Widmer MK, Malik J (eds): Patient Safety in Dialysis Access.
Contrib Nephrol. Basel, Karger, 2015, vol 184, pp 123–135
DOI: 10.1159/000365827

Careful and Safe Vascular Access Creation

Thomas R. Wyss • Matthias K. Widmer

Department of Cardiovascular Surgery, Swiss Cardiovascular Center, Bern University Hospital, Bern, Switzerland

Abstract

Morbidity and mortality are significant in hemodialysis patients, and every vascular access (VA) is prone to complications – some more, some less. The risk of complications rises from arteriovenous fistulae to arteriovenous grafts and peaks in nontunneled central lines. Strategies to achieve complete evaluation of the patient and precise planning mark the start of successful VA creation. Furthermore, preoperative considerations include safety checklists, team time-out procedures, and antibiotic prophylaxis. Intraoperative technical features and postoperative aspects of documentation and surveillance schemes complete careful and safe VA creation.

Recommendations to Improve Patient Safety

- Clinical evaluation and duplex sonography examination are important in preoperative decision making.
- Safety checklists and team time-out are standard protocol.
- Fistula first concept should be constantly encouraged.
- Synthetic and biological grafts are important adjuncts to arteriovenous fistulae.
- Artery-side-to-vein-end anastomosis is the preferred type.
- Perform careful and meticulous surgical preparation to avoid tissue and vessel trauma.
- Patient education is essential for outcome.

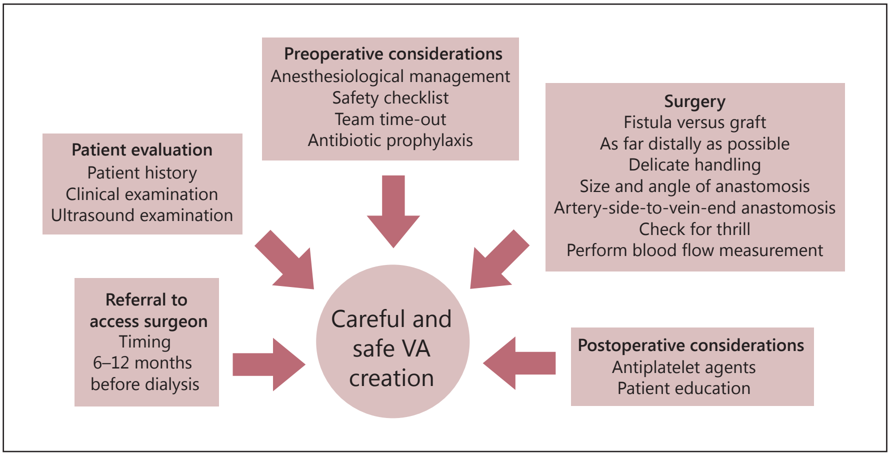

Fig. 1. Tasks for careful and safe VA creation.

Introduction

Considerable morbidity exists when dealing with vascular access (VA) creation. Native arteriovenous fistulae (AVF) are the desired VA for patients on dialysis due to their comparably low morbidity and fairly good long-term patency. However, they are also at risk for nonmaturation, stenosis, thrombosis, infection, aneurysm formation, and steal syndrome [1]. Fistula success is dependent on the center of access creation. Hence, the vascular surgeon's skills and decisions are key [2]. Furthermore, success is also determined by preoperative, technical, and postoperative factors that will be discussed in this chapter (fig. 1).

Preoperative Decision Making

First of all, one has to respect that future hemodialysis calls for sufficient timing of VA creation. AVF require a period of ideally 4–6 weeks [3], sometimes even months, of maturation to become suitable for cannulation. Early decision making is needed to guarantee enough time to have a functioning access ready at the start of hemodialysis. Therefore, patients with advanced chronic kidney disease (glomerular filtration rate <20–25 ml/min, late stage 4) should be referred to an access surgeon [4]. Six to 12 months prior to the expected first hemodialysis, fistula creation should be initiated on the nondominant extremity.

A certain blood flow is necessary to make hemodialysis possible and to avoid recirculation of dialyzed blood: fistulae should have a blood flow of >600 ml/

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min, and the majority of proper fistulae report a blood flow of 800–1,200 ml/min [5, 6]. Serving only as a rough guide, criteria for fistula maturation have been summarized as the 'rule of 6s': >6 mm diameter, <6 mm deep from the skin surface, >600 ml/min blood flow, and if after 6 weeks the fistula does not meet these criteria, evaluation for nonmaturation should be commenced. However, many AVF (up to 50%) never mature properly or early thrombosis occurs [3, 5]. In order to avoid nonmaturing AVF and to have enough time for the growth process, certain measures have to be taken. For this purpose, we are referring to the chapter by Malovrh [this vol., pp. 13–23]. Malovrh elaborates on the mandatory preoperative physical and noninvasive duplex ultrasound examination of patients and their vessels. All of these variables affect the surgeon's decision.

When comparing the outcome of fistulae created after using physical examination alone versus physical examination and ultrasound vein mapping, it has been shown that the rate of successfully constructed AVF increased significantly with preoperative ultrasound imaging. Furthermore, the surgical site for fistula creation and type of procedure were considerably modified by ultrasound results and negative surgical explorations were eliminated. Fistula patency rates at 6 months were higher when ultrasound mapping was used [7].

Arteriosclerosis for example can possibly limit fistula maturation due to restricted capacity of the vessel to accommodate the higher flow that is needed for a cannulable hemodialysis access [6].

Consequently, preoperative vessel mapping adds valuable information concerning the choice of fistula type [8]. All this supplementary information eliminates risks of surgical failure and increases the proportion of AVF over arteriovenous grafts (AVG), contributing to the widely accepted 'fistula first' concept. It is generally believed that AVF are preferred over AVG due to better long-term patency. VA is placed as far distally in the upper extremity as possible, beginning with posterior radial branch-cephalic direct wrist access (snuffbox), then radial-cephalic forearm (Cimino-Brescia) fistulae and so on. This leaves more proximal sites for future access [4].

However, if there is limited maturation time available, AVF have failed, suitable vessels are lacking and central venous catheters have to be avoided, AVG represent a good option. Key features of the ideal graft include early access, rapid hemostasis, good long-term patency, and resistance to infection. Generally, grafts can be divided into synthetic or biological vascular substitutes. Expanded polytetrafluorethylene (ePTFE) is the most widely used synthetic graft. Its recommended minimum waiting time until first cannulation is 2 weeks. This period is required for adequate attachment to the subcutaneous tissue surrounding the graft and contributing to hemostasis after puncture. Ideally, immediate graft puncture is possible to evade temporary dialysis catheter place-

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ment. Myointimal hyperplasia leading to stenosis and finally thrombosis and therefore access failure is more prominent in AVG than AVF. Development of modified graft materials is important to counteract these issues. A few examples: Heparin bonding aims at reducing the graft's intrinsic thrombogenicity through impregnation of the luminal surface. Multilayer graft wall structures, alterations in graft pore size and mesh configuration as well as changes in material composition try to reduce excess formation of neointima and enable cannulation within 24 h after AVG creation (so-called early stick grafts). Geometrical modifications (e.g. cuffed grafts, swirl/spiral grafts, venous cuffs/collars) have been developed to decrease AVG neointima formation and stenosis, however with variable success compared to standard ePTFE [9]. All of the available artificial implants put the patient at a higher risk of fistula failure, compared to AVF, mainly due to thrombosis and infection, venous hypertension and steal syndrome. These aspects have to be kept in mind when making decisions for different VA models.

Drug-eluting perivascular wraps, intended to reduce myointimal hyperplasia, are under investigation. Paclitaxel- or Sirolimus-eluting and endothelial cell-loaded wraps have shown some benefit in reducing PTFE graft stenosis [10].

Biological and bio hybrid materials (e.g. cryopreserved veins, bovine grafts, ovine matrix collagen grafts) mainly come to use in infected situations due to their lesser susceptibility to reinfection. Rerouting concepts (i.e. using a new subcutaneous tunnel) and biological grafts are advisable when infections of VA are present [11]. Myointimal hyperplasia also seems to be rare in these grafts. Still, data are inconsistent when it comes to patency rates and infections, and surgical handling of synthetic and biological grafts can be difficult as well [12].

Central venous catheter placement can be performed in emergency cases that most likely will need immediate and serial dialysis. Risk of bleeding and pneumothorax as well as higher infection rates, shorter service life and often prolonged hemodialysis treatment times have to be taken into account.

Anesthesia, Safety Checklist and Antibiotic Prophylaxis

Anesthesiological impact is generally small in VA surgery, although often dealing with multimorbid patients. Local anesthesia is sufficient for the majority of procedures if the patient is compliant and an outpatient setting is usually adequate. When dealing with more extensive procedures, regional nerve blocks such as brachial plexus anesthesia offer patient and surgeon comfort as well. Furthermore, a desired advantage of regional block anesthesia is the

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marked increase in venous diameter of the superficial veins, which may improve the rate of native fistula placement [13]. General anesthesia is rarely needed.

In order to promote a safety culture, the World Health Organization has introduced a so-called surgical safety checklist aiming at reducing the number of surgical deaths across the world. Events of inadequate anesthetic safety practices, avoidable surgical infection and poor communication among team members in the operating theatre put the patient at risk. A list of safety checks has been designed to address this issue. It consists of three parts: (a) sign in (before induction of anesthesia), (b) time-out (before skin incision), and (c) sign out (before the patient leaves the operating room). Each part is made up of multiple questions that need to be checked before the next part can be initiated. For example, the 'sign in' reconfirms patient identity and mentions possible allergies. The 'time-out' introduces all team members and possible critical events during the procedure. Finally, the 'sign out' lists instrument counts, labelling of pathological specimens, and planned postoperative patient management. Adhering to a pattern like this should reduce the number of avoidable risks endangering the lives and well-being of surgical patients [14].

The possibility to develop a surgical site infection depends on bacterial colonization of the operative field. Perioperative antibiotics are central to prevent postoperative surgical wound infection [15]. To reach the best effect, timing of administration of the single-shot antibiotic prophylaxis is crucial: 30–60 min before skin incision is adequate. Errors due to too early or too late medication put the patient at risk for an infection.

General Technical Aspects

A multitude of factors has been identified to affect patency of AVF. Results from a recent review show that nonmodifiable patient factors such as age, diabetes, peripheral vascular disease, predialysis hypotension and vessel characteristics (<2 mm diameter, reduced distensibility) negatively influence patency. When it comes to modifiable factors, smoking, early referral, ultrasound imaging, anastomosis type, vascular staples/clips, flow assessments, antiplatelet therapy, and timing of first cannulation have an effect on patency. Systemic heparin use, cannulation technique and fistula surveillance do not alter the rate of fistula patency according to latest data [16]. Traditionally, systemic heparin use has been of widespread use to counteract clotting in clamped vessels. However, data show that it only increases bleeding complications without adding to the success of primary fistula creation or fistula patency [16].

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Marking the vein with duplex ultrasound before the operation and palpation of the artery can help to place the incision in an ideal area. After having decided at which location the anastomosis will be performed, skin incision under antibiotic prophylaxis follows. A short longitudinal incision is preferred to gain good target vessel access and to avoid damage to neighboring structures such as nerves and lymphatic vessels. Attention should be paid that the incision and the suture line are not lying on the top of the vessel but a little bit aside. S-shaped incisions in the cubital fossa or in areas of grafts are ideal because the incision can be prolonged, and the potential exposure of the underlying AVG is, in the middle part of the incision, very short so that the risk for an infection is low.

Creation of AVF

In surgical preparation of the desired vessels, care must be given to avoid wall damage, which could lead to leakage or stenosis of the vessel. Different ways of blocking blood flow exist (e.g. vascular clamp, local vascular tourniquet, proximal pneumatic tourniquet, balloons, cardiac shunts, and endovascular occlusion gel). The safety of pneumatic tourniquet occlusion over clamps to gain vascular control has been documented and its advantage shown when it comes to shorter operative time and technically easier operation as well, especially in redo cases. It has no impact on complications (e.g. nerve injury, bleeding, hematoma, vascular steal, infection, or swelling) and primary patency rates [17]. It must be remembered that the anesthesiological management also influences the possibilities of available blood flow control.

Flushing the distal end of the venous segment with saline allows the surgeons to assess the properties (e.g. diameter, side branches, stenoses) of the vein [4]. Especially in cases of vein transposition, the dissected vein is dilated with heparinized saline and can be marked with a skin scribe to avoid rotation. The vein has to be released from its surrounding tissue for a certain distance to approach the artery. One has to bear in mind that this mobilization causes tissue damage and can lead to devascularization of the vessel. The vein tends to lengthen a bit during fistula maturation. Kinking (due to excess length) has to be avoided because this could lead to severe postanastomotic stenosis. On the other hand, pulling and stretching of the artery and/or vein causes mechanical trauma to the vessel wall. Torsion of the vein or inadequate tension has to be omitted before performing the anastomosis [18].

Available types of preparation include artery-side-to-vein-end, end-to-end, and side-to-side anastomoses. The preferred mode is artery-side-to-vein-end anastomosis leading to less complications (no distal arterial ligation as in end-

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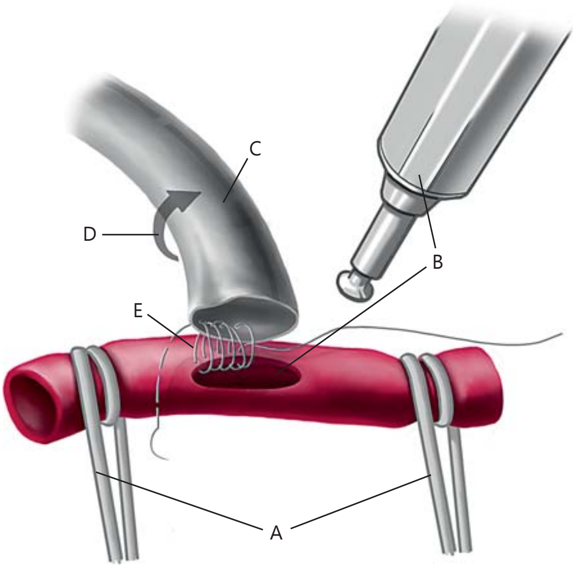

Fig. 2. Safe creation of an arteriovenous anastomosis. A = Control of inflow and outflow using clamps, vessel loops or tourniquets; B = incision of the artery and creating round ends using a punch; C = instillation of heparinized saline solution to check the outflow of the vein and enlarge the vein so it can be marked; D = mild outward rotation of the vein; E = running suture inside artery out in parachute technique.

to-end technique and no hyperemia of the hand as in side-to-side technique) and equal patency rates [19].

The distal end of the vein is ligated and the vein approximated to the artery. This in turn results in varying angles between the artery and the vein at the site of the anastomosis. Hence, the lengths of the arteriotomy and venotomy have to be precisely tailored according to this angle. If the angle is more acute, the length of the arteriotomy/venotomy is longer than if the vein approaches the artery at a right angle [20]. In a rectangular anastomosis, Konner [20] recommends to mildly rotate the vein outward to avoid juxta-anastomotic kinking and stenosis. We prefer the use of a punch to achieve an accurate opening in the arterial wall at the future anastomotic site. It offers good visibility and reduces trauma to the vessel (fig. 2).

Anastomotic technique: surgical telescopes and 6-0 or 7-0 thread for sutures are generally recommended [6]. Vascular nonpenetrating U-shaped clips in an interrupted manner can alternatively be used: maturation and patency rates in forearm fistulae are good [21]. We normally perform a running suture starting at the back wall, then passing the proximal corner, then passing the distal corner with

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the other end of the thread to complete the anastomosis in the middle of the front wall. In our experience, this offers good visualization during the whole procedure.

Once completed, the arteriovenous connection leads to a drop in peripheral resistance increasing arterial flow. With larger anastomosis size, proximal artery flow increases further. However, larger anastomoses can eventually lead to distal artery flow reversal. Therefore, it is important to respect both size and angle of anastomoses. Van Canneyt showed a distinct hemodynamic impact of anastomosis size and angle in an AVF flow model. For larger anastomoses, arterial inflow and venous outflow increase and arterial outflow decreases. In anastomosis >58°, the arterial inflow was insufficient, leading to distal arterial flow reversal. This in turn could lead to ischemic complications. For larger anastomoses, the pressure drop over the anastomosis decreases at a fixed angle. For more acute anastomosis, the pressure drop was less dependent on anastomosis cross-sectional area [22].

Recently, Bharat et al. [23] showed that their so-called 'piggy back' straight-line onlay technique led to a significant reduction in juxta-anastomotic stenosis, which is the leading cause for fistula failure. In this technique, an anastomosis between the posterior (underside) aspect of the vein and the anterior (upper) aspect of the artery is created and the arterial blood is supposed to flow into a straight cylindrical lumen.

Intraoperative Quality Control

Both, a continuous palpable thrill and a continuous audible (stethoscope) low-pitched bruit should be present upon completion of the fistula. AVF maturation can be predicted by intraoperative blood flow measurement. Low flow calls for immediate revision. Minimal flow values needed for radiocephalic fistulae are 120 ml/min and for brachiocephalic fistulae 310 ml/min. When reaching these values during fistula creation, one can expect maturation [24]. In revision procedures, intraoperative angiography is an essential adjunct. It provides insight into local or distal stenoses that might affect in- or outflow properties. Such issues can be resolved by direct interventional or surgical treatment.

Creation of AVG

If there are no veins available, grafts are an alternative. They can be placed either as straight (= bridge) grafts or as loops. In creating AVG, technical aspects to avoid tissue trauma and infection include gentle and atraumatic soft tissue handling (i.e. no touch technique), avoidance of skin contact of graft materials and

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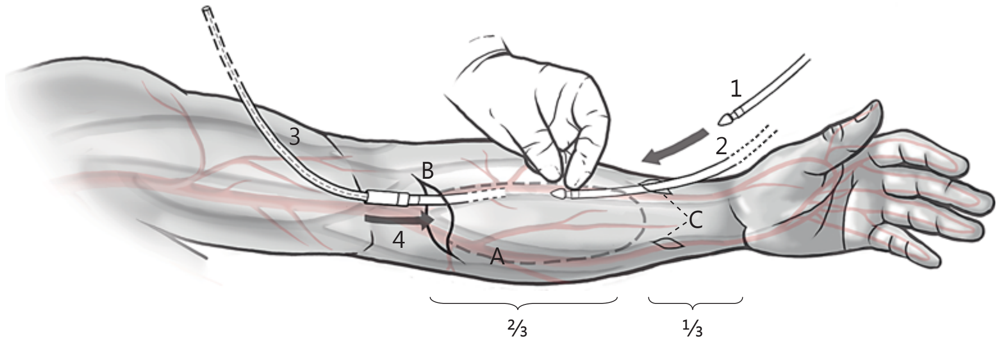

Fig. 3. Instructions for safe AVG placement. A = Mark the planned landing zone for the AVG. The graft length should be about 2/3 of the forearm. B, C = S-shaped incision in the cubital fossa and two incisions far away from the final graft bed. Use of a tunneler: (1) Oversize the olive by 1 mm (e.g. 7 mm for 6-mm graft). (2) Check the tissue depth of your tunneler using your hand. (3) Fix the graft to the tunneler avoiding skin contact. (4) Pull the tunneler and graft through and check to avoid rotation and kinking.

avoidance of scars in the puncture area. A popular tool to limit tissue damage in loop configurations is a tunneler, available in different diameters and lengths. It aids in minimizing skin incisions, and it creates an adequately sized tunnel, avoiding extensive subcutaneous tissue damage as opposed to the use of traditional tunneling forceps (fig. 3). Subsequently, the graft can be pulled through along the tunneler facilitating rotational control.

In graft-vein anastomosis of AVG, Konner recommends a very acute, almost parallel position of the graft along the vein and a length of the anastomosis of up to 20–30 mm. This will result in undisturbed blood flow through the anastomosis without a great change in direction, omitting turbulence which could lead to neointimal hyperplasia [20].

Hand Ischemia and Its Prevention

Steal syndrome can occur after VA creation and put the patient at risk for impaired distal perfusion or even ischemia of the forearm and hand. Accepted risk factors for its development are diabetes, hypertension, smoking, female gender, and coronary artery disease [25]. Two situations have to be distinguished in steal syndrome since they call for different management. If there is a considerably higher than desired blood flow in the arteriovenous segment, flow reduction has to be achieved by narrowing the anastomosis, banding of the postanastomotic venous segment (e.g. narrowing suture, plication, interposition, banding/cuff) or the revision using distal inflow technique which results in a more distal feeding

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of the venous segment and therefore preserves an antegrade arterial flow pattern. On the other hand, if there is adequate or low blood flow in the arteriovenous segment and blood flow cannot be reduced, angioplasty of arterial in- or outflow vessel stenoses, proximalization of arterial inflow into the arteriovenous segment or proximalization of the post-anastomotic outflow artery by distal revascularization and interval ligation are effective methods. The 'extension technique' by Ehsan is a modified technique for brachiocephalic fistulae to prevent hand ischemia (fig. 4) Anastomosis is performed between the median cubital vein and the radial or ulnar artery just below the brachial bifurcation. This preserves part of the blood supply to the hand avoiding steal syndrome. An additional advantage of this technique is maturation of both, cephalic and basilic, veins [26]. In the case of AVG, the use of a tapered graft is an option to prevent hand ischemia.

Postoperative Management

Cannulation within the first 2 weeks after the operation should be avoided to allow for tissue ingrowth [16]. Consequently, if sufficient fistula maturation has been achieved at that time, access cannulation can start.

Medication that improves patency includes antiplatelet agents, fish oil and calcium channel blockers [27]. A Cochrane review investigated the effect of adjuvant medical treatment to improve patency rates of AVF and AVG. The results of the meta-analysis showed a positive effect of antiplatelet treatment on VA patency in the short term. An included trial comparing low-dose warfarin with placebo was stopped early due to increased bleeding complications in the treatment group [28].

The patient and treating nephrologist have to be well informed about the VA they are dealing with, allowing them to anticipate potential problems in advance and to guarantee best access survival. This can include a schematic drawing of the VA that has been created. Visual understanding of the detailed anatomic conditions supports correct cannulation. Moreover, with every revision procedure, the degree of complexity increases, and therefore it is important to keep track of the structural setting as part of the patient's fistula history (fig. 5). So called 'vascular access passports' represent a helpful documentation tool to achieve this goal (http://heartlandkidney.org/article_resources/passport.pdf). Educational material (http://www.fistulafirst.org/Patients/PatientEducationalMaterials.aspx) for patients is key in raising patient compliance levels and outcome after AV access surgery, implementing correct patient behavior: keeping the wound clean and the fistula protected, touching the access daily to feel the thrill. Additionally, hand squeezing exercises increase the diameter of the outflow vein and seem to help in AVF maturation [29].

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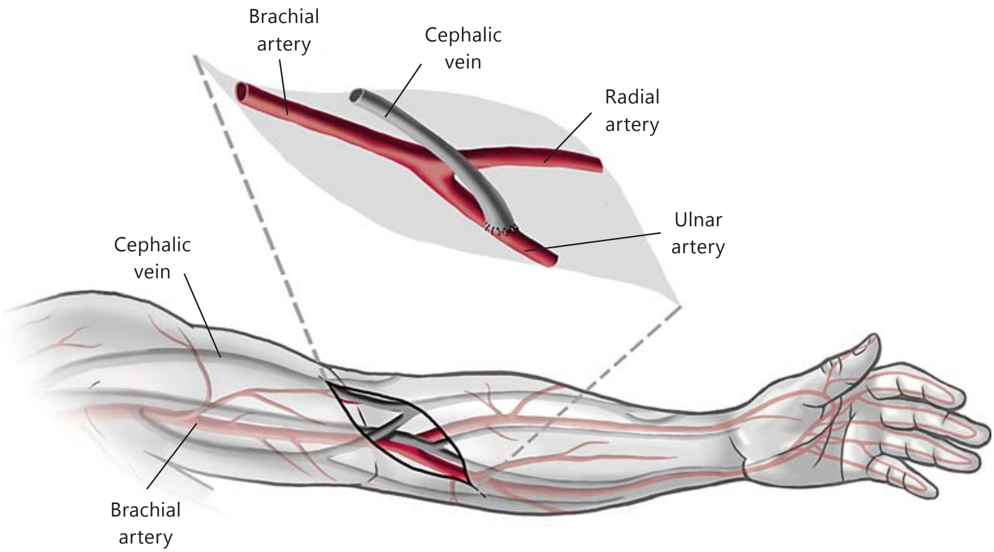

Fig. 4. Cubital AVF in extension technique to avoid hand ischemia in patients with critically diseased arteries.

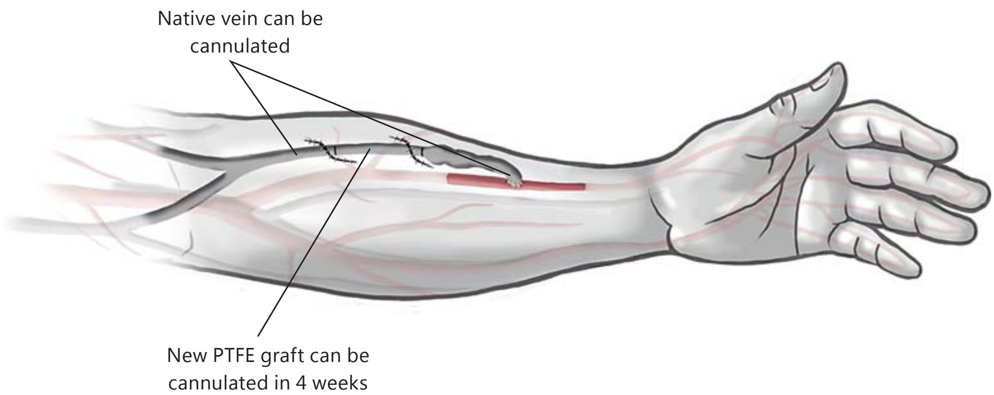

Fig. 5. Visual documentation of VA creation or revision procedures help the dialysis staff to understand where and when they are allowed to puncture.

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Evidence regarding the actual benefit of access surveillance is limited. Postoperative surveillance by duplex scanning (detecting inflow or outflow problems) after 6–8 weeks has a high sensitivity (100%) and specificity (85%) for final access outcome [8]. If necessary, endovascular (angiography and angioplasty) or surgical interventions for nonmaturing fistulae can be planned. Preemptive repair of subclinical stenoses detected on postoperative access surveillance by blood flow measurements positively affects access survival [30]. However, only low-quality evidence exists suggesting a potentially beneficial effect of access surveillance followed by interventions to restore patency [31]. Surveillance with blood flow measurements may prevent fistula thrombosis, but does not influence the risk of access loss [32].

Disclosure Statement

T.R. Wyss declares no conflicts of interest. M.K. Widmer is a convenor and tutor at the Vascular International Foundation and School and consultant of Bio Nova International and MAQUET GETINGE GROUP.

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Thomas R. Wyss, MD
Department of Cardiovascular Surgery
Swiss Cardiovascular Center
Bern University Hospital
Freiburgstrasse 10, CH–3010 Bern (Switzerland)
E-Mail thomas.wyss@insel.ch

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Widmer MK, Malik J (eds): Patient Safety in Dialysis Access.
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