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Pregledni rad

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CLINICAL IMPORTANCE OF COLOR DOPPLER ULTRASONOGRAPHY IN PREOPERATIVE ASSESMENT OF HEMODIALYSIS VASCULAR ACCESS CREATION

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Summary: Chronic kidney failure is characterized with progressive and ireversible diminishing of glomerular filtration rate. Arterio-venous fistula (AVF) for hemodialysis should be created in patients with endogenous creatinine clearance ≤ 20 mL/min/1,73m^2. Inner diameter of a.radialis ≥ 2.0 mm, inner diameter of v.cephalica ≥ 2.5 mm, flow velocity through the a.radialis — VmaxS ≥ 50 cm/s and flow through the a.radialis — Qa.radialis ≥ 40 mL/m intenable adequate maturing of distal radio-cephalic AVF. Diameter of v.cephalica ≥ 4.0 mm and blood flow Q_{AV} ≥ 500 mL/min, four weeks after the AVF creation, indicate adequately matured AVF and possibility of puncturing it. Maximal blood flow velocity through AVF of 100–350 cm/s and blood flow of 500–1000 mL/min, are signs of good function of AVF and adequate hemodialysis. Color Doppler ultrasonography enables preoperative planning of AVF, early complication detection, choice of appropriate therapeutical procedure for complication treatment, estimation of maturation, prime time for puncture and AVF function, which all contribute to a significant morbidity decrease and better life quality in hemodialysis patients.

Key words: arterio venous fistula, hemodialysis, color doppler.

INTRODUCTION

Chronic kidney failure is characterized with progressive and ireversible diminishing of glomerular filtration rate (GFR) (1–4). When glomerular filtration rate falls bellow 20 mL/min/1.73 m^2, and serum creatinine concentration rises above 220 mmol/L, chronic kidney failure progressively advances, leading to ireversible renal parenchymal disorder and finally, to an end stage renal disease (1–4). In patients with diagnosed chronic kidney failure cephalic veins should be preserved for arterio-venous fistula (AVF) creation (5–7). If hemodialysis planned, vascular access should be created when endogenous creatinine clearance — Ccr ≤ 20 mL/min/1.73 m^2, and regular hemodialysis treatment should be started when Ccr ≤ 10 mL/min/1.73 m^2. Dialysis should start earlier if there is hypervolemia (Ccr = 15–20 mL/min/1.73m^2) (5–7).

Native distal radio-cephalic AVF is anastomosys between radial artery and cephalic vein (Brescia-Cimino fistula). Upon arterial flow venous limb of AVF becomes dilated and thickened (6–10 mm) ("maturation of AVF"). Maturation of native AVF should take at least a month, ideally 3–4 months before puncture (5–8). Planning of prime time for creation of vascular access for hemodialysis enables creation of good vascular access, adequate hemodialysis, cardiovascular morbidity and mortality decrease and better life quality in hemodialysis patients (5–9).

PREOPERATIVE ASSESSMENT OF VASCULAR ACCESS

Before vascular access creation it is mandatory to take anamnestic data (data about previous central venous dialysis catheter, diabetes mellitus, peripheral arterial and venous diseases, trauma and surgical interventions at upper limbs, anticoagulant therapy and coagulation disorders and previous vascular access), per-

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form physical examination of upper limb vessels, Allen test, upper limb vessels Color Doppler evaluation and echocardiography (6, 7, 8, 9). Preoperative evaluation of arteries and veins should be performed first in patient's non-dominant arm (6, 7, 8, 9).

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 (poststenotic dilatation) (6, 7, 8, 9). 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 (6, 7, 8, 9). The third step in the arterial system evaluation is Color Doppler ultrasonography (CDU). Color Doppler ultrasonography is used for the measurement of arterial diameter, velocity and flow through the arteries of non-dominant arm (10, 11, 12).

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 arm (arm planned for 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 > 5 mm to allow adequate development of A-V fistula), compressibility and extensibility of the veins (6, 7, 8, 9). Second step is Color Doppler ultrasonography (transducer of 10–12 MHz). It is used for the measurement of the cephalic and basilic vein diameter, and flow through the subclavian vein (10, 11, 12). The inner diameter of the cephalic vein ≥ 2.5 mm enables adequate maturation of a distal radio-cephalic A-V fistula. For better visualisation of the venous system and accessory veins assessment the digital subtraction angiography (DSA) with 20–40 mL of contrast is employed (6, 7, 8, 9).

CLINICAL IMPORTANCE OF COLOR DOPPLER ULTRASONOGRAPHY

Ultrasound equipment and technique of examination

Color Doppler ultrasonography reqires ultrasound machine equiped with B-mode and Color and Doppler mode with linear transducer od 5–7.5 MHz as well. Upper limb arteries are traced longitudinally by Color Doppler ultrasonography from distal subclavian artery (a.subclavia) till the radial (a.radialis) and ulnar arteries (a.ulnaris). Arterial segments in which disturbance in color appearance is detected require additional assesment by B-mode and spectral doppler, for detection of stenosis or occlusion. Stenosis is considered hemodinamically significant if more 50%, and stenosis discovered by ultrasonography before vascular access creation, requires angiography (golden standard in blood vessels imaging) (13, 14).

Clinical importance

In evaluation of a.radialis, for preoperative assessment of arterio-venous fistula creation, one should examine: inner diameter of a.radialis, morphology of the wall of a.radialis (measuring of thickness of intima-media, atherosclerotic plaques, presence of calcifications), velocity and flow through a.radialis, as well as response of a.radialis to reactive hyperemia (10, 11, 12, 13, 14). Distal a.radialis diameter measurement (intima to intima distance) and measurement of intima-media thickness (IMT) is performed in longitudinal scan, in distal forearm, just above the wrist. Inner diameter of a.radialis — Id ≥ 2.0 mm, flow velocity through the a.radialis — VmaxS ≥ 50 cm/s and blood flow through the a.radialis — Qa.radialis ≥ 40 mL/min maintain adequate maturing of distal radio-cephalic AVF (10, 11, 12, 13, 14). Measurement of diameter of a.radialis in systole and diastole enable assessment of its pulsatility (14).

Evaluation of venous system includes examination of cephalic vein in the forearm. Cephalic vein is traced downstream (proximally) all way down till the confluence with deep venous system (14). Besides cephalic vein, assessment includes basilic vein as well (v.basilica). Assessment of appropriateness of cephalic vein for creation of vascular access for hemodialysis includes: appearance, diameter, extensibility (strech degree, elasticity of the vein). Veins for creation of vascular access must be at least shallower than 6 mm from the skin (14). Diameter of the vein is measured before and 2 min after the cuff application, in order to estimate percentage of diameter or distensibility of the vein (14). Diameter of v.cephalica ≥ 2.5 mm enables adequate maturation of AVF (enables good outcome of AVF), equally as diameter of v.cephalica ≥ 2.5 mm after the cuff application. Minimal diameter of 2.5 mm with cuff indicates good outcome of AVF (8% early insufficiency, 83% functional AVF a year after primary creation — functional primary patency) (14). Inner diameter of cephalic vein ≥ 2.5 mm and flow through the subclavian vein above 400 mL/min enable adequate maturation of distal radio-cephalic AVF (13, 14).

Preoperative ultrasound examination of upper limb blood vessels for assessment of AVF outcome is indicated in patients with increased risk of arterio-venous fistula insufficiency (elderly, female gender, obesity, diabetes mellitus, cardiovascular diseases) (14). It is specially indicated in patients with difficult physical examination blood vessel assessment (pulseless, previous numerous surgical attempts of vascular access creation), those with any arterial disease (arteritis, atherosclerosis) and patients with venous disease/disorder (previous punctures, previously placed central venous hemodialysis catheters) (14). In conclusion, pre-operative ultrasonographic examination of upper limbs blood vessels should be performed in high risk patients for better outcome of AVF (14).

FAILURE OF AVF FOR HEMODIALYSIS

Significant number of AVF doesn't develop adequately (28–53%) (15, 16). Failure of the A-V fistula can be early and late. Early failure of the vascular access for hemodialysis is accounted for the period between creation and the beginning of the work of the fistula, or the first three months of its use (15, 16). Reasons for early haemodialysis access failure can be divided into two groups. First group consists of inflow problems, whilst second one consists of outflow problems (table 1) (15, 16). Late failure of the A-V fistula on the other hand, is considered if it happens after three months of its use for hemodialysis (16).

Adequate maturation of the A-V fistula demands adequate inflow of the arterial blood (15, 16). 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 (15, 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 weak and compressible, continuous thrill (systolic-diastolic) is palpable and also auscultatory audible (15, 16). In the case of 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 (15, 16). This type of stenosis requires either percutaneous transluminal angioplasty (PTA) or surgical revision of the vascular access (17, 18).

INFLOW problems	OUTFLOW problems
Preexisting arterial anomalies	Preexisting venous anomalies
• Anatomically small • Atherosclerosis disease	• Anatomically small • Accessory veins
Acquired	Acquired
• Juxta-anastomotic stenosis	• Fibrotic vein (stenotic)

Modified according to reference [15].

Table 1. Causes of early fistula failure

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 veinpuncture (table 1) (15, 16).

ASSESSMENT OF PRIME TIME FOR PUNCTURE OF AVF

In clinical practise, for nephrologists, it is very important to maintain good outcome of vascular access for hemodialysis (preopreative planning of vascular access creation, adequate maturing and prime time for puncture of vascular access for hemodialysis) (17, 18). Along the way to a good vascular access, which enables adequate hemodialysis, there are numerous obstacles: late presentation of the patient to nephrologyst, preoperative vascular mapping of upper limb blood vessels, AVF creation, adequate maturation of AVF, prime time for puncture of AVF (17, 18). Every patient who begins hemodialysis treatment should have adequately matured AVF, ready for puncture. Practically, it means that AVF should be created well-timed, in predialysis period of terminal chronic kidney insufficiency, along with previous preoperative mapping, which should give precise information to a surgeon about the diameter of the arteries and veins, presence of venous thrombosis or stenosis. Based on these, surgeon makes decision about localisation and type of vascular access creation (17, 18). Three most frequent reasons for inadequate maturing of AVF are: local stenosis, presence of great accessory vein branches and very deep AVF (assessment of need for efferent vein superficialisation) (17, 18).

Procedures for improvement of native AVF outcome are shown in table 2. Postoperative (four weeks after the AVF creation) ultrasonography examination helps in assessment of AVF maturation. Diameter of efferent vein ≥ 4.0 mm and blood flow Q_{AV} ≥ 500 mL/min indicate adequately matured A-V fistula and possibility of its puncture, table 2 (17, 18).

ASSESSMENT OF AVF FUNCTION

In order to assess vascular access function Color Doppler ultrasonography of blood flow through the native AVF is used. Blood flow through the vascular access is characterized by pulsatility, low resistance and

MEASURES	
1.	Pre-ESRD nephrology care
2.	Preoperative vascular mapping: • arterial diameter ≥ 2.0 mm • venous diameter ≥ 2.5 mm • patent venous drainage system (no stenosis or thrombosis) • abscence of central vein stenosis or thrombosis (venogram or MRV in selected patients)
3.	Postoperative sonographic assessment of fistulas: • early (4–6 wk) postoperative imaging of fistulas • criteria for mature fistulas: • fistula diameter ≥ 4.0 mm • access flow ≥ 500 mL/min • distance from skin ≤ 5.0 mm • assess for remediable anatomic lesions • stenosis • accessory veins • excessively deep fistula
4.	Salvage procedures for immature fistulas: • angioplasty or surgical revision for stenosis • ligation of accessory veins • superficialization of deep fistulas
5.	Improve proficiency of dialysis staff in cannulation of new fistulas
6.	Surveillance for stenosis
7.	Thrombectomy of clotted fistulas

ESRD — end-stage renal disease, MRV — magnetic resonance venography
Modified according to reference [17].

Table 2. Measures to increase fistula prevalence

high amplitude (high peak systolic and end dyastolic velocity) (19, 20). Peak systolic velocity through the vascular access is normaly 100–350 cm/s (19, 20). As a parameterfor assessment of vascular access function blood flow through the access is used — Q_{AV}. Flow through the vascular access is counted according to appropriate equation (19, 20):

$$Q_{AV} = r^2\pi/4 \text{ x Vmean x } 60 \text{ (mL/min)}$$

where: r — inner radius of vascular access (cm), and Vmean — mean velocity through the access, calculated from equation:

$$\text{Vmean} = (\text{PSV} - \text{EDV})/\text{PI},$$

where: PSV — peak systolic velocity (cm/s), EDV — end diastolic velocity (cm/s), and PI — pulsatility index.

Blood flow through the vascular access is normaly 500–1000 mL/min, for an AVF, and for A Vgraft as well. The lowest blood flow through the A Vfistula indispensable for adequate hemodialysis is 300 mL/min. Flow below 300 mL/min leads to a sub dialysis and cessation of AVF, while flow above 1000 mL/min, leads to progressive left ventricle dilatation and heart failure. Flow through the PTEF A V graft < 650 mL/min is followed by increased risk for thrombosis (19, 20).

Color Doppler ultrasonography of AVF should be prformed before dialysis or when dialysis is not planned, in order to avoid infection (as a result of an examintion) or bleeding from AVF puncture site (19, 20). Before ultrasonography examination of AVF anamnestic data about vascular access should be collected (number of AVF created, actual fistula age, previous infections, previous diseases that might have damaged blood vessels) and data about the nature of the problem (low arterial blood flow, increased venous dialysis pressure, difficulties at needle puncture, collateral development, puncture site bleeding from AVF after hemodialysis, pain and swelling in the limb with vascular access, progressive heart failure as a consequence of increased flow through the vascular access, suspicious infection of vascular access) (19, 20).

CLINICAL IMPORTANCE OF GOOD AVF HEMODIALYSIS OUTCOME

Adequate hemodialysis depends on quality and degree of functionality of vascular access. Complications of vascular access for hemodialysis are among major causes of morbidity and mortality increase in patients with end stage renal disease, table 3 (21, 22, 23, 24, 25, 26).

Blood flow through the AVF for hemodialysis influences remodelling of cardiovascular system and heart function. After creation, hemodialysis vascular access increases cardiac minute volume for 10–20% (25). Complications related to AVF creation contribute to a

Risk factors	
1.	Increased flow through the AV shunt — QAV > 1000 mL/min a) congestive heart failure b) distal steal phenomenon
2.	Decreased flow through the AV shunt — QAV < 300 mL/min a) inadequate hemodialysis — Kt/V index < 1.2 b) malnutrition-hypoalbuminemia (albumin < 35 g/L)
3.	Infection of arteriovenuos shunt a) infective endocarditis b) chronic microinflammation — CRP > 10 mg/L

Modified according to reference [21].

Table 3. Risk factors for the development of cardiovascular complications in association with arteriovenous shunt for hemodialysis

left ventricle hypertrophy, worsening of coronary ischemia and development of congestive heart failure (25, 26, 27, 28, 29). Left ventricle hypertrophy is adaptive response to increased cardiac work due to a left ventricle volume overload and risk factor for bad outcome in hemodialysis patients (25, 26, 27, 28, 29, 30). Patients with high-flow AVF have high risk for congestive heart failure development and express significant end-diastolic volume of left ventricle (25, 26). Most clinicians believe that AVF shouldn't be created in patients with diminished heart function (ejection fraction less than 30%) (25).

Prevalence of infective endocarditis in hemodialysis population is high up to 20% (31). In hemodialysis patients vascular access is mostly primary site of infection causing bacteriemia and infective endocarditis. Bacteriemia connected with vascular access puncture is frequently present in patients treated with hemodialysis (one episode in 100 patients per month). Risk of bacteriemia depends on type of vascular access (native AVF, synthetic A-V graft, central venous catheter for hemodialysis), and minimal risk is with puncture of native vascular access (31).

CONCLUSION

Color Doppler ultrasonography enables preoperative planning of AVF creation, assessment of prime time for puncture, early detection of complications and choice of appropriate therapeutic procedure for their treatment, which contribute to a significant decrease of morbidity and better life quality in hemodialysis patients (32, 33, 34).

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Sažetak

KLINIČKI ZNAČAJ COLOR DOPPLER ULTRASONOGRAFIJE U PREOPERATIVNOM PLANIRANJU IZRADE VASKULARNOG PRISTUPA ZA HEMODIJALIZU

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Hroničnu slabost bubrega odlikuje progresivno i nepovratno smanjenje jačine glomerulske filtracije. Arterio-vensku fistulu (AVF) za hemodijalizu treba uraditi kod bolesnika kod kojih je klirens endogenog kreatinina ≤ 20 mL/min/1,73 m^2. Unutrašnji dijametar a.radialis ≥ 2.0 mm, unutrašnji dijametar v.cephalica ≥ 2.5 mm, brzina protoka krvi kroz a.radialis — VmaxS ≥ 50 cm/s i protok krvi kroz a.radialis — Qa.radialis ≥ 40 mL/m obezbeđuju adekvatno sazrevanje distalne radio-cefalične AVF. Dijametar v.cephalica ≥ 4.0 mm i protok krvi Q_{AV} ≥ 500 mL/min, četiri nedelje posle izrade AVF, ukazuju na adekvatno sazrelu AVF i na mogućnost njene punkcije. Maksimalna brzina protoka krvi kroz AVF od 100 do 350 cm/s i protok krvi od 500 do 1000 mL/min, ukazuju na dobru funkciju AVF i adekvatnu hemodijalizu. Color Doppler ultrasonografija omogućava preoperativno planiranje izrade AVF, rano otkrivanje komplikacija, procenu razvoja, pravovremene punkcije i rada AVF, što doprinosi značajnom smanjenju morbiditeta i poboljšanju kvaliteta života bolesnika na hemodijalizi.

Ključne reči: arterio-venska fistula, hemodijaliza, color doppler.

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