CLINICAL IMPORTANCE OF EARLY DETECTION OF VASCULAR ACCESS FAILURE IN HAEMODIALYSIS PATIENTS

Nikola Jagić1, Dejan Petrović2, Vladimir Mlakarović3 and Božidar Novaković4
1Center for Radiology, Interventional Radiology Dept. Clinical Center „Kragujevac“, Kragujevac; 2Clinic of Urology and Nephrology, Haemodialysis Dept. Clinical Center „Kragujevac“, Kragujevac; 3Clinic of Internal Medicine, Cardiology Dept. Clinical Center „Kragujevac“, Kragujevac; 4Clinic of Surgery, Vascular Surgery Dept. Clinical Center „Kragujevac“, Kragujevac, Serbia

ABSTRACT
Vascular access for hemodialysis should be performed in patients with chronic kidney disease, if they have endogenous creatinine clearance lower than 25 mL/min. Based on anamnestic data, physical examination and Doppler evaluation of the vessels, a decision is to be made about the kind of AV access in patients with chronic kidney disease: primary radio-cephalic AV fistula, primary brachio-cephalic AV fistula or tunnelling of central venous catheter for haemodialysis. Color Doppler ultrasonography enables estimation of development and vascular access for haemodialysis. Maximum speed of blood flow through vascular access of 100–350 cm/s and blood flow between 500 and 1000 mL/min, are the parameters which express the right functioning of vascular access and adequate haemodialysis. Color Doppler ultrasonography enables early detection of complications in vascular access, a selection of suitable therapeutic procedure for dealing with complications of vascular access, which contributes to significant decrease of morbidity and improvement of life quality of haemodialysis patients. Therefore, this article will serve as a quick orientation by means of exact parameters and a useful tool for everybody who is involved in the treatment of this patient population.

Key words: arteriovenous fistula, haemodialysis, color Doppler

INTRODUCTION
Native arterio-venous (A-V) fistula is anastomosis between the radial artery and cephalic vein (Brescia-Cimino fistula). Arterio-venous fistula should be performed in a patient with chronic renal disease with endogenous creatinine clearance bellow 25 mL/min within one year of planned beginning of haemodialysis treatment (1–3). Under the constant arterial blood pressure flow, venous part of the fistula undergoes dilatation (6–10mm) and thickening process which is called „maturation“ of the fistula. The maturation process should last at least a month, and ideally 3–4 months before the index puncture (1–3). Timely planning of haemodialysis vascular access creation enables good access, good haemodialysis as well as good quality of life for the patient on haemodialysis.

Preoperative Assessment of Vascular Access Development
Before vascular access creation it is necessary to take anamnestic data (about the previous central venous catheter for haemodialysis, diabetes mellitus, peripheral arterial or venous diseases, injuries or surgical interventions in the upper limbs, anticoagulant therapy and coagulation disorders and eventual previous vascular access), perform physical examination of the upper limb blood vessels, Allen test, Doppler evaluation of the upper limb blood vessels and echocardiographic examination (1–3). Preoperative evaluation of the arteries and veins should be performed first in non-dominant hand.

Evaluation of Arteries for A-V fistula
The first step in the arterial system evaluation includes palpation and measurement of arterial blood pressure in the upper limbs (a. brachialis). Difference of more than 20 mm Hg between both hands raises suspicion of proximal stenosis on the side of the lower pressure value (1–3). The second step is Allen test. Allen test serves in the estimation of presence of anastomoses between a. radialis and a. ulnaris, basically the presence and functionality of palmar arches (superficial and deep arch) between the aforementioned arteries (1–4). The third step in the arterial system evaluation is Color Doppler Ultrasonography (CDU). Color Doppler Ultrasonography is used for the measurement of arterial diameter. The inner diameter of the artery ≥ 2 mm enables adequate maturation of the A-V fistula (radio-cephalic A-V fistula), (Table 1).
**Evaluation of veins for A-V fistula**

The first step in the venous system evaluation (‘venous outflow’) includes inspection of the superficial veins of the non-dominant hand (hand planned for vascular access creation), after ‘outflow’ occlusion (cuff inflated in the upper arm above diastolic value for 5 minutes). During the inspection of the superficial veins one should pay attention to continuity and direction as well as their diameter (there should generally be > 5mm to allow adequate development of A-V fistula), compressibility and distensibility of the veins. Color Doppler Ultrasonography (transducer of 10–12MHz) is used for the measurement of the cephalic and basilic vein diameter. The inner diameter of the cephalic vein ≥2.5mm enables adequate maturation of a distal radio-cephalic A-V fistula. For better visualisation of the venous system and accessory vein assessment the DSA (Digital Subtraction Angiography) is employed, (Table 2) (1–3).

**Color Doppler Ultrasonographic evaluation of the upper arm blood vessels enables preoperative anticipation of development of A-V fistula, (Table 3).** A. Radialis inner diameter > 1.6 mm, arterial inflow > 40 mL/min, v. cephalica inner diameter ≥2 mm and flow through the subclavian vein > 400 mL/min are good prognostic parameters of development of distal radio-cephalic A-V fistula (5–9). Arterial inflow ≥40 mL/min anticipates definite flow through fistula of at least 600 mL/min (adequate maturation process) (9). RI (Resistance Index) in a. radialis, after reactive hyperemia, less than 0.7 (RI<0.7) is also a good predictor of development of the native radio-cephalic A-V fistula (5–9). The inner diameter of artery equal or larger than 2.0 mm and peak systolic velocity ≥50 cm/s, in majority of patients, maintain adequate maturation of the distal native radio-cephalic A-V fistula, (Table 3) (5–10).

**Table 1. Evaluation of arterial system for A-V fistula.**

<table>
<thead>
<tr>
<th>EXAMINATION</th>
<th>FINDINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood pressure in the upper limbs</td>
<td>Pressure difference ≤20 mmHg</td>
</tr>
<tr>
<td>Allen test</td>
<td>Positive – palmar arches present</td>
</tr>
<tr>
<td>Color Doppler ultrasonography (CDU)</td>
<td>Inner diameter of the artery-UR a. radialis ≥ 2.0 mm</td>
</tr>
</tbody>
</table>

**Table 2. Evaluation of the veins for A-V fistula.**

<table>
<thead>
<tr>
<th>EXAMINATION</th>
<th>FINDINGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation of the veins with „outflow“ occlusion</td>
<td>Continuity, diameter, distensibility, compressibility</td>
</tr>
<tr>
<td>Color Doppler ultrasonography (CDU)</td>
<td>Inner diameter of the vein - UR v. cephalica ≥ 2.5 mm</td>
</tr>
<tr>
<td>Subtraction angiography</td>
<td>Accessory veins (collaterals) absent</td>
</tr>
</tbody>
</table>

**Postoperative Assessment of Vascular Access Development**

Considerable proportion, 10–25 % of primary arterio-venous fistulas, matures inadequately. Therefore, these ones may not obtain the adequate standard haemodialysis process. Optimal maturing period for A-V fistula is 4–6 weeks (11). Blood flow of more than 400 mL/min through the fistula two weeks after its creation implicates its adequate development. On the other side, blood flow of less than 250 mL/min two weeks after the creation is a predictive sign of inadequate development and possibility of its failure (11). Outflow vein diameter of more than 4mm and blood flow through the fistula of more than 500 mL/min are positive signs of well developed fistula and maintain the adequate haemodialysis (11).

**Assessment of Vascular Access Quality**

Vascular access quality is checked by recirculation as well as by the flow parameters through the fistula. In order to assess recirculation of vascular access the STOP METHOD (stop-blood-flow method) is used (2, 13). After 30 min of haemodialysis, after stopped the ultrafiltration, blood samples are taken from the arterial/venous line (A, V). Blood pump is slowed to 50 mL/min, venous line is clamped, blood pump is turned off (in order to avoid contamination from the arterial line) and shortly afterwards, not longer than 30 sec, the blood sample from the arterial line is taken (S) (2). The method with slow blood flow (low-blood-flow method) is identical, except that the blood sample is supposed to be taken 30 sec after slowing down of the pump (2).

The following formula is used for the recirculation calculation:

$$R = \frac{S - A}{S - V} \times 100(\%)$$

A: concentration of urea in arterial line (mmol/L)
V: concentration of urea in venous line (mmol/L)
S: concentration of urea in serum (mmol/L)
Normal value for the recirculation of vascular access is ≤ 10% (1). Recirculation rise (R > 10%) is a sign of low flow through the fistula and possible stenosis of the vascular access (2).

Blood flow through the vascular access is characterised by the pulsatility, low resistance and high amplitude (high peak systolic and peak diastolic velocity) (13–15). Peak systolic velocity through the vascular access is normally 100–350 cm/s. As a parameter for assessment of the quality of vascular access, blood flow through the access itself (Q_AV) is used according to the following formula:

$$Q_{AV} = \frac{r^2 p / 4 \times V_{mean} \times 60}{mL/min}$$

$r$: inner half diameter of vascular access (cm); $V_{mean}$: mean blood flow velocity through the vascular access, which can be calculated as:

$$V_{mean} = \frac{(PSV \ - \ EDV)}{PI}$$

PSV – Peak Systolic Velocity (cm/s); EDV – End Diastolic Velocity (cm/s) and PI – Pulsatile Index (13–15).

Blood flow through the vascular access is normally 500–1000 mL/min, and these figures account for native fistula and the synthetic graft as well. The threshold value for the flow through the A-V fistula necessary for the adequate haemodialysis is 300mL/min. Flow of less than 300 mL/min leads to the subdialysis and access failure, and more than 1000 mL/min leads to progressive left ventricular dilatation and consecutive heart failure. Blood flow through the PTFE A-V graft < 650 mL/min is accompanied with a higher risk of thrombosis (13–15).

A-V fistula failure

Failure of the A-V fistula can be early and late. Early failure of the vascular access for haemodialysis is accounted for the period between creation and the beginning of the work of the fistula, or first three months of its use. Reasons for early haemodialysis access failure can be divided into two groups:

1) Inflow reasons and
2) Outflow reasons, (Table 4).

Late failure of the A-V fistula on the other hand, is considered if it happens after three months of its use (16).

Adequate maturation of the A-V fistula demands adequate inflow of the arterial blood. One of the reasons of early failure of the vascular access is stenotic process of the vein, nearby the anastomotic site, the so-called juxta-anastomotic stenosis (16). Manipulation with this segment of the vein during surgical access creation can be the cause of the vein damage. In the absence of stenosis, pulse on the spot of anastomosis is soft and compressible, continuous thrill (systolic-diastolic) is present and also auscultatory audible (16). In the case of present stenosis of the vein segment quite close to anastomosis the pulse is harder, intense, thrill is palpable only during systole, and auscultatory only systolic component is present (16).

This type of stenosis requires either PTA (Percutaneous Transluminal Angioplasty) or surgical revision of the vascular access (16).

Good blood outflow is also very important for the adequate development of the vascular access for haemodialysis. The most frequent problems of the outflow tract are small inner diameter of the vein, presence of the accessory veins and stenosis of the proximal part of the outflow vein due to previous trauma or vein puncture, (Table 4) (16).

### Table 4. Causes of early vascular haemodialysis access failure.

<table>
<thead>
<tr>
<th>INFLOW reasons</th>
<th>OUTFLOW reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precondition artery anomalies</td>
<td>Precondition vein anomalies</td>
</tr>
<tr>
<td>Small artery diameter</td>
<td>Small vein diameter</td>
</tr>
<tr>
<td>Atherosclerosis of the artery</td>
<td>Accessory veins</td>
</tr>
<tr>
<td>Acquired reasons</td>
<td>Acquired reasons</td>
</tr>
<tr>
<td>Vein stenosis proximal to anastomosis (juxta-anastomotic stenosis)- segment of the vein nearby the anastomosis</td>
<td>Stenosis of vein limb of the fistula (trauma, vein puncture)</td>
</tr>
</tbody>
</table>

### Protocol for Evaluation of the Early Vascular Access Failure

The first step in the evaluation of early haemodialysis vascular access failure is to know the exact type of the vascular access (16, 17).

The second step is a detailed physical examination of anastomosis of the A-V fistula: pulse is marking the antegrade resistance (peripheral resistance of the outflow vein - segment of the outflow vein nearby anastomosis), whilst the thrill is marking the blood flow through anastomosis itself. On the very spot of anastomosis the pulse is soft. Strong pulse of high intensity is marking the proximal stenosis or obstruction of the outflow vein. Intensity of the pulse is proportional to the severity of stenosis of the outflow vein. Without stenosis the pulse is characterised by systolic and diastolic component. In the case of juxta-anastomotic and proximal outflow vein stenosis, the so-called „downstream stenosis“ the thrill loses its diastolic component, and therefore only systolic component is felt (16, 17).

The third step is a detailed physical examination of the body of the fistula (outflow vein). Normally, pulse is soft and compressible. In the case of the proximal stenosis of the outflow vein (downstream stenosis) pulse is strong and hyperpulsatile. Physical examination also enables assessment of the presence of the accessory veins (16, 17).

The fourth step is estimation of the pulse of the augmentation. Proximally to the anastomotic site (the body of the A-V fistula; the middle third of the forearm) manual occlusion of the outflow vein is performed. If there is not augmentation of the pulse intensity during manual occlusion that implicates a significant degree of stenosis on anastomosis itself. The pulse of augmentation therefore enables assessment of anastomosis stenosis, or stenosis of the inflow artery, namely stenosis of the arterial inflow tract (16, 17). The pulse assessment without manual compression reflects the state of the outflow tract, and with manual compression, the state of the inflow tract (16, 17).
The fifth step includes Color Doppler evaluation of the vascular access. Proximal stenosis of the outflow vein of the access of more than 50% (≥ 50%) is accompanied with higher venous dialysis pressure (VDP > 150 mmHg), higher recirculation of the vascular access (R > 10%), inadequate haemodialysis (Kt/V index < 1.2) and diminished flow through the fistula (QAV < 300 mL/min). Stenosis of the outflow vein of the vascular access rises the risk of thrombosis development and definite access failure (14, 15).

Parameters in the evaluation of A/V fistula stenosis are PSV (Peak Systolic Velocity) and ratio between PSV on the site of stenosis and PSV 2–4 cm proximally from stenosis: VmaxS/VmaxP. Peak systolic velocity of more than 350 cm/s (VmaxS > 350 cm/s) and ratio VmaxS/VmaxP ≥ 0.44, are predictors of haemodynamically important vascular access stenosis (stenosis ≥ 75%) (14, 15). Pressure measurement on the spot of the needle (arterial and venous one) puncture enables the diagnosis of stenosis localised between needles and outflow vein segment nearby Anastomosis (juxta-anastomotic area) (17). Normal ratio aIAP/VAP for A-V fistula is 0.13–0.43; and vIAP/VAP 0.08–0.34 (17).

Rising of the ratio for 0.2 (aIAP, vIAP) is considered an indication for DSA (Digital Subtraction Angiography) of the vascular access (17).

DSA should also be performed when venous dialysis pressure VDP is > 150 mm Hg (30 minutes after the beginning of haemodialysis with extracorporal blood flow of 200 mL/min); diminished flow through the A-V fistula (QAV < 300 mL/min); peak systolic velocity on the spot of stenosis of > 350 cm/s; VmaxS/VmaxP ≥ 0.44 as well as when ratio aIAP/VAP < 0.13 or ≥ 0.44; when ratio vIAP/VAP < 0.08 or ≥ 0.35, (Table 5) (14–17).

Table 5. Criteria for angiography of vascular access for haemodialysis based on measurement of blood pressure on the site of the arterial and vein haemodialysis needle puncture.

<table>
<thead>
<tr>
<th>Segment of the A-V fistula</th>
<th>aIAP/VAP</th>
<th>vIAP/VAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial inflow segment</td>
<td>&lt; 0.13</td>
<td>&lt; 0.08</td>
</tr>
<tr>
<td>Juxtaanastomotic segment</td>
<td>≥ 0.44</td>
<td>&lt; 0.35</td>
</tr>
<tr>
<td>Venous outflow segment</td>
<td>≥ 0.44</td>
<td>≥ 0.38</td>
</tr>
</tbody>
</table>

Adequate haemodialysis depends on the quality and functionality of the vascular haemodialysis access. Complications of the vascular access are among the most important reasons for morbidity and mortality of the patients with terminal chronic renal failure, table 6 (17–22). After the creation of the vascular access (native A-V fistula), periodic monitoring (every two weeks), early detection of function disturbance of the vascular access (stenosis or presence of the accessory veins) and adequate therapy are all factors that dramatically lower incidence of access failure (22–24). Vein stenosis is defined as lumen shrinkage of ≥ 50% compared to the normal vein lumen. According to the localization stenosis of the A-V fistula can be juxtaanastomotic, downstream (proximal) and central. Juxtaanastomotic stenosis IAS is defined as stenosis of the segment of the vein quite near anastomosis. Proximal stenosis is defined as stenosis of the outflow vein from the juxta-anastomotic segment to the central vein. The central vein stenosis is lumen shrinkage of ≥ 50% in subclavian, innominate vein or superior caval vein (SCV) (12).

Table 6. Risk factors for cardiovascular complications connected with vascular haemodialysis access.

<table>
<thead>
<tr>
<th>No</th>
<th>RISK FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Raised blood flow through the AV fistula-QAV &gt; 1000 mL/min</td>
</tr>
<tr>
<td></td>
<td>a) congestive heart failure</td>
</tr>
<tr>
<td></td>
<td>b) digital steal phenomenon</td>
</tr>
<tr>
<td>2.</td>
<td>Diminished blood flow through the AV fistula-QAV &lt; 300 mL/min</td>
</tr>
<tr>
<td></td>
<td>a) inadequate haemodialysis - Kt/V index &lt; 1.2</td>
</tr>
<tr>
<td></td>
<td>b) malnutrition - hypoalbuminemia (albumin &lt; 35 g/L)</td>
</tr>
<tr>
<td>3.</td>
<td>Infection of vascular access</td>
</tr>
<tr>
<td></td>
<td>a) infective endocarditis</td>
</tr>
<tr>
<td></td>
<td>b) chronic microinflammation - CRP &gt; 5.0 mg/L</td>
</tr>
</tbody>
</table>

Detection of the patient population with early access failure enables timely therapeutic approach, therefore lower morbidity and better quality of life for haemodialysis patients (25–26). Angioplasty (PTA) of vascular access stenosis and ligation of accessory veins enable proper development of the A-V fistula, good blood flow and adequate haemodialysis (25–26).

CONCLUSION

Strategy of searching for early detection of the patients with early failure of the A-V fistula provides timely interventional procedure or surgical correction of the accessory veins thus having a direct impact on their life quality.

REFERENCES


