
*Review***Vascular Access for Hemodialysis: When and how?**Andreja Figurek¹, Evangelos Papachristou² and Dimitrios S. Goumenos²¹Department of Nephrology, Clinical Center Banja Luka, Banja Luka, Republic of Srpska, Bosnia and Herzegovina, ²Department of Nephrology and Transplantation, University Hospital Patras, Patras, Greece**Abstract**

As chronic kidney disease (CKD) progresses to the terminal stage, proper actions must be taken to prepare the patient for the initiation of the renal replacement therapy (RRT). If hemodialysis is an option for RRT, decisions should be made about the right vascular access for each individual patient. The available options for vascular access include the use of native arteriovenous fistulas (AVF), synthetic arteriovenous grafts (AVG) and double lumen dialysis catheters. With the help of ultrasound mapping, chances for choosing a right access are today very high. For hemodialysis patients the selection of the proper vascular access is of vital issue in regard of preventing complications and unnecessary procedures. Planning, creation and monitoring of the vascular access in dialysis patients should involve not only the nephrologist, but also the vascular surgeon and the interventional radiologist. Thus, multidisciplinary approach should be taken, in order to choose the way that has the most advantages and the least damage for the patient. That is the proper mode for hemodialysis patients to have longer and better quality of life.

Key words: vascular access, hemodialysis, arteriovenous fistula, graft, catheter, ultrasound

Introduction

As chronic kidney disease (CKD) progresses to the terminal stage, proper actions must be taken to prepare the patient for the initiation of the renal replacement therapy (RRT). If hemodialysis is an option for RRT, decisions should be made about the right vascular access for each individual patient. The available options for vascular access include the use of native arteriovenous fistulas (AVF), synthetic arteriovenous grafts (AVG) and double lumen dialysis catheters. In the following text, the proper approach to each patient in the creation of vascular access will be discussed.

Arteriovenous fistulas

Arteriovenous fistula (AVF) is a surgically created direct juncture between an artery and a vein resulting in dilatation and maintenance of arterial blood flow rates in the adjacent vein. This groundbreaking type of access was first introduced by Brescia and Cimino in 1966 and enabled hemodialysis to be widely applied around the world [1]. In their publication, the authors described the creation of side-to-side anastomosis between the cephalic vein and the radial artery in the wrist. This originally described type of anastomosis is still created for almost 50 years now without major modifications.

According to the 2006 published KDOQI Guidelines, in patients with CKD stage 4 or 5, arm veins should be spared from venipuncture allowing them to be used in the future for creation of AV fistulas. Also, the use of jugular vein catheters should be preferred over subclavian vein catheters because of the smaller propability of stenosis and vein occlusion. An AVF should be created at least 6 months before the planned start of hemodialysis, and when glomerular filtration rate (GFR) is less than 25 ml/min and the serum creatinine level is above 350 µmol/l. European Best Practice Guidelines (EBPG) suggest that patients should be referred to the surgeon for preparing a vascular access in stage 4 of CKD (GFR<30 ml/min/1.73 m²) or earlier in case of rapidly progressive nephropathy or specific clinical conditions (e.g. diabetes, severe peripheral vascular disease) [2]. Similarly, UK Renal Association advises that planning for access should be started in stage 4 of CKD, and the exact time will be determined by the rate of decline of renal function, comorbidities and by the surgical pathway [3]. Canadian Society of Nephrology recommends that vascular access should be provided when GFR is about 15-20 ml/min [4]. Arteriovenous fistulas are the preferred type of vascular access because of their better long-term patency rates, the lower frequency of infection and the lesser need for interventions to maintain patency and functionality compared to the other types of access [5,6].

The American Vascular Surgery Society recommends

that the first created native fistula should be located in the non-dominant arm and as far distally as possible in order to preserve proximal sites if needed for future access creation [7]. The order for creating AV fistula, according to KDOQI Guidelines is: radio-cephalic or distal AV fistula, brachio-cephalic or proximal AV fistula, brachial-basilic AV fistula with transposition or proximal AV fistula [8].

When an AVF is surgically created, maturation process is the next important issue that determines its future use and long-term patency. Therefore, besides an adequate surgical technique, the quality of the veins is an important factor that allows a sufficient maturation process. It is known that the fistula failure is more common among women, older patients, and patients that have vascular disease or diabetes [9-11].

The percentage of patients who are using a native arteriovenous fistula as a vascular access varies remarkably between Europe and the United States (US). It is interesting to note, that the use of AV fistulas is much more common in Europe than in the US, while patients on hemodialysis have lower comorbidity in Europe than in the US as it was shown in the DOPPS study [12]. More than half of the US dialysis patients receive a synthetic arteriovenous graft. Meta-analysis done by Murad *et al.* on 83 studies, has shown that AVF for chronic hemodialysis is superior to the AVG (significant reduction of death and access infection, non-significant reduction in the risk of postoperative complications-hematoma, bleeding pseudoaneurysm, steal syndrome, and also shorter length of hospitalization and primary and secondary patency at 12 and 36 months) [13]. But, it has to be pointed out that hospitalization rates for vascular access problems are equally common in Europe and in the US [14].

Arteriovenous grafts

If there are no suitable veins for creating an AVF, then the creation of a synthetic arteriovenous graft (AVG) should be considered as an option. AVG are usually made of expanded polytetrafluoroethylene (ePTFE). Anastomotic configuration of AV grafts includes [15]:

- curved brachio-axillary,
- looped axillo-axillary,
- forearm looped brachio-basilic,
- straight radial to cubital fossa vein,
- looped graft between the common femoral artery and saphenous or femoral vein.

The most common complication with AV grafts is outflow stenosis of the vein and infection that usually requires complete removal of the graft in spite of antibiotic therapy [16]. Arteriovenous graft failure is the result of a dynamic process involving hyperplasia of vascular smooth muscle cells that finally causes stenosis and occlusion of the vascular lumen [17].

The use of catheters

Catheters for hemodialysis can be used for short- or long-term periods. Short-term catheters can usually be placed into the internal jugular veins, the subclavian veins or the femoral veins by using the standard Seldinger technique. The use of this kind of catheters is predicted for a period of about 3 weeks and is mostly a bridging access until arteriovenous fistulas or grafts are ready for use. Long-term catheters can be placed also in the same above-mentioned veins and are designed for use for a longer period. In both cases, the preferred site of insertion should be the right jugular vein due to its lower rates of central venous stenosis, the more straight course allowing better flow rates during hemodialysis sessions and the lower complication rates in comparison to the other insertion sites [18,19].

Taking into account the increasing number of patients with implanted pacemakers and defibrillators, usually inserted via the subclavian vein and superior vena, special consideration should be taken in the decision of where to place a central venous catheter [20].

The meta-analysis by Ravani P. *et al.* that included 62 cohort studies comprising over 500,000 participants found that patients using hemodialysis central venous catheters had a much higher risk of death, infection, cardiovascular events and hospitalization compared to patients who used arteriovenous fistulas or grafts as a vascular access for hemodialysis [21].

Complications of the vascular access

Access failure is the most common complication. The blood flow needed for adequate dialysis is about 200-400 ml/min. Some factors that may contribute to the vascular access failure are advanced age, diabetes, female gender and forearm fistula [22] and hypotension and obesity [23]. Some future perspectives may help in maintaining AV fistula functioning, like the use of far infrared electromagnetic radiation to improve endothelial function with antiproliferative and anti-inflammatory effect [24] or transdermal glyceryl trinitrate administration that increases local blood flow in the new AV fistulas [25].

Steal phenomenon refers to ischemic lesions that result from an arterial steal phenomenon and is more frequent in elderly patients with comorbid conditions and diabetes. The first type that is also called "high-flow steal phenomenon" is mostly associated with the presence of a high-flow anastomosis, thus creating critical ischemia of the fingers. The other type of steal phenomenon involves patients with low fistula flow. In this case peripheral ischemia is a result of the occluded peripheral arteries so even normal blood flow in the anastomosis will create critical ischemia in the peripheral vascular bed. According to the clinical features and level of effect, the steal syndrome is classified into four stages, from the first stage where the hands are

blue, pale, or cold without any pains, till the forth stage when there are ulcers, necrosis and gangrene lesions [26]. Therapeutic options are few and include measure for narrowing the anastomosis or closing of the fistula and insertion of a dialysis catheter. Arterial steal phenomenon appears in 1% of AVF's and 9% of AVG's [27].

Aneurysm, a progressive destruction of venous vessel wall and replacement of normal tissue with scar collagenous tissue resulting in the formation of aneurysms [28,29]. Major complications of aneurysms are rupture, infection and rarely embolism. Because of their tendency to progress spontaneously, sometimes it is necessary to perform a partial or complete resection of the aneurysmal sac, to correct any accompanying stenoses and to create an adequate lumen [30].

Pseudoaneurysm may occur during the placement of temporary catheter when there is an arterial puncture and consequent arterial bleeding into the surrounding subcutaneous tissue. In this case, the patient should be on bed rest and with the use of focal compression. In case of greater pseudoaneurysms, an ultrasound-guided thrombin injection into the aneurysmal neck can resolve about 75% of cases [31]. Pseudoaneurysm of arteriovenous grafts is more common. Surgical ligation is one of the treatment options for resolving this complication. It is important to note that covered stent grafts are a safe, flexible and durable treatment option for patients with AV graft pseudoaneurysms that improve graft patency [32].

Congestive heart failure is a result of hypercirculation because of the too low outflow resistance, and involves mostly patients with pre-existing cardiac problems and arteriovenous grafts. Hypercirculation is present on the field of too large anastomotic diameter that usually is the case in AV grafts and brachial artery fistulas. Banding procedures that narrow the anastomosis have been recommended but the results are poor and unpredictable. Ligation of the anastomosis is probably the most reliable procedure.

Central vein stenosis

Central stenosis is usually the result of past subclavian vein catheters, but also in rare cases of previous pacemaker cables or coagulation disorders. Clinically a central vein stenosis becomes symptomatic only when flow is increased as it is the case in AV fistula or grafts. This situation results in the swelling and cyanosis of the arm as well as the formation of collaterals on the chest wall. Therapeutic options include ligation of the anastomosis or if applicable, dilation and stenting of the stenosis using interventional techniques and rarely surgical correction [33,34].

The role of ultrasound mapping

Ultrasound examination of the veins and arteries of the upper extremities, the so called "vascular mapping"

has been increasingly implemented as a standard preoperative procedure when planning and creating an arteriovenous fistula or graft. With this procedure the veins are examined for the presence of stenotic or fibrotic lesions, the vessel diameter is measured, while for the arteries factors such as diameter and the presence of atherosclerotic lesions is also examined. This approach has increased the success of arteriovenous fistula maturation and the frequency of arteriovenous fistulas [35]. Patients who benefit from vascular mapping are particularly those with:

- insufficient clinical examination (absent pulses, obese, multiple previous access surgery),
- possible arterial disease (diabetes, cardiovascular disease, older age),
- possible venous disease (previous cannulation) [36].

In order to perform a good vein mapping, a proper technique should be used. Firstly, we need to examine the superficial veins using the B-mode (cephalic, basilic, median cubital vein) by checking a compressibility every 2 cm and then by measuring the diameter of the veins in transverse view. Also whenever possible, the proximal deep veins should be examined: brachial, axillary, subclavian. In order to perform a dilatation of the veins and to make a more accurate diameters, tourniquets should be used. Accordingly, the first tourniquet is placed on the upper arm so that deeper veins are occluded, and the second is placed below the elbow to occlude the superficial veins. After B-mode, doppler spectral analysis should be performed with adjustment of an angle at 60 degrees or less and with alignment of Doppler cursor parallel to the vessel walls [37].

Vessel mapping using ultrasound has become the standard of care for preoperative planning of AV access, and Duplex Doppler ultrasound has the capability to provide functional evaluation of vascular access-fistula maturation evaluation and maturation failure thus facilitating early intervention [38].

The following factors indicate adequate vessels for creating distal radio-cephalic AV fistula [39]:

- inner diameter of radial artery ≥ 2 mm,
- inner diameter of cephalic vein ≥ 2.5 mm,
- flow velocity through radial artery $V_{maxS} \geq 50$ cm/s,
- flow through radial artery $Q_{a.radialis} \geq 40$ ml/m.
- Four weeks after the AV fistula creation, the following factors indicate adequately matured AV fistula and a good possibility of achieving puncture [40]:
- diameter of cephalic vein ≥ 4 mm,
- blood flow $Q_{AV} \geq 500$ ml/min.

Finally, maximal blood flow velocity through AV fistula of 100-350 cm/s and blood flow of 500-1000 ml/min are the signs of a good function of AV fistula providing sufficient blood flow for hemodialysis [41].

Lockhart *et al.* showed in their study on 112 patients that there were no differences in the preoperative peak systolic velocity nor in the resistive index (RI) of successful and failed fistulas, but the measurement of the

radial artery peak systolic velocity changes after release of fist clenching identified a subset of female patients with a very low likelihood for success [42].

However, Hasaballah *et al.* found an accuracy of 94.8% in 455 End-Stage Renal Disease patients of duplex based decision in reference to intraoperative findings and post-operative results of upper arm arteriovenous fistulas. Accordingly, they suggest that preoperative duplex planning should be performed in all patients, and that brachiocephalic fistulas should be the first choice in the upper arm because of their best patency rates and lower complications. Brachio basilic fistulas should be considered as a second option, and then grafts, which were most prone to infection (27.7%) and thrombosis (10.6%) [43].

Lauvao *et al.* in their study on 185 native arteriovenous fistula showed no significant difference in fistula maturation according to age, gender, diabetes and body-mass index, but they have underlined that vein diameter was a sole independent predictor of fistula functional maturation [44].

Also, Zadeh *et al.* in their study on 96 hemodialysis patients with AV fistula discovered that the maturation of fistula showed some correlation between duration of maturation period and vein diameter in patients with radiocephalic fistula, but did not show a correlation with arterial diameter, diabetes mellitus, gender and age [45]. It is suggested that after performing a preoperative vein mapping with ultrasonography in patients with a minimal cephalic vein size of 2.0 mm or less, a procedure other than wrist fistula should be considered for optimization of dialysis access [46].

In dialysis patients with a functioning vascular access, the following signs are indicative of malfunction and should prompt initiation of an ultrasound examination of the access [47]:

- **abnormal fistula functioning:** difficult cannulation, thrombus aspiration, elevated venous pressure greater than 200 mmHg on a 300 ml/min pump, elevated recirculation time of 15% or greater, urea reduction rate of less than 60%;
- **clinical signs and symptoms of AV access insufficiency:** access collapse suggesting poor arterial inflow, poorly matured fistula, loss or change in the intensity of thrill, clinical signs of infection, distal limb ischemia, perigraft mass, aneurysm, pseudoaneurysm.
- Duplex ultrasound evaluation of hemodialysis access should include the following examinations:
 - inflow artery proximal to the fistula or graft,
 - inflow artery distal to the fistula or graft,
 - anastomotic sites (fistula: one site, graft: two sites),
 - puncture sites,
 - proximal, mid, and distal outflow vein or graft,
 - axillary and subclavian veins [47].

It is important to emphasize that the sensitivity of ultrasound in the diagnosis of AV fistula and graft stenosis is

very high and comparable to the fistulography especially when performed by an experienced operator [48].

In summary, ultrasound is a relatively inexpensive and readily available tool that has an important contribution for a successful placement and maintenance of dialysis access. Using it to diagnose a stenosis if a clinical problem occurs, helps the interventionist to choose a better approach for the procedure [49]. On the other hand, angiographic evaluation of the artery end veins using radiocontrast optimally visualizes both, peripheral as well as central veins, but exposes the patient to the risk of radiocontrast-induced nephropathy in pre-dialysis patients and has a greater economic cost [50].

Also, ultrasound-guided placement of a central venous hemodialysis catheter is more precise and visualizes anatomical variants and vein thrombosis in regard to landmark technique. In this way, repeated puncture can be prevented, as well as the complications like pneumothorax and arterial laceration [51]. In conclusion, many studies have demonstrated that the use of ultrasound in pre-operative mapping increases the success of AV fistula creation and patency [52,53].

Conclusions

For hemodialysis patients the selection of proper vascular access is a vital issue in regard of preventing complications and unnecessary procedures. It is known that mortality and morbidity among patients who start dialysis with a catheter is two- to three-fold higher than in those who start hemodialysis with a functioning AV fistula [54,55]. Therefore, it is important to carefully prepare and plan the right vascular access for every patient in an individual manner.

The planning, the creation and the monitoring of the vascular access in dialysis patients should involve not only the nephrologist, but also the vascular surgeon and the interventional radiologist in a multidisciplinary approach in order to achieve the maximum benefit for the patients.

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