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Editorial comment

Ultrasonography Mapping of Blood Vessels Before Arteriovenous Fistula Construction

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Introduction

End-stage renal disease (ESRD) leads to severe illness and death if left untreated. The number of patients requiring renal replacement therapy by haemodialysis is rising rapidly [1-2]. A well functioning vascular access is a prerequisite for successful haemodialysis treatment. Achieving long-term haemodialysis vascular access is becoming a challenge because of an increase in elderly haemodialysis patients with various co-morbidities that are associated with poor and diseased vessels. This makes successful vascular access creation cumbersome [3]. To reduce vascular access related complications, autogenous arteriovenous fistulas (AVF) are preferred over arteriovenous grafts (AVG) [3,4]. The clinical success of AVF is jeopardized by high early failure and non-maturation rates. Early failure and no-maturation necessitate salvage procedures and the use of indwelling central venous catheters. Guidelines recommend the use of diagnostic modalities, duplex ultrasound (DUS) in particular, to enable tailored vascular access creation for individual patients to avoid vascular access early failure and non-maturation [3,4]. In order to increase the number of mature and functional AVFs, adequate history taking, physical examination and preoperative assessment of upper extremity vessels are important to potentially prevent early AVF thrombosis. Increasingly, arterial and venous diameters as well as the presence and location of pre-existing atherosclerotic occlusive disease and venous stenosis, occlusions and side-branches are used to guide the choice of fistula type and location. Consequently, interest has risen in preoperative imaging of upper extremity vessels. The goal of preoperative imaging is assessment of vessel calibre and identification of sites where arteries and veins are of suboptimal quality of access purposes [5-8].

The current review will provide the radiologist and nephrologists with an overview of the clinical role and relative merits and shortcomings of physical examination and DUS in the preoperative work-up of patients awaiting surgical creation of vascular access for haemodialysis.

History taking and physical examination

Underlying any pre-surgical workup is a thorough history and physical examination [9-11]. Females, elderly patients and patients suffering from diabetes mellitus, obesity, cardiovascular morbidity, and patients with history of previous vascular access procedures, especially central venous catheters as well as previous limb or thoracic surgery or radiation therapy, are at increased risk of AVF non-maturation. Physical examination is an important and sometimes valuable tool. Skin lesions, local infections, generalized dermatological problems and scars may indicate problems for AVF creation.

Vigorousness of arterial pulsation in the brachial, radial and ulnar arteries is reasonable measures for the quality of the arterial tree. The use of the Allen test for information about palmar arch patency in the workup prior to vascular access creation remains controversial and should be considered of little clinical value [12].

The superficial venous system should be assessed before and after application of a proximal tourniquet to determine venous compliance. Venous continuity, calibre, compliance, compressibility and the presence of accessory veins determine the suitability of each vein for AVF use. Although physical examination can be clinically valuable preoperative tool, it should be recognized that it is challenging and of limited value in obese patients [10]. Malovrh found that physical examination failed to identify suitable vessels in over half of all patients undergoing dialysis access surgery [6]. Details of history and physical evaluation are shown in Table 1.

Duplex ultrasonography

Beside physical examination non-invasive ultrasonography of upper extremity arteries and veins should be performed before vascular access creation, especially in risk patients for critical quality of vessels like elderly and diabetics. DUS enables assessment of vessel parameters such as patency, diameter, flow and flow velocities. Multiple studies have found that the application of DUS resulted in changes in surgical procedures, changes in site of exploration, a decrease in unsuccessful explorations, an increase in the relative number of AVFs created, and a decrease in non-maturation rates, when compared to the use

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of physical examination alone [6,8,10,13]. It remains to be established whether a combination of parameters might enable better prediction of vascular access function and minimize early failure and non-maturation rates.

Duplex ultrasonography of veins

The superficial venous system of the upper extremity is easily assessable by DUS and results in detection of more veins compared to physical examination alone [10,14-15]. Routine preoperative sonographic vascular mapping results in increase of patients with suitable veins. Many of patients were found to have large calibre vein that were simply too deep to be visualised. Malovrh [6] reported that the veins were clinically visible only in 54/116 (46.5%) of patients and from 62/116 (53.5%) patients with no visible veins they were detected by ultrasound in 48/62 (77.4%).

Table 1. Key elements of the history and physical examination in planning haemodialysis access surgery

Patient history	
	Age, onset and cause of CKD
	Concomitant illness (*e.g. hypertension, diabetes, coronary artery disease, peripheral vascular disease*)
	Smoking, drugs and alcohol
	Medication: *antiplatelet agents and anticoagulants*
	Location and type of prior vascular access procedures
	Prior placement of central catheters, pacemakers or defibrillators
Physical examination	
	Bilateral blood pressure
	Look for skin lesions, infections and scars
	Arterial evaluation: radial, ulnar, brachial
	Assess quality of the arterial pulse (absent, weak, normal, strong)
	Vein evaluation
	Apply a simple tourniquet or blood pressure cuff
	Use help of gravity to distend veins
	If need be exercise and warm the limb
	Make sure vein is no thrombosed by collapsing and refilling
	Look for venous bifurcation, side branches and accessory veins

DUS derived venous diameters have been reported as and important parameter to predict vascular access outcome. Vein diameters smaller than 1.6 to 2.5 mm has been associated with AVF failure [6,9,13,]. However, reported cut-off diameters are inconsistent and the exact cut-off diameter remains a subject of discussion. For assessment of venous diameter a proximally applied cuff should be used to induce venous dilatation for better appreciation of “maximum” or “true” venous diameter. An inflatable pressure cuff or tourniquet at the upper arm is recommended to induce venous dilatation. Determination of venous diameter is not straightforward because superficial venous cross sectional area is pressure dependent and non-circular in shape and may have important consequences for preoperative diameter measurements. There is no consensus on how exactly venous diameter should be measured. Reported vein mapping protocols differ by venous congestion method and exact venous congestion pressure [16]. Planken *et al.* found that diameter measurements on B-mode images are largely observer independent. Both maximum and minimum venous diameters should determined at a venous congestion pressure >40 mmHg [17]. Measurement condition has important influence on venous diameter. Time of measurement during the day, room temperature, patient positioning and the type of venous congestion method used have a significant effect on superficial venous diameter [16-17]. Measurement should be performed in the morning, room temperature about 22^{o}C is wanted, patient must be in the supine position with the arm next to the body at heart level and a 10 to 15 minutes acclimatization period are required. Two dimensional linear probe, pulse wave Doppler, and colour wave Doppler at 7-10 MHz ordinary is used. Furthermore, DUS also allows for assessment of local haemodynamic. During deep inspiration subclavian vein flow-velocities assessed by DUS are increased and absence or diminished flow or loss of venous compressibility is important finding indicative for local venous stenosis or occlusion and as such associated with a higher risk of vascular access early failure and non-maturation [15]. Dynamic parameters to characterize upper extremity veins include flow and velocity measurements as well as assessment of flow velocity changes due to respiratory manoeuvres.

The capacity of superficial veins to dilate due to venous congestion (compliance, distensibility) has been reported to be higher within group of patients in whom AVF creation was successful compared to patients with AVF that failed to mature [15]. Planken *et al.* concluded that forearm superficial venous compliance measurements are poorly reproducible due to poor reproducibility of venous diameters at low congestion pressures [17]. Other studies showed that forearm venous distensibility is a predictor of AVF success, whereas luminal diameters are not [15,18,19]. Venous distensibility is determined by measurement of venous diameter before and than after proximal compression.

Duplex sonography of arteries

Preoperative DUS examination should include assessment of the arteries from the radial and ulnar arteries up to the infraclavicular subclavian artery.

The exact course and continuity as well as the presence of stenosis should be addressed. For detection of stenosis in the upper extremity arterial system, DUS has a sensitivity and specifity of 90.9% and 100% for the subclavian artery, 93.3 and 100% for upper arm arteries, 88.6 and 98.7 % for forearm arteries [20].

The cause of most early AVF failure is often unknown although the quality of the radial artery is thought to play an important risk. Important morphological parameter is arterial diameter. Preoperative DUS arterial measurements correlate well with operative diameter measurements although they reflect a light overestimation [6]. Diameter cut-off <1.5 mm have been associated with increased non-maturation rates of AVFs. In different studies different cut-off have been suggested (1.5 to 2.0 mm) [9,13,15]. Very small arteries (e.g. less than 1.5 mm) will likely fail but above this lower limit preoperative vessel size does not accurately predict maturation. Malovrh demonstrated an immediate patency rate of 92% in patients with a preoperative internal diameter >1.5 mm in the feeding artery, as compared to a maturation rate of 45% in patients with an internal diameter <1.5 mm. At 12 weeks, the patency rate in the two groups was 83% and 36%, respectively [6]. Arterial wall calcifications can be detected well by ultrasound, which shows hyperechogenicity and wall irregularities. Persic *et al*. examined 129 patients aged 75±6 (65-93) years, 58% men, 37% diabetics by ultrasound before AV fistula construction. The inner diameter of veins (under compression) and arteries, were measured. The presence of arterial calcifications was noted. The positions for possible native AV fistula construction (radiocephalic and brachiocephalic) were suggested and an AV fistula was constructed by a trained nephrologist. An adequate cephalic vein was present in 76 (59%) in the right arm, and in 83 (64%) patients in the left arm. Suitable veins in the forearm were recorded in 73 (57%) patients on the right and in 76 (59%) patients on the left side. The inner diameter of radial artery 2.3 ± 0.4 mm and calcification in 36% was found. In 32% of patients, one native AV fistula was possible, in 17% two, in 23% three and in 18% four, while in 10% no AV fistula was possible. In 84% of patients AV fistula was constructed, with no significant difference in nondiabetic vs. diabetic patients (88% vs. 80%) or females vs. males (87% vs. 83%). It was concluded that native AV fistula can be constructed in the majority of elderly patients, often in multiple positions, with no significant differences in terms of sex or diabetic status [21].

Many studies suggest that the functional ability of the artery to dilate and achieve a rapid increase in blood flow after surgery may be the most important determinant for fistula maturation [5-6,8,13,15]. Consequently, it is obvious that not only the initial diameter but also the arterial compliance affect access outcome. The distensibility of the arterial wall can be assessed preoperatively by evaluating the Doppler waveform in the radial artery during reactive hyperaemia, induced by reopening a fist that was clenched for 2 min. After releasing the fist high-resistance triphasic Doppler ultrasound signal with clenched fist (regular signal of peripheral arteries) changes to a low-resistance biphasic waveform and the resistance index (RI) at reactive hyperaemia can be calculated using the formula: RI=(maximal systolic velocity - minimal diastolic velocity) divided by maximal systolic velocity.

Instead of clenching the fist a cuff above the cubital fossa and inflated to 20 mmHg above systolic pressure could be used to provoke reactive hyperaemia and than hyperaemic respond of brachial and radial artery could be measured [22]. Impaired hyperaemic response has been documented in patients with chronic renal failure, smokers, diabetics, and in patients with coronary artery disease or hypertension. A preoperative RI of ≥0.7 in the feeding artery after release of the fist indicates that arterial blood flow will not increase sufficiently so that the chance of successful creation of an AVF is reduced. We recommend preoperative screening to exclude an inappropriate response to reactive hyperaemia. This manoeuvre is especially helpful in planning the location of the initial operation, i.e. selecting the wrist/forearm or elbow region [6,15,23].

Table 2. Evaluation of vessels by duplex ultrasonography prior to arteriovenous fiatula construction

Venous evaluation	
	Appearance of the veins
	Put tourniquet or blood pressure cuff inflated to 70 to 80 mmHg
	Trace cephalic vein from distal part of forearm toward axilla
	Examine veins for continuity, side branches and accessory veins
	Measure internal diameter at different parts of vein (1.6 to 2.5)[6,9,13]
	After releasing tourniquet/cuff measure internal diameter-difference is the vein distensibility
	Test changes of venous Doppler signal during deep inspiration – increased flow during inspiration, probably no proximal stenosis
	Choose the most distal part of a suitable vein
Arterial evaluation	
	Start artery assessment at the nearest place of a suitable vein
	Measure luminal diameter (1.6 to 2.0 mm)[6,9,13], wall thickness and amount of calcification
	Assess Doppler waveform, systolic velocity, diastolic velocity, resistive index (normally ≥1)
	Consider reactive hyperaemia test with clenching the fist for 2 minutes, calculate resistive index (≤0.7)[6,15] – provide distensibility of artery
	Choose the most appropriate region of artery according to the most appropriate region of the suitable vein but as distal as possible

Another possible cause for AVF failure is pre-existing intimal hyperplasia [6,24]. Intima-media thickness (IMT) can be measured by high-resolution ultrasonography using linear 7-10 MHz linear transducer on a longitudinal ultrasound image. The IMT is defined as the distance between blood-intima and media-adventitia interfaces and the internal diameter is defined as the distance between blood-intima interfaces of anterior and posterior walls. Ku *et al.* reported that IMT is significantly increased in uraemic patients compared to healthy person. There was also a significant negative correlation between internal diameter and IMT [25]. The presence of atherosclerotic changes (hyperechogenicity and wall irregularities) and calcifications of the artery wall have to be estimated. When the vessel wall of the examined artery appeared smooth, atherosclerotic changes are classified as absent, otherwise as present. Calcifications of the artery wall are recorded and classified into four categories: absent, mild, moderate, and severe [21]. Algorithm for vessels evaluation is shown in Table2.

Conclusions

Preoperative physical examination provides essential information about patient needed AV fistula construction but in last decade is not sufficient any more because more and more elderly and diabetic patients are accepted for long-term dialysis treatment and a rising proportion of patients with history of dialysis therapy over more than 20 years are observed presenting special vascular, mainly arterial problems. Non-invasive assessment of veins by duplex sonography is very helpful in patients with inadequate clinical visible veins.

In this way we can get also more information about functional characteristics of the veins and delineate venous outflow. A calcified artery with small lumen and a thickened wall will never provide adequate fistula function. Duplex sonography is method of choice for evaluation of the arteries. The advantages of Duplex sonography in comparison to phlebography, native X-ray or arteriography are that this is non-invasive method and beside morphological information enables information about functionnal characteristics of vessels. On the base of morphological and functional characteristics of the arteries and veins determined by duplex sonography the optimal site for AV fistula construction should be selected The consequences of such procedure are less surgical interventions, earlier maturation of AV fistulas, less stress for patients and at last but not least less money for AV fistula surgery.

Conflict of interest statement. None declared.

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