter (4 to 5 mm) prosthetic graft. The major advantage of proximalization is the preservation of arterial anatomy. Thermann and Wollert[18] report a 65% success rate for disappearance of steal symptoms, 26% improvement in symptoms, and 9% with persistent symptoms after the PAI procedure. The secondary patency rate was 85% at 18 months.

iv. Flow-limiting procedures

The various banding or flow-limiting procedures involve creating a stenosis in the AV access near the arterial anastomosis, which increases the venous outflow resistance through an AV access, thereby improving the distal arterial flow. These various methods can include suturing and prosthetic wraps. The advantages are potential salvage of the access and a minimally invasive intervention. One of the disadvantages is the difficulty in determining how much to narrow the access to restore distal flow without endangering the patency of the access. Thrombosis is relatively common after these procedures and reported as 5.6% for RUDI and 11% for banding.[19] Another disadvantage is that the flow often rebounds to previous levels in a relatively short period of time. However, flow reduction using intraoperative access flow monitoring was found to be an effective and durable technique allowing for the correction of distal ischemia in high-flow autogenous access.[14,20]

Another variant on banding is the MILLER procedure: the Minimally Invasive Limited Ligation Endoluminal-Assisted Revision has been used for the treatment of steal.[21] This modification uses a 4 to 5 mm endoluminal balloon placed percutaneously to achieve more uniform banding.

v. Ligation

Patients with distal radial-cephalic AV accesses can develop hand ischemia. In this case, retrograde flow through the intact palmar arch results in inadequate digital flow. Ligation or embolization of the distal radial artery has been shown to correct the ischemia in this uncommon situation. In general, ligation will result in loss of the access and should be considered when surgical revision techniques are not feasible.[15]

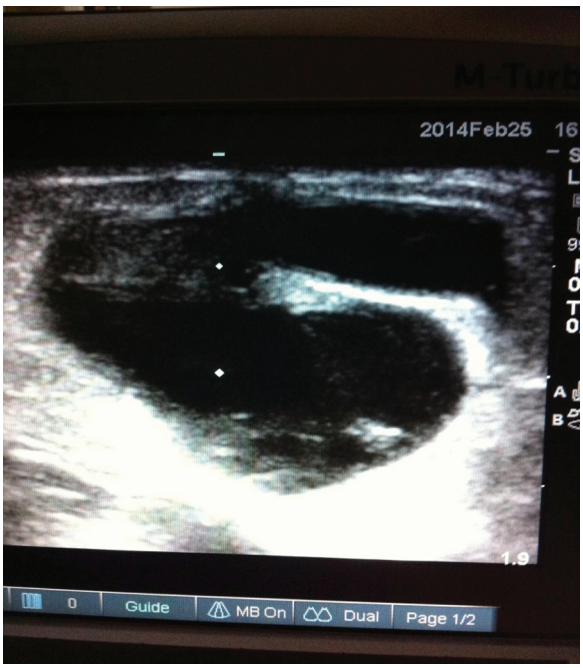

Figure 1. Pseudoaneurysm from miscannulation.
Source. Photo courtesy of J. MacRae.

Aneurysm

The incidence of aneurysm in fistulas ranges from 0% to 10%.[22] Aneurysms can be true aneurysms involving all layers of the venous wall or false (pseudo) aneurysms involving fibrous tissue and thrombus. Complications can include skin erosion, infection, thrombosis, inability to dialyze, and rupture (sometimes leading to exsanguination). These aneurysms may be associated with hemodynamically significant stenosis.

Pathophysiology of true aneurysms can occur due to repeated needling of the same sites or repeated dilatation of recurrent stenoses—both of which result in degenerative changes in the vessel walls causing dilatation. Increased blood flow in the arterialized vein can also contribute, as can stenosis in the draining vein or central vein (by increasing the pressure).

Pathophysiology of pseudoaneurysms usually forms after damage to the vessel wall after cannulation mishaps—often with synthetic grafts. Mishaps occur when they are repeatedly needled in the same area[22,23] (see Figure 1).

Prevention. The most important point is adherence to needling guidelines—rotation of needling sites and avoidance of needling areas of aneurysmal dilatation. There may be a role for buttonhole cannulation to decrease aneurysm size[24] and prevent further fistula diameter growth.[25] For a discussion of the relative merits of buttonhole technique, see "Needle Technique Options" section in MacRae et al.[26]

Monitoring. Aneurysms should be closely monitored at every hemodialysis session for any concerning signs such as: thinning of the skin, ie, skin takes on a shiny translucent appearance (see http://esrdncc.org/wp-content/uploads/2015/12/Access-Atlas.pdf), a necrotic skin patch, or rapid enlargement. Routine documentation of the maximal length and width of the aneurysm on a regular basis is recommended. A stable aneurysm without any of the above concerning characteristics should be monitored.

Treatment

Endovascular. Endovascular stent graft repair has been reported in the setting of pseudoaneurysm management as a minimally invasive option that permits immediate use of the AV access postintervention.[23] About 50% of these patients also had concomitant balloon angioplasty of outflow stenoses. This report is limited by its small sample, short follow-up time (269 days) and the use of stent grafts that had not been approved for this indication.[23] The use of stent grafts for any type of intervention in an AV access is off label in North America with the exception of 1 type of stent graft that is only approved for use at the venous anastomosis of a graft.[27]

Surgery. The following options can be considered:

i. Pseudoaneurysm resection with interposition graft placement. A tunneled central venous catheter is needed as a bridge access for dialysis until the new graft is ready for use.
ii. Partial aneurysmectomy and reduction venoplasty of dilated venous segments involve excision of excess aneurysmal wall and reduction of the venous luminal diameter. In cases of extensive dissection, a temporary catheter access may be needed.[28]
iii. Ligation—results in loss of access.

Access Flow and Heart Failure

High-Flow Access

The flow rate of a fistula and graft varies according to their location with typical flows of 600 to 1000 mL/min in the forearm and 1200 to 1500 mL/min in the (upper) arm.[29,] Expert opinion suggests that AV access flows greater than 2 L/min are generally considered to be high. The estimated prevalence of high-flow fistulas ranges in the literature from 9% to 20% of hemodialysis patients.[31] The risk factors for developing high-flow fistula include young age, male sex, upper arm access,[29] and previous access surgery.

Typically, an AV access requires about 20% of the cardiac output (similar to the native kidneys in the absence of kidney failure). Studies show that the access flow to cardiac output ratio (Qa:CO) is normally in the range of 17% to 23%.[30,31] When the Qa:CO increases beyond this standard range, the risk of heart failure increases.[30,32] Basile et al[30] explored the relationship between access flow and cardiac output in a

group of 96 hemodialysis patients. They found that among the subset of patients with symptoms of heart failure and structural heart disease (n = 10), the mean access flow was 2.3 L/min and mean Qa:CO was 25%.

High-Output Cardiac Failure

High-output cardiac failure is defined by the presence of symptoms of heart failure symptoms (shortness of breath, reduced exercise tolerance, peripheral or pulmonary edema) in the presence of an elevated cardiac index (≥3 L/min^2) and low systemic vascular resistance.

The contribution of the fistula to heart failure is likely underrecognized. There are case reports of high-output cardiac failure caused by high-flow grafts,[33] but prospective controlled studies of the contribution of AV access to cardiac geometric changes and clinical outcomes are lacking.

Most patients tolerate the increased cardiac output and increased oxygen demand caused by fistula creation through various cardiac adaptations that increase filling pressures and cardiac performance. However, patients with underlying ischemic or valvular heart disease may not be able to sustain the cardiac remodeling requirements, making them more susceptible to developing heart failure. It is thought that higher flow fistulas probably have a bigger impact on cardiac remodeling, which places the patient at a higher risk of developing high-output heart failure.

Diagnosis

i. Symptoms: Heart failure symptoms of shortness of breath, decreased exercise tolerance, and edema. These symptoms improve when the AV access flow is reduced or obliterated. A careful history regarding timing of onset of these symptoms in relation with access creation must be obtained.
ii. Signs: Elevated heart rate, widened pulse pressure, increased jugular venous pressure, abnormal hepatojugular reflex, S3, edema, and an enlarged often aneurysmal fistula, usually in the upper arm. A bounding arterial pulse indicating elevated left ventricle stroke volume may be present along with Traube's sign (pistol shots in the femoral artery) and Quincke's pulse (pulsations in capillary beds of the fingers).
iii. Special tests: Serial echocardiograms showing decreasing left ventricle, LV function and progressive increase in LV dilatation over time. The ultrasound dilution technique should be used to determine both the access flow (>2 L/min) and the cardiac output (CO > 5 L/min). An access flow: CO ratio (Qa:CO) greater than 25% (normal is around 20%) may be associated with increased risk of high-output cardiac failure.[30,31,34]

Treatment. The main treatment options revolve around reducing the flow[35] through the AV access; there are several techniques available such as RUDI, flow-limiting procedures, and access ligation (see "Treatment of Steal" section).

Summary

- In patients in whom high-output cardiac failure is considered, a detailed cardiac history and symptoms should be obtained.
- A baseline echo or cardiac magnetic resonance imaging should be done to evaluate the left atrial and left ventricle chamber size as well as the right ventricle chamber size and degree of pulmonary hypertension (see Hemodynamics of Fistula Creation section in MacRae et al ref Arteriovenous Vascular Access Selection and Evaluation reference).
- An access flow of > 2 L/min is considered to be high flow.
- In cases of suspected high-output cardiac failure, a baseline access flow/cardiac output (Qa:CO) ratio should be done. Qa:CO > 25% is considered high.
- Refer for flow reduction surgery if there are concerns of heart failure or if Qa:CO is increasing.
- Prospectively follow patients with high-flow fistulas with annual serial echocardiograms to track for any progression in left ventricle dilation, worsening left ventricle hypertrophy, decreasing left ventricle function, or the development of pulmonary hypertension.

Last Access Options

There are a limited number of potential vascular access sites; therefore, it is important to be aware of atypical access options and their outcomes for the patients that have developed access complications. Table 1 lists some nonconventional fistula and graft sites as well as atypical catheter locations. For patients who have central vein obstruction and no further upper arm fistula or graft conventional options, consideration for placement of a lower extremity graft or a hybrid catheter-graft device is often the next step.

Unconventional Fistula

Upper extremity: Forearm options. While most conventional forearm fistula utilize the superficial cephalic vein, its medial counterpart, the basilic vein, can also provide an adequate venous outflow. Using the ulnar or radial artery and anastomosing with the basilic vein in the forearm was first described over 40 years ago.[37] The use of radial/ulnar–basilic fistula has had limited uptake due to perceived low patency rates, long maturation times, and potential discomfort due to patient position during hemodialysis.

Maturation rates of 36% were reported in a series of 52 forearm ulnar-artery–basilic-vein fistulas, with 17% requiring further surgical revision.[38] The primary and secondary patency rates at 1 year were 43% and 54%, respectively.[38]

Table 1. Atypical Locations of Fistulas, Grafts, and Central Venous Catheters.

Fistula	Upper extremity	Ulnar artery-basilic vein
		Radial artery-basilic vein
		Brachial artery-median cubital vein
		Brachial artery-brachial vein
		Brachial artery-basilic vein
		Axillary artery-axillary vein
	Lower extremity	Tibial artery-saphenous vein
		Femoral artery-saphenous vein
		Popliteal artery-femoral vein
		Popliteal artery-saphenous vein
		Dorsalis pedis-saphenous vein
Graft	Upper extremity	Axillary artery-axillary vein ("necklace")
		Subclavian artery-subclavian vein
		Brachial artery-internal jugular vein
		Axillary artery-femoral vein
		Axillary artery-popliteal vein
	Lower extremity	Femoral artery-femoral vein
		External iliac artery-external iliac vein
		Superficial femoral artery-femoral vein ("adductor loop")
		Femoral artery-contralateral femoral vein ("bikini")
		Iliac artery-inferior vena cava
Catheter	Upper body	External jugular vein
		Translumbar
		Transhepatic
	Lower extremity	Femoral
		Saphenous

Shintaku et al[39] report more favorable secondary patency rates of 85% at 1 year among 29 ulnar-basilic fistulas. The best patency rates for ulnar-basilic fistula are by Salgado et al,[40] with primary and secondary patency rates at 1 year being 71% and 78%.

Radial-artery–basilic-vein fistulas have been described in isolated case reports or lumped into retrospective surgical series which include ulnar-basilic fistulas. Patency rates are similar to ulnar-basilic fistulas, with primary 1-year patency rates of 50%.[41]

Upper extremity: Upper arm options. The brachial-artery–basilic-vein transposed fistula is increasingly becoming a conventional option and is associated with better maturation and patency outcomes than the forearm options described above. Whether the transposition is carried out at the time of brachial-artery–basilic-vein anastomosis (single stage) or whether it is carried out at a later time once the basic vein is matured (2 stage) does not seem to have significant impact on patency outcomes.[42-44] Maturation rates tend to be high with a primary 1-year patency rate around 68%, and secondary 1-year patency rates of 70% to 80% depending on the series.[42,43,45]

The brachial artery can also be anastomosed to the brachial vein and subsequently transposed. The outcomes vary in the literature with smaller series reporting maturation rates of 65% and 1-year primary patency rates of 46%.[46] Dorobantu et al[47] report a maturation rate of 82% and a secondary patency rate at 14 months being 70%. The complication of arm swelling, however, is a concern with these types of fistulas, affecting 36% of patients.[48]

The use of the median antecubital vein has been described for brachial-artery–median-antecubital-vein and radial-artery–median-antecubital vein fistulas.[49,50] In addition, the axillary-artery–axillary-vein fistula has been described,[51] but data on outcomes are limited for these types of fistulas.

Lower extremity: Thigh. The largest lower extremity vein, the femoral vein (and its closely related superficial femoral vein), can be anastomosed with the femoral artery for fistula creation. The femoral artery-femoral vein fistula has 1-year primary patency rates around 90% and secondary patency rates 80%.[52,53] Unfortunately, given the high-flow nature of femoral artery and vein, up to 20% of these fistulas develop ischemic complications requiring fistula ligation. Femoral-artery–superficial-femoral-vein fistulas[54] and popliteal-artery–femoral-vein fistulas have been described, but outcome data are limited.[55]

The medially located saphenous vein is a potential venous outflow for lower extremity fistula creation. Femoral-artery–saphenous-vein fistulas, created from transposing the saphenous vein across the anterior thigh, have been described in 42 patients with a 1-year primary and secondary patency of 70% and 80%, respectively.[56] The saphenous vein is smaller than the femoral vein, and in keeping with this, no ischemic complications were reported. A second study of 7 patients showed mean primary and secondary patency of 7 months and 16 months, respectively. Similarly, there were no ischemic complications.[57] Popliteal-artery–saphenous-vein fistulas have also been described, but lack long-term outcome data.[58]

Distally, posterior-tibial-artery–saphenous-vein fistulas and the dorsalis-pedis-artery–saphenous-vein fistulas have been described in isolated case reports without long-term outcomes.[59-61]

Unconventional Arteriovenous Grafts

Upper extremity. In those with limited peripheral veins, the use of central AV grafts has been described. In a study of 67 patients[62] with axillary-artery–ipsilateral-axillary-vein grafts using polytetrafluoroethylene (PTFE) graft, the primary and secondary patency rates at 1 year were 70% and 82%, respectively. Although no steal complications developed, there was a 9% rate of infection and multiple interventions due to

thrombosis and venous stenosis. In a second series of 27 patients undergoing the same procedure,[63] the 1-year primary and secondary patency were similar at 51% and 87%, respectively. Complications of infection, thrombosis, and outflow stenosis occurred in 41% of patients.

The data specific to axillary-artery–contralateral-axillary-vein (sometimes called a necklace graft) have been limited to small studies[64-66] with a median primary patency rate of 9 months and secondary patency of 24 months.

A small case series of 16 patients[67] has described the creation of brachial-artery–jugular-vein grafts with primary patency between 8 and 26 months. There have been isolated case studies or combined case series describing internal-jugular-artery–contralateral-internal-jugular-vein, subclavian-artery–contralateral-subclavian-vein, axillary-artery–axillary-vein, and axillary-artery–femoral-vein grafts.[68-71]

Lower extremity. Lower extremity grafts are placed after fistula, and graft options in other locations have been exhausted. Of all lower extremity graft options, the femoral-artery–femoral-vein graft is best described by 4 studies[72-75] each reporting over 100 grafts. The first and largest femoral-artery-femoral-vein graft study,[74] a prospective single-center analysis of 209 patients, reported a 1-year assisted primary and secondary patency rate of 38% and 62%, respectively. Infection-free graft survival at 1 and 5 years was 79% and 61%, respectively.

In the second-largest study[73] of 127 PTFE femoral-artery–femoral-vein grafts, the primary and secondary 1 year patency rates were 54% and 75% with a median survival of 31.6 months (range, 0-149 months). Similar to the first study, 73% of grafts remained infection free during the follow-up period. The remaining 2 smaller studies showed similar patency and infection rates.[72,75]

The femoral-artery–contralateral-femoral-vein graft (sometimes called the bikini graft), although an option, has very limited data.[68]

In cases of limited lower extremity vascular anatomy, small case series or case reports have been described for PTFE grafts using femoral-artery–superficial-femoral-vein[76] (adductor loop graft), superficial-femoral-artery–femoral-vein,[77] external-iliac-artery–external-iliac-vein graft,[78] common-iliac-artery–inferior-vena-cava-graft,[79] and femoral-artery–renal-vein graft.[80]

Atypical Tunneled Catheter Placement

The preferred sites of tunneled cuffed catheter placement are the right internal jugular (IJ) followed by left IJ vein, external jugular (EJ) veins, femoral vein, and other exotic sites described below. In a series of 492 hemodialysis patients,[81] representing over 212 000 patient catheter days, the position of the tunneled catheter was the most significant independent risk factor for catheter failure. Catheter placement in the right IJ vein had the best median survival (633 days) followed by left IJ (430 days) and femoral (116 days).

Jugular vein catheters. Cannulation of the EJ with a cuffed central dialysis catheter has been described with fairly similar outcomes as IJ catheter placement. In a study of 45 patients[82] with cuffed EJ catheters, 82% were functional after 3 months. One was exchanged after 1.5 months for infection. Two other studies describe combined EJ and IJ cohorts; the first reported an average functional period of 78 days (range, 22-115 days),[83] and the second no difference in functionality between the 2 types of jugular catheters at 1 and 3 months.[84]

Translumbar catheters. Translumbar cuffed catheters, first described as an alternate access option in 1995,[85] have limited reported outcomes based on small patient series. These catheters are inserted via the translumbar route into inferior vena cava[86,87] and are generally reserved for dialysis patients who have exhausted all other access options. They are technically challenging and may be associated with procedure-related complications (eg, retroperitoneal hematoma). The largest study[88] involves 33 patients receiving 92 translumbar catheters. The median time from placement to catheter exchange or removal was 47 days (interquartile range, 96 days), with 44% of exchanges due to infection.

Similarly, Liu et al[89] report a median catheter duration of 65 days in a series of 28 patients with 84 catheters. The main indication for catheter exchange in this study is infection (36% of catheters) followed by poor blood flow (31%). However, 43% of patients were successfully converted from a translumbar access to either another vascular access or peritoneal dialysis, suggesting that translumbar catheters may be a "bridge" access in these patients.

Transhepatic catheters. Transhepatic catheters are another access option. The largest and most comprehensive study is of 127 transhepatic catheters in 22 patients.[90] The mean duration from initial placement until catheter removal or exchange is 141 catheter days (range, 0-565 catheter days). The rate of catheter-related sepsis is 2.2 per 1000 catheter days, thrombosis 1.8 per 1000 catheter days, fibrin sheath 0.2 per 1000 catheter days, migration 3.9 per 1000 catheter days, and hematoma 0.1 per 1000 catheter days. There are 3 smaller studies assessing transhepatic central venous catheters, with shorter follow-up periods or not limited to translumbar catheters.[91,92,94]

Lower extremity catheters. There are 2 major sites for tunneled central venous catheters in the lower extremity: the femoral and saphenous vein. Outcome data are limited on saphenous vein catheters.[94] Femoral catheters are less challenging technically to insert and can be considered when upper access options are exhausted.[95] Important aspects to consider are catheter length (they are 70 cm long usually, with the cuff at 45 cm) and infection prophylaxis, given their exit site in close proximity to the groin. Complications include bacteremia, deep vein thrombosis, iliac vein occlusion, and catheter dysfunction.

Several studies[96,97] report on outcomes of femoral dialysis catheters, the majority of which highlight the increased risk of

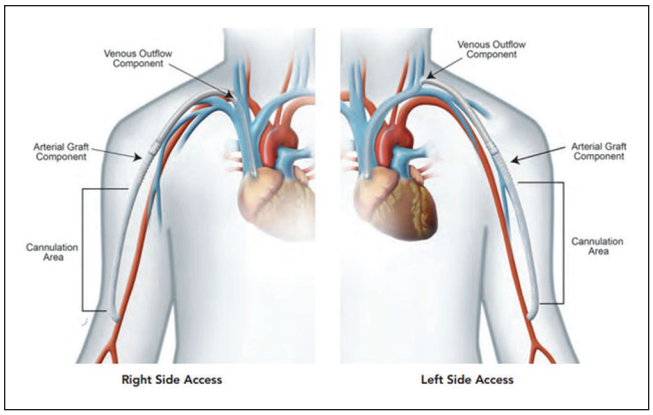

Figure 2. Hybrid graft catheter device.
Source. http://www.medgadget.com/2013/06/hero-graft-for-improved-hemodialisys-access-coming-to-europe-video.html.

infection and reduced catheter survival as compared with IJ locations. The mean catheter patency was only 51 days in Falk et al[96] and a mean of 2 interventions per catheter were required to maintain patency. Complications included deep venous thrombosis, iliac vein occlusion, and catheter retraction (ie, falling out). One of the largest retrospective series[98] in 194 tunneled femoral catheters highlights complications of bacteremia (2.3 per 1000 catheter days) and catheter-related thrombosis (2.1 per 1000 days) while 90-day patency was low at 50%.

Hybrid Graft Catheter Device

The Hemodialysis Reliable Outflow (HeRO) vascular access device (Figure 2) was approved by the US Food and Drug Administration in 2008 as a graft for hemodialysis patients who have exhausted traditional AV fistulas and grafts options, in an attempt to avoid central venous catheters. It is not yet approved in Canada but is available through a "Special Access Program" (www.cryolife.com). The HeRO graft is comprised of 2 parts, a standard expanded PTFE graft component that is connected to a nitinol-reinforced silicone outflow component. The graft component is tunneled in the upper arm over the biceps muscle. The distal end of the graft is anastomosed to an artery, typically the brachial artery. The silicone outflow component is inserted similar to a traditional central venous catheter, with the proximal component placed in the right atrium. The 2 components are joined subcutaneously with a titanium connector at the deltopectoral groove to provide continuous arterial blood flow to form an AV access that bypasses any central venous stenosis without the need for a graft-to-vein anastomosis[99] (see video link http://www.youtube.com/watch?v=A0Ew55eRMPw).

To date, there are several published studies involving the HeRO graft, of which only 1 is a randomized trial. In an industry-funded multicenter randomized control trial, Nassar et al evaluated the safety and efficacy between the HeRO graft and upper limb graft in 72 graft-eligible patients.[100] Participants who had significant central venous stenosis were excluded. Participants were randomized in a 2:1 fashion (HeRO:graft). The efficacy endpoints were primary and secondary patency; ancillary outcomes included interventions and blood stream infections. The trial was terminated early by the investigators because of slow enrollment after 72 patients (52 in HeRO group, 20 in the control, graft group) had been enrolled. The primary and secondary patency rates at 12 months did not differ between the HeRO and graft groups, 35% versus 31%, and 68% versus 58%, respectively. In a retrospective cohort study,[101] Steerman et al compared the outcomes of lower extremity graft (21 patients) with those of HeRO graft implants (59 patients) over a 6.5-year period. The primary patency was significantly lower in the HeRO patients at 12 months, but secondary patency was similar.

The largest study of the HeRO graft is a retrospective cohort study by Gage et al.[102] A total of 164 consecutive patients who received the HeRO graft from 4 centers with an average follow-up of 12.8 months were described. At 12 months, the primary and secondary patency rates were at 49% and 91%, respectively.

Overall, it appears that patency rates and infection rates with HeRO device are similar to either upper arm or lower limb grafts and that an average of 2 interventions per year is required to maintain the HeRO device.

Summary

- There are a limited number of potential vascular access sites; clinician must be aware of all options, including nonconventional ones
- Nonconventional forearm options include radial- or ulnar-basilic forearm fistula
- Transposed brachial-basilic fistulas are increasingly common with maturation rates of 80% and 1 year primary patency rates of 70%
- Transposed brachial fistulas provide alternative upper arm fistula option but are associated with complications of arm swelling
- Femoral-artery–femoral-vein fistulas have a high ischemic complication rate while femoral-artery–saphenous-vein fistulas have no reported ischemic complications and a 70% primary patency rate
- Upper arm graft options include axillary-artery–ipsilateral-axillary-vein graft and axillary-artery–contralateral-axillary-vein (necklace) graft
- The most common lower leg graft is the femoral-artery–femoral-vein graft, which has a 1-year secondary patency rate of 60%; infection occurs in 20% in the first year
- Atypical catheter locations include transhepatic and translumbar; these have higher infection rates than catheters in conventional sites
- Tunneled femoral catheters have shorter survival and higher risk of deep venous thrombosis compared with conventional catheters

- The HeRO device offers an alternate access for patients with central vein occlusion and no suitable veins for upper arm fistula or graft
- The order of preferred vascular access in the hemodialysis patient with reasonable life expectancy remains fistula followed by graft in the upper extremity

Ethics Approval and Consent to Participate

Ethics approval and consent to participate was not required for this trial.

Consent for Publication Availability

Consent for publication was obtained from all authors.

Availability of Data and Materials

There is no data to share.

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Author Contributions

J.M. conceived, designed, and coordinated the review; drafted the manuscript; and critically revised the manuscript. C.D., L.M., C.L., S.Y., K.L., E.C., M.K., and R.L. helped draft the manuscript and provided critical review. M.O., S.H., and J.K. helped design and draft the manuscript and provided critical review. L.M.M. helped design and coordinate the review and provide critical review. All authors read and approved the final manuscript.

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