

EDUCATIONAL ARTICLE

Preoperative Radiological Assessment for Vascular Access

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There is increasing evidence that routine preoperative duplex scanning ultrasound cannot only increase the utilisation of native AVF for dialysis access but also allow proper selection of a target vessel with adequate luminal diameter to improve outcome. A minimum arterial diameter of 2 mm is associated with successful fistula formation. A threshold for minimal venous diameter is difficult to establish. Most clinical studies use a value of 2.5 mm for AVF and 4 mm for prosthetic grafts. Traditional contrast venography is mandatory where there is suspicion of central vein stenosis. In predialysis patients where there is a risk of contrast nephropathy MR venography is emerging as a possible alternative.

Keywords: Vascular access; Renal failure; Duplex ultrasound; Arteriovenous fistula; Venography; MR venography.

Introduction

In many centres patients presenting for primary access proceed directly to arteriovenous fistula (AVF) formation after careful physical examination and if there is a satisfactory radial pulse and suitable forearm veins there is a good chance of success. Clinical guidelines provided by NKF-DOQI in 1997 state that imaging is only necessary in certain patients. Venography is indicated where there is a suspicion of central vein stenosis or trauma, and in patients with multiple previous access attempts.¹ Ultrasound or MRI is suggested in certain complex cases or in predialysis patients with minimal residual renal function where there is a risk of iodinated contrast causing acute renal failure. Rarely, angiography or arterial duplex are indicated when arterial pulses in the access location are diminished.

Despite these guidelines up to one third of access procedures will either fail or not mature well enough to be useful for dialysis. More widespread use of preoperative imaging could reduce the rate of primary fistula failure and reduce unnecessary surgery.

Traditional contrast venography, which for many years has been the gold standard, has several limitations including relative invasiveness, risk of allergic reaction, contrast nephropathy and cost. These drawbacks prevent its generalised introduction. More recently, there is increasing evidence that preoperative duplex ultrasound cannot only increase the utilisation of native AVF for dialysis access, but also allow proper selection of a target vessel with adequate luminal diameter to improve dialysis access outcome.² Ultrasound is being increasingly utilised in many centres, as it is readily available and cheap but its major limitation the relative inability to assess central vein patency so that contrast venography may still be needed if a central venous stenosis or occlusion is suspected. In those patients in whom iodinated contrast is contra-indicated, magnetic resonance venography (MRV) and carbon dioxide venography have recently become available as alternatives. MRV can also give excellent anatomical detail of peripheral arm veins although its relative lack of availability and high cost will probably prevent its widespread introduction.

This article briefly describes the current literature on preoperative imaging prior to vascular access formation. Duplex ultrasound is rapidly emerging as an essential investigation and its widespread introduction in the future will have major resource implications.

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Duplex Ultrasound Scanning

Technique

A high frequency linear phased array probe should be used with the arm dependent.

Venous study

This can be performed at the same time as the arterial study. The arm is scanned proximal to distal, with and without a tourniquet. If there is a significant proximal arterial or venous narrowing, or abnormality, which would jeopardise the success of the AVF, the examination is discontinued. Veins should be thin walled, vary in size with respiration, collapse completely on compression with the transducer, and augment with distal compression. Essential parameters which are measured include vessel depth, internal diameter with and without the tourniquet, continuity with the deep system and the presence of any stenosis or thrombosis. Veins should dilate by approximately 50% by the use of a tourniquet. There

should be respiratory variation in the subclavian vein and, if indicated, the venous flow rate can be recorded during unforced inspiration. Recordings of depth and diameter (with and without a tourniquet) should be recorded on a chart, which can be taken with the patient to theatre (Fig. 1).

Arterial study

The arm is again scanned proximal to distal. Internal diameters are recorded at different levels, as well as calcification, and abnormal arterial wall thickening. Recordings are made on another suitable chart (Fig. 2).

The arterial waveform should also be evaluated both proximally and distally and, in particular, at the site of the proposed AVF. Peak systolic velocities should be recorded. The normal waveform should be triphasic high resistance flow with no evidence of dampening which could indicate a proximal stenosis. Following AVF construction blood flow through the feeding artery is increased and the peripheral resistance is decreased because of diversion to the low resistance venous circulation. The Doppler waveform

Venous Map

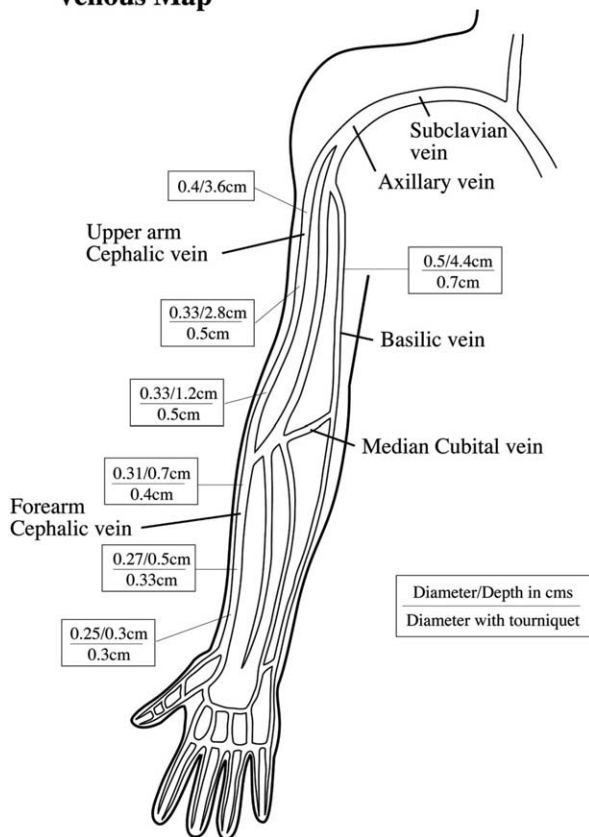


Fig. 1. A suitable chart for recording readings during a preoperative venous duplex examination.

Arterial Map

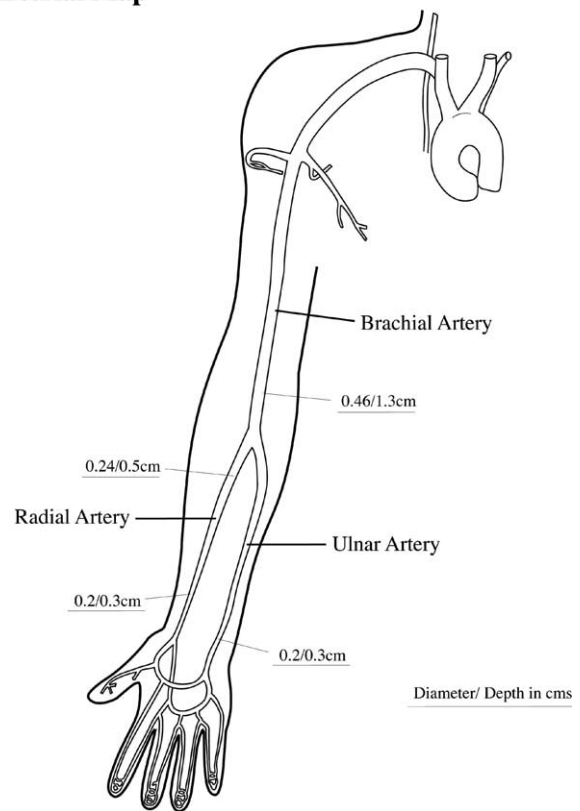


Fig. 2. A suitable chart for recording readings during a preoperative arterial duplex examination.

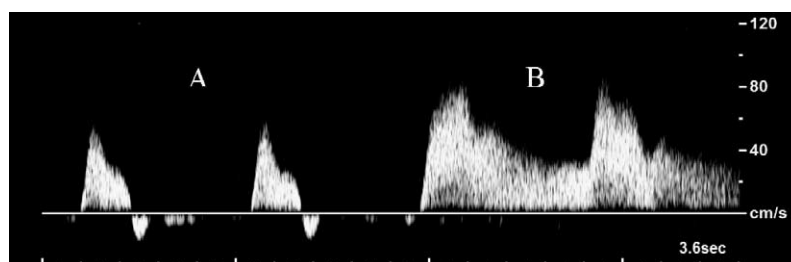


Fig. 3. Radial artery waveform during clenched fist (A) and on release showing a hyperaemic response (B).

is changed from a triphasic high resistance waveform, to biphasic low resistance waveform with increased diastolic flow. Reactive hyperaemia (RH) simulates the decreased vascular resistance after AVF construction and the Doppler waveform during RH can be used as a test for the ability of an artery to sustain the increased flow³ (Fig. 3). RH can be induced by opening a fist, which has been clenched for 2 min. The change in the waveform can be recorded by measuring the resistive index (RI) as well as changes in peak systolic and end diastolic velocity.

Criteria for successful AVF construction

Arterial diameter

The normal diameter of the radial artery ranges from 2 to 3.5 mm. Unfortunately, there is limited literature on the influence of arterial diameter and vessel quality on fistula success rates. Wong *et al.*⁴ showed that a luminal diameter of less than 1.6 mm was associated with early fistula failure and Malovrh⁵ reported that a diameter of less than 1.5 mm was associated with a success rate of only 45%. Similarly, Lemson *et al.*⁶ observed significantly smaller mean preoperative radial artery diameters among patients with failed forearm fistulae compared with successful fistulae (1.9 versus 2.8 mm). A minimum diameter of 2 mm has been proposed by Silva *et al.*⁷ and adopted by other investigators.⁸ Above this minimal diameter there seems to be no correlation between arterial diameter and fistula success.⁸

Arterial flow and velocity

Adequate arterial inflow is crucial to the successful maturation of forearm fistulae.

However, accurate preoperative flow rates are difficult to measure due to the small diameter of the radial artery. Yerdel *et al.*⁹ reported that a preoperative arterial flow of less than 40 ml/min was associated with a higher rate of immediate failure although this finding was not statistically significant. Malovrh³ also reported a mean preoperative flow rate of 54.5 ml/min

in AVF with a successful outcome and a mean flow rate of 24.1 ml/min in those that failed.

Peak systolic velocity (PSV) of the proposed inflow artery is easier to measure and has also been evaluated as a predictor of a successful AVF. Sedlach¹⁰ suggested that a threshold PSV of at least 50 cm/s for fistula success whereas Lockhart⁸ found no difference in preoperative PSV between adequate and inadequate fistulae and no increased failure rates with a PSV of < 50 cm/s. A possible explanation is the exclusion of arteries measuring <2 mm in diameter in the Lockhart study. Above this threshold for arterial diameter, arterial flow and PSV may be unimportant in determining fistula outcome.

Reactive hyperaemia

Ultimately, the best predictor of subsequent fistula maturation may be the ability to increase arterial inflow. Lockhart⁸ found that some women are unable to increase PSV during the clenched fist manoeuvre and AVF created in these patients have a poor outcome. Interestingly, a failure in men to increase PSV during reactive hyperaemia did not influence outcome so that fistula maturation in women may depend on other variables.

The resistive index is another potential measure of the artery to dilate. As diastolic flow increases in the hyperaemic state, the resistive index should fall. Malovrh^{3,5} found that 95.3% of AVFs were successful if the hyperaemic resistive index of the feeding artery was less than 0.7, but only 38.7% when the hyperaemic RI was greater than 0.7. A preliminary report by Wiese *et al.*¹¹ also found that it is not arterial diameter, but the fundamental quality of the arterial wall and its ability to dilate which influence access outcome. In contrast, Lockhart⁸ found no difference in the preoperative change in RI between inadequate and adequate fistulae, although arteries <2 mm in diameter were excluded. It seems that although the ability of an artery to dilate is crucial in determining outcome for small arteries, above a threshold value of 2 mm it is no longer important.

Venous diameter

Two studies have directly assessed venous diameter and its importance in determining fistula outcome. Brimble¹² performed a retrospective study on 106 patients who had venous ultrasound before the creation of a forearm fistula. Only 27.4% of patients had a successful outcome using stringent outcome criteria. The mean forearm cephalic vein diameter was 2.52 and 2.23 mm in successful and failed fistulae, respectively. The result was mainly due to differences in women. A receiver operator curve analysis showed that a cut off point of 2.6 mm for minimum forearm cephalic vein diameter had the greatest predictive value of fistula failure in women. No cut off point was found in men. The authors concluded alternative access should be considered in women with a minimum forearm cephalic vein diameter of less than 2.6 mm but make no specific recommendations for men. Mendez¹³ analysed 44 consecutive patients who underwent preoperative vein mapping prior to wrist AVF construction. Successful maturation of the fistula was achieved in 22 patients (50%) and was significantly higher if the preoperative cephalic vein diameter was greater than 2.0 mm. In these studies, venous measurements were undertaken without a tourniquet, demanding the application of a very precise pressure by the transducer during scanning to achieve accurate results. Although a precise threshold for minimal vein diameter in successful fistulae has not been established, most clinical studies use a cut off value of 2.5 mm for AVF, and 4.0 mm for synthetic grafts as suggested by Silva *et al.*⁷

The ability of a vein to dilate is also an important predictor of a successful fistula. Measurements of venous diameter should be taken with and without augmentation with a tourniquet. Malovrh³ (2002) found that venous diameter increased by an average of 48% in patients with successful fistulae compared with only 11.8% in fistulae that failed.

Venous flow

Yerdel *et al.*⁹ prospectively evaluated venous flow in the subclavian vein prior to fistula formation in 32 patients and correlated this with fistula outcome. Infraclavicular subclavian flow was measured during unforced inspiration. Preoperative subclavian venous flow rates <400 ml/min were associated with a significantly higher rate of immediate failure.

Evidence for the effectiveness of preoperative ultrasound

A number of studies have evaluated the impact of preoperative ultrasound on the utilisation of native AVF. Ultrasound is especially useful in the evaluation of obese

patients in whom superficial veins are impalpable. Studies define minimal requirements for a distal native AVF. Most require a distal radial artery diameter of 2 mm or greater with a normal waveform and patent palmar arch, as well as a cephalic vein of 2.5 mm or larger throughout its course to the subclavian vein. There must be no segmental stenosis or occluded segments. Drainage of the cephalic vein into a large (> 2.5 mm) forearm medial cubital vein and brachial or basilic vein is also generally acceptable. The ipsilateral central veins must be normal. A prosthetic graft is recommended only if the outflow vein is greater than or equal to 4.0 mm. Measurements of volume flow, peak systolic velocities or changes in RI following reactive hyperaemia do not seem routine.

Silva *et al.*⁷ compared access outcome in 172 patients undergoing preoperative venous mapping with historical controls. Routine preoperative ultrasound increased the prevalence of native access from 14 to 63% ($p < 0.05$). The early failure rate of native AVF also improved from 36 to 8.3% and primary patency at 1 year increased from 48 to 83%. As a result of the increased utilisation rate of native AV access, the prevalence of prosthetic AV access reconstruction as well as probable AV access complications decreased significantly. A similar study by Allon¹⁴ increased the proportion of native fistulae from 34% in the historical control period to 64% with preoperative mapping.

Two prospective studies have also evaluated the effect of preoperative ultrasound. Mihmanli *et al.*¹⁵ randomised 124 patients undergoing assessment for fistula construction into preoperative physical examination alone or evaluation with ultrasound alone. The rate of primary non-function was 5.6% in the ultrasound group compared with 25% in patients undergoing physical examination. No long term follow up data was recorded. Robbins *et al.*¹⁶ assessed 70 patients with preoperative ultrasound before surgical evaluation. The surgeon documented the planned access procedure based on physical examination results before reviewing the ultrasound report. The surgical procedure and outcome were recorded. Preoperative US mapping resulted in a change to the planned surgical procedure in 31% of the patients who subsequently had a fistula constructed. Native fistulas were placed in 58% of patients compared with 32% in a historical control period when mapping was not performed. Furthermore, no patient underwent unnecessary exploration of the arm.

These studies provide convincing evidence for the routine use of preoperative duplex scanning which is likely to become routine for screening prior to AVF formation. In many units, however, the availability of

resources may restrict such preoperative assessment to certain patients, e.g. diabetic and obese subjects.

Venography

For many years contrast venography has been the gold standard imaging investigation prior to AVF formation. It has the particular advantage of providing a venous map, which many surgeons find useful. According to DOQI¹ venography is mandatory in patients with a history of ipsilateral central vein catheterisation, collateral vein development, oedema or differential extremity size as these findings may indicate inadequate venous drainage or central vein obstruction. Construction of a peripheral fistula in these patients can cause massive arm swelling and poor dialysis. Until recently temporary dialysis catheters were frequently placed in the subclavian veins causing a high incidence of venous stenosis near the catheter insertion site. Surratt¹⁷ found moderate or severe subclavian vein stenosis in as many as 40% of patients with a history of a prior or existing line (Fig. 4).

Today best practice is to establish an AVF before commencing dialysis and if this is not possible insert a tunneled right internal jugular line. This has reduced the incidence of central vein stenosis although innominate vein stenosis remains a significant problem.

Venography with iodinated contrast is relatively contraindicated in predialysis patients as contrast nephropathy may precipitate acute renal failure. Duplex ultrasound is an alternative but is poor at assessing central vein stenosis. Contrast enhanced MR



Fig. 4. A conventional venogram showing a tight subclavian origin stenosis (arrow).



Fig. 5. A contrast enhanced MR venogram of the right upper arm.

venography has emerged as a promising alternative as the small volume of paramagnetic contrast agent used does not compromise renal function. A similar technique to conventional venography is used with contrast injected upstream of the venous territory to be evaluated (Fig. 5).

To avoid T2 shortening effects the paramagnetic contrast should be diluted by a factor in the range 1:10–20.¹⁸ Non-contrast MRI using 'Time of Flight (TOF)' techniques have also been evaluated for preoperative venous mapping as there is also no risk of compromising renal function. Patients are examined prone with the arm under investigation inserted into a surface coil. Laisey *et al.*¹⁹ have demonstrated the technique can be used successfully for venous mapping of the distal upper arm, elbow, and forearm with veins larger than 2 mm visualised. The main limitation of non-contrast techniques is their inability to demonstrate proximal or central veins.

Menegazzo *et al.*²⁰ prospectively compared TOF MR venography and conventional venography in 24 patients prior to fistula formation. MR and venographic results were well correlated for demonstration of superficial veins and assessment of venous diameter. The correlation between MR venographic and surgical findings ($\kappa=0.78$) was superior to that between conventional venographic and surgical findings ($\kappa=0.56$). These results are encouraging but much more data is needed before MR venographic techniques can be recommended for routine preoperative evaluation.

Two further venographic techniques are available for the assessment of predialysis patients without compromising renal function. Carbon dioxide (CO₂)

venography has been used successfully to visualise both peripheral and central veins but has significant drawbacks including local pain during injection, overestimation of venous stenoses and the risk of potentially serious complications for example acute right heart failure.²¹ A costly special injector may also be required. Despite these drawbacks CO₂ venography is widely used in several centres, particularly in France.²²

MRI contrast agents have also been evaluated using conventional X-ray digital subtraction techniques rather than magnetic resonance. Gadolinium based contrast agents have shown they absorb sufficient energy to be visualised during angiography by digital subtraction and have been used for several years for angiographic interventions where conventional iodine based contrast is contra-indicated. Gadoterate meglumine (Gd-DOTA) has been evaluated in 45 predialysis patients with renal insufficiency undergoing venography because of inconclusive physical examination prior to AVF formation.²³ Three sequences were performed on then forearm, arm and chest at 3 ml/s using a total of 35 ml of Gd DOTA. There was satisfactory visualisation of the forearm and arm veins allowing the identification of 33 forearm cephalic veins, which would allow the creation of an AVF. However, the innominate veins and SVC were relatively poorly visualised which may limit the introduction of the technique.

Summary

- There is increasing evidence that routine preoperative duplex ultrasound reduces the rate of primary fistula failure and unnecessary surgical exploration.
- Ultrasound increases the utilisation of native AVF and allows proper selection of suitable target vessels of adequate diameter.
- A minimum arterial diameter of 2 mm is associated with successful fistula formation. Below this diameter the ability of an artery to increase flow and dilate will determine fistula success.
- A threshold for minimal venous diameter is difficult to establish. Most clinical studies use a value of 2.5 mm for AVF and 4 mm for prosthetic grafts.
- Traditional contrast venography is still an essential investigation if there is suspicion of central vein stenosis. In predialysis patients MR venography is emerging as a suitable alternative.

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