Editorial Review

Vascular ultrasound for the pre-operative evaluation prior to arteriovenous fistula formation for haemodialysis: review of the evidence

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Introduction

The arteriovenous fistula (AVF) is the preferred access for haemodialysis [1]. However, AVF failure has become more common over the last three decades as more patients are older, and have diabetes or vascular disease. For radiocephalic AVF, a meta-analysis estimated modest primary (63%) and secondary (66%) patencies at 1 year [2]. AVF failures have been attributed to inadequate vessels used for surgery [3]. Pre-operative evaluation with ultrasound may select suitable vessels and reduce AVF failures [3].

We review the evidence for ultrasound evaluation for AVF formation. The following areas are addressed:

- Ultrasound criteria for pre-operative evaluation
- Pre-operative ultrasound findings and AVF outcomes
- Comparison of pre-operative physical examination and ultrasound in terms of AVF outcomes

Methods

The published literature was searched on 29 October 2007 through Pubmed, Embase and the Cochrane library using the following keywords: (‘arteriovenous fistula’ or ‘vascular access’) and (‘kidney disease’ or ‘dialysis’) and (‘ultrasound’ or ‘vein mapping’). Relevant papers were reviewed and their references were also searched.

Ultrasound criteria for pre-operative evaluation

Ultrasound equipment and technique

A comprehensive review of ultrasound is beyond the scope of this article but we describe aspects relevant to pre-operative evaluation. The ultrasound scanner should allow examination with B-mode and Doppler mode. Linear array probes with a frequency of 7 MHz or higher for B-mode, and 5 MHz or higher for Doppler, are appropriate for most vessels. The ultrasound gel should be warmed and the patient in a supine position [4,5].

Arterial scan The arm arteries are followed longitudinally with directional colour Doppler, from the distal part of the subclavian artery to the radial and ulnar arteries; segments with abnormal colour Doppler are further assessed with B-mode and spectral Doppler [6] to identify a stenosis or occlusion. A 50% narrowing of the arterial luminal diameter or a twofold increase of the peak systolic velocity in the narrowing may be considered as a haemodynamically significant stenosis [6]. However, even a lesser stenosis may become significant after AVF formation when blood flow increases. Ultrasound accurately estimates stenosis severity compared to angiography [7]. Ultrasound identifies anatomical variations, such as a proximal origin of the radial and ulnar arteries in the upper arm [8].

Successful use of AVF for dialysis requires adequate blood flow, ideally at least 500 ml/min. Ultrasound measurements of the vessel diameter and time-averaged velocity allow calculation of blood flow. However, blood flow estimates in a small calibre radial artery are often inaccurate [4,9]. Therefore, the suitability of the radial artery for AVF formation is determined by other criteria, including the diameter, wall morphology and the hyperaemic response [10].

Arterial diameter The internal diameter is measured in longitudinal or transverse sections in the radial artery at the wrist and in the distal forearm [5,11]. In the longitudinal section, the probe is aligned to show the intimal layers at the near and far walls to measure the distance from intima to intima perpendicular to the arterial wall (see Figure 1). In
the transverse section, the probe needs to be perpendicular to the skin surface and the long axis of the artery parallel to the skin surface to avoid diameter overestimation. There is some systolic–diastolic diameter variation due to arterial pulsatility. With M-mode, a point of the artery may be insolated over time and the diameter may be measured at the desired point of the cardiac cycle, e.g. at peak systole, as shown in Figure 2 [9,12]. M-mode measurement is useful when the small error due to arterial pulsatility could become relevant, for instance in small calibre arteries. The arterial diameter correlates well with the diameter measured at surgery [9].

Arterial wall morphology During AVF maturation, AVF blood flow increases with dilatation of the feeding artery, but this may not occur in a diseased artery. Morphologic information on the thickness and structure of the arterial wall (smoothness of the intima, wall thickening, calcification) can be obtained with B-mode [10]. Using high resolution ultrasound, the intima–media thickness (IMT) may be quantified on the far wall of a longitudinal section of the distal radial artery as shown in Figure 1 [10,13]. Heavy calcification, identified in B-mode, may make surgery difficult [5].

Hyperaemic response A healthy artery responds to ischaemia with reactive hyperaemia, i.e. increased blood flow and dilation of downstream arterioles. This can be assessed with spectral duplex ultrasound (see Figure 3). After ischaemia has been induced by clenching a fist or by placing an upper arm pressure cuff, reactive hyperaemia is observed immediately after release. Spectral Doppler in the distal radial artery shows a triphasic high-resistance waveform during ischaemia, which changes to a monophasic low-resistance waveform with overall increased velocity during reactive hyperaemia [5,14,15]. The spectral waveform change may be quantified by the resistive index or by the difference in peak systolic velocity (see Figure 3). The greater the hyperaemic response of the artery the lower the resistive index [10] or the greater the peak velocity difference [14,15]. The resistive index is less prone to error because it is less dependent on the Doppler angle [16].
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**Fig. 3.** Spectral Doppler waveform in a normal radial artery: during ischaemia (fist clenched), the waveform is triphasic due to high resistance (left part of the picture). As the fist is opened, there is monophasic flow continuing throughout diastole with systolic accentuation (right part of the picture). The velocity scale in cm/s is shown on the right. (A) peak systolic velocity during ischaemia. (B) peak systolic velocity at reactive hyperaemia. (C) end-diastolic velocity. The resistive index (RI) at reactive hyperaemia is defined as: 

\[ \text{RI} = \frac{\text{B} - \text{C}}{\text{B}} \]

The difference in peaks systolic velocity is defined as: 

\[ \Delta \text{PSV} = \text{B} - \text{A} \]

**Venous scan** The forearm cephalic vein is distended by placing a tourniquet downstream. The cephalic vein is followed to the point of drainage into the deep venous system. Patency is assessed by frequent intermittent compression with the probe placed in transverse section [11,17]. If no suitable cephalic vein is found, the basilic vein is examined. The deep venous system beyond the drain point should be followed to the subclavian vein. Often, the more central veins cannot be assessed directly [17]. This scan yields an anatomic vein map and may identify an outflow obstruction that could result in AVF failure.

Criteria used to determine the suitability of the cephalic vein for AVF formation include appearance, diameter, distensibility, Doppler and suitability for cannulation.

**Venous appearance and suitability for cannulation** A normal vein has a thin and smooth wall, an anechoic lumen, and is fully compressible [18].

The vein considered for AVF formation should have sufficient length for future needle placement and should be <6 mm deep [19].

**Venous diameter and distensibility** The diameter and depth are measured at points throughout the upper limb, but direct pressure on the vein must be avoided by using sufficient gel and resting the probe to the side of the vein. Diameters can be measured in the longitudinal [5] or transverse section [11]; in the transverse section, the probe needs to be perpendicular to the skin surface and the long axis of the vein parallel to the skin surface to avoid diameter over-estimation.

Venous diameters can be measured before and after 2-min application of a tourniquet, to assess the percentage increase in venous diameter or venous distensibility [5].

Venous diameter measurements are reproducible between observers and not different when distended by a tourniquet or pressure cuff [20]. However, there is a considerable day-to-day variation [20] and change with patient position or immersion of the arm in a warm bath, which remains even after placement of a tourniquet [21]. In order to minimize diameter errors, it is necessary to examine patients in a warm room, using warm gel, and in a standardized position [5].

**Venous Doppler** If in doubt, venous patency can be further assessed with Doppler [5,10]. To obtain a venous spectral Doppler waveform, the duplex settings need to be optimal (correct angle, low pulse repetition frequency). In a normal vein, spectral Doppler shows spontaneous flow [18].

Central vein disease occurs with dialysis catheters. With ultrasound, the veins central to the subclavian vein are rarely visualized directly but the spectral Doppler waveforms in the subclavian and internal jugular veins allow an indirect assessment. A Doppler waveform changing with respiration and cardiac cycle suggests central venous patency, whereas a monophasic waveform indicates complete occlusion [22]. Conventional contrast venography is used to identify a central vein stenosis [19].

**Pre-operative ultrasound findings and AVF outcomes**

**Definitions of AVF outcomes and their relevance to pre-operative assessment**

Different outcomes of AVF have been reported in studies examining the effect of pre-operative evaluation: immediate
outcome [9,23], functional primary patency [24,25], AVF survival [26,27] and early and primary failure [28,29].

Immediate failure on the day of surgery is generally regarded as a ‘technical’ failure of surgery [29] but can also occur with inadequate vessels [9]. Functional patency describes dialysis use of AVF and is a better outcome than simple patency. Functional primary patency refers to all AVF providing adequate dialysis without further repair and AVF survival is the period from surgery to AVF failure [30]. Early failure counts all AVF failures during the first 8–12 weeks after surgery [12,28,29]. Primary failure counts all AVF that remain inadequate for dialysis after formation [3]. Compared to early failure, primary failure can take account of AVF in patients not already on dialysis. Therefore, primary failure is probably the best measure for the effect of pre-operative evaluation on AVF outcome. Primary failure can be further divided into categories such as immediate thrombosis, early thrombosis and failure to mature [29].

**Individual pre-operative ultrasound criteria and their relation to AVF outcome**

**Arterial criteria** The arterial diameter has been studied in radiocephalic AVF. Immediate and early AVF failures are well recognized when very small calibre arteries <1.6 mm are used for AVF construction: Malovrh [9] reported 55% immediate and 64% early failure rate for arteries of 1.5 mm diameter or below, compared to 8% and 17%, respectively, for arteries >1.5 mm. Parmar et al. [12] found a 46% early failure rate for arteries <1.5 mm diameter, compared to 0% for arteries >1.5 mm. Wong et al. [28] reported early failure in all arteries of 1.6 mm diameter or below. Therefore, the larger the arterial diameter the more certain is AVF patency [9,10,28,31]. The ideal cut-off point for the arterial diameter in terms of AVF maturation and adequacy for dialysis is not known [5], probably because other factors such as the presence of arterial disease may also play a role. A minimum diameter of 2 mm was first suggested by Silva et al. [27] who reported good AVF outcomes (8% early failure, 83% functional primary patency at 1 year). There are no diameter recommendations for the brachial artery, but because of its larger calibre, diameter measurement may be less crucial for AVF outcome. However, ultrasound is still useful as it can identify a common anatomical variation, the upper arm division of the axillary or proximal brachial artery into radial and ulnar arteries, which means that two smaller calibre arteries are found at the level of the elbow.

Radial artery wall changes due to arterial disease are common in patients with end-stage renal disease and worse in patients with diabetes or renovascular disease [10]. Ku et al. [13] reported that measurement of IMT with ultrasound correlated significantly to histology ($r = 0.786, P < 0.001$). Furthermore, Ku et al. [13] found a significant correlation between IMT and AVF failure due to thrombosis or dialysis inadequacy at 1 year ($r = 0.358, P = 0.027$). These studies show that pre-existing arterial disease is important for AVF outcome and can be assessed by ultrasonography.

Three studies examined the pre-operative arterial response to reactive hyperaemia with ultrasound and related this to AVF outcome [10,14,15]. Malovrh [10], who did not select radial arteries for AVF construction by diameter, found that the lack of hyperaemic response (defined as a resistive index of >0.7 at reactive hyperaemia) predicted immediate AVF failure (5% for arteries with hyperaemic response compared to 61% without). For the AVF patent at 24 h, Malovrh showed that blood flow had increased significantly more in AVF with pre-operative hyperaemic response (close to 500 ml/min) compared to those without (just >300 ml/min) by 12 weeks. By contrast, Lockhart et al. [15] found no difference in AVF outcome for hyperaemic response overall; only among women were more AVF were adequate for dialysis with a pre-operative hyperaemic response, defined by the change in systolic velocity ($\Delta PSV \geq 0$). This study excluded radial arteries of <2 mm for AVF formation, but women had smaller calibre arteries than men [15]. Wall et al. [14] found no difference in functional primary patency of access based on arteries with hyperaemic response (defined as $\Delta PSV > 5$ cm/s), but a significantly better secondary patency after AVF revision, compared to those without. This was more pronounced for radial-compared to brachial artery-based access. These studies are heterogeneous and difficult to compare but suggest that the hyperaemic response may be a useful adjunct in radial arteries of borderline quality or calibre.

**Venous criteria** Three studies examined pre-operative venous diameter and AVF adequacy for dialysis [24,25,28]. Wong et al. [28] found no difference in the average venous diameter at the wrist between failed and adequate AVF but reported that all AVF failed if the diameter was 1.6 mm or less. No tourniquet was used in the studies by Brimble et al. [24] and Mendes et al. [25] who measured the cephalic vein at several points in the arm and used the smallest vein diameter to predict AVF outcome. Mendes [25] reported that 16% of AVF were adequate with a diameter of 2 mm or less, compared to 76% of those >2 mm. Brimble et al. [24] found a cut-off value of 2.6 mm, but the difference of venous diameter between failed and adequate AVF was only significant for women.

Venous distensibility of the forearm cephalic vein was examined in two studies. Malovrh [10] reported that venous distensibility predicted immediate AVF failure: the pre-operative vein diameter increased by 12% in failed, compared to 48% in patent AVF. Lockhart et al. [32] reported that dialysis adequacy of radiocephalic AVF was similar for cephalic veins of $\geq 2.5$ mm pre-operative diameter compared to smaller veins that dilated to $\geq 2.5$ mm only after tourniquet application.

While it is accepted that very small calibre veins will fail, there is no agreed minimum venous diameter to predict radiocephalic AVF maturation [5]. A minimum diameter of 2.5 mm with tourniquet was first suggested by Silva who reported good AVF outcomes (8% early failure, 83% functional primary patency at 1 year) [27]. Criteria for upper arm veins are not established but a diameter of at least 3 mm has been recommended [5]. One should remember that vein diameters have a considerable day-to-day variation and depend on the examination conditions (ambient temperature and patient position) [20,21]. Therefore, veins should be evaluated under optimal conditions and venous distensibility tested in the case of apparently small veins.
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**Table 1.** Vascular access outcomes after (and before) using pre-operative ultrasound

<table>
<thead>
<tr>
<th>Author</th>
<th>n</th>
<th>Ultrasound</th>
<th>% AVF-based access after–before ultrasound</th>
<th>I-year primary patency after–before ultrasound</th>
<th>% AVF in forearm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prospective</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patel 2003 [38]</td>
<td>256</td>
<td>selective</td>
<td>73%</td>
<td>61%</td>
<td>57%</td>
</tr>
<tr>
<td>Allon 2001 [37]</td>
<td>217</td>
<td>routine</td>
<td>64%</td>
<td>34%</td>
<td>54%</td>
</tr>
<tr>
<td>Silva 1998 [27]</td>
<td>172</td>
<td>routine</td>
<td>63%</td>
<td>14%</td>
<td>83%</td>
</tr>
<tr>
<td>Huber 2002 [39]</td>
<td>139</td>
<td>routine</td>
<td>90%</td>
<td>–</td>
<td>84%</td>
</tr>
<tr>
<td>Jungling 2003 [47]</td>
<td>51</td>
<td>routine</td>
<td>94%</td>
<td>–</td>
<td>71%</td>
</tr>
<tr>
<td>McGill 2005 [40]</td>
<td></td>
<td>routine</td>
<td>72%</td>
<td>32%</td>
<td>–</td>
</tr>
<tr>
<td>Nguyen 2003 [41]</td>
<td></td>
<td>selective</td>
<td>98%</td>
<td>–</td>
<td>52%</td>
</tr>
<tr>
<td>Retrospective</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Konner 2002 [46]</td>
<td>748</td>
<td>selective</td>
<td>&gt;95%</td>
<td>–</td>
<td>76%</td>
</tr>
<tr>
<td>Asher 2000 [26]</td>
<td>267</td>
<td>selective</td>
<td>68%</td>
<td>5%</td>
<td>84%</td>
</tr>
<tr>
<td>Gibson 2001 [42]</td>
<td>187</td>
<td>selective</td>
<td>74%</td>
<td>41%</td>
<td>56%</td>
</tr>
<tr>
<td>Ackad 2005 [43]</td>
<td>111</td>
<td>routine</td>
<td>87%</td>
<td>49%</td>
<td>–</td>
</tr>
</tbody>
</table>

Pre-operative ultrasound use and AVF outcomes in patients at higher risk of AVF failure  
It is well recognized that AVF as access for haemodialysis are less prevalent among patients of older age, of female gender, with obesity, diabetes or cardiovascular disease [33].

Two retrospective studies investigated AVF outcomes for diabetic versus non-diabetic and obese versus non-obese patients, respectively, and showed that the risk of AVF failure was not different when pre-operative ultrasound evaluation was used [34,35].

Several studies looked at the effect of pre-operative ultrasound and the AVF outcome among women versus men. Arterial diameters in women tend to be smaller than in men, whereas venous diameters are not different [29,32,36].

Allon et al. [37] reported a high primary failure rate for forearm AVF among women, which improved after routine use of pre-operative ultrasound (93% versus 64%). While Miller et al. [29] reported worse primary failure among women compared to men (68% versus 50%), Caplin et al. [36] found no difference (28% versus 23%) when pre-operative ultrasound was used. Overall, women appear to benefit from the use of pre-operative ultrasound.

Pre-operative ultrasound use and vascular access outcomes  
Several US American studies were recently published that report good or improved AVF outcomes achieved with the use of pre-operative ultrasound. Almost all report a higher rate of AVF in preference to arteriovenous grafts (AVG) and better primary patency AVF as outlined in Table 1 [26,27,37–43]. Some authors compare their results achieved with ultrasound to historical controls.

However, a comparison to historical controls may not be appropriate because practice changes other than ultrasound may have contributed to the increase in AVF [44]. The rates of AVF-based access need to be interpreted in the context of US practice patterns for vascular access that are very different from the European setting. AVF use among prevalent haemodialysis patients in the USA has been significantly lower than in Europe due to a preference for AVG (24% versus 80%), even after accounting for patient differences, which suggests a difference in practice patterns [33]. The US practice has been influenced by reimbursement issues of the US healthcare system [3,44]. The vascular access guidelines of 1997 of the Dialysis Outcomes Quality Initiative (DOQI) and the 2000 update recognized the serious negative effects of AVG use and defined strategies and targets to increase AVF use on dialysis (50% for patients initiating and 40% for patients established on haemodialysis) [1]. The 40% target for prevalent patients was met by 17 out of 18 renal networks in the USA by December 2006 [45]. By contrast, AVF formation is predominant in European countries [46,47]. The report by Nguyen et al. [41] of a 98% AVF-based access in a US renal network is exceptional and reflects Dr Nguyen's personal initiative in terms of promoting AVF use. This study supports the view that substantial increases in AVF rates can be achieved by changing established practice patterns.

Comparison of pre-operative physical examination and ultrasound in terms of AVF outcomes  
So far we have shown that pre-operative ultrasound is useful. In the following we examine how pre-operative ultrasound compares to physical examination that has been traditionally used. Physical examination can be carried out rapidly at the patient's bedside at no extra cost or equipment. Ultrasound, in turn, allows non-invasive and safe imaging but requires some time for the scan as well as skill and experience of the operator.

In general, physical examination usually yields more information from venous than arterial assessment: if the forearm vein is palpable, its calibre, patency and course can be readily assessed. Arterial examination is limited to palpation of the pulse and measurement of the blood pressure [10,28]. The pulse may appear strong due to raised blood pressure, common among renal patients. By contrast,
ultrasound gives relatively more information about the artery than the vein, as we have discussed above. Wong et al. [28] compared the accuracy of predicting AVF failure for pre-operative evaluation of the forearm cephalic vein: positive predictive value was better for ultrasound than for physical vein palpation (1.0 versus 0.5), indicating that AVF failure occurred for all veins that were abnormal on the ultrasound scan (defined by a diameter < 1.6 mm or a stenosis) [28].

Clinical examination alone is insufficient in a considerable proportion (~25–50%) of patients [10,48]. Parmley et al. [49] reported good AVF outcomes (98% AVF of all access formation, 94% functional primary patency at 1 year) for ultrasound use in a selected group of 47 patients with insufficient clinical findings. Two prospective studies compared the findings of clinical and ultrasound examinations directly. The assessments were performed by different examiners unaware of each others’ findings. Robbin et al. [50] followed 52 patients and reported that ultrasound information changed the clinical plan in 32%: among those, half could receive a fistula rather than a graft while 19% did not undergo unnecessary wrist exploration. Wells et al. [48] followed 145 patients and found that clinical examination was insufficient in 27%; ultrasound made a relevant contribution for half of those. However, clinical examination appeared sufficient in 73%; in this group ultrasound changed the surgical plan in < 1%. This shows that clinical assessment correctly identifies those patients who benefit from further imaging. Furthermore, Nursal et al. [51] studied 70 selected patients who had adequate vessels on physical examination and randomized them to have AVF formation on the basis of physical or ultrasound examination alone. There was no significant difference in terms of immediate or simple primary patency at 1 year. These studies provide evidence that selected patients with insufficient clinical examination benefit from ultrasound, while ultrasound is not needed when adequate vessels are defined by clinical examination.

Routine use of ultrasound was compared to exclusive physical examination in two randomized trials. Mihmanli et al. [23] reported that immediate patency among 124 patients was significantly greater in the ultrasound than in the clinical group (95% versus 75%). Zhang et al. [52] reported that among 68 patients, simple primary patency at 6 months was higher in the ultrasound than in the clinical group (90% versus 80%). These studies show that a strategy of routine ultrasound, compared to one of the exclusive physical examination without imaging, can reduce early AVF failure. However, as exclusive clinical assessment without an option for imaging is not usual clinical practice, the benefit of routine ultrasound may appear greater than it would be, if ultrasound had been used selectively in the clinical groups.

Conclusions

Most haemodialysis patients nowadays are older and have diabetes or cardiovascular disease. These vascular risk factors are associated with increased arterial disease and an increased risk of AVF failure. Pre-existing arterial disease can be assessed by ultrasound assessment that is particularly important for the radial artery.

Furthermore, clinical assessment may be inconclusive in a considerable proportion of patients, for instance when veins are not apparent in the obese. Pre-operative ultrasound assessment predicts AVF patency and maturation for dialysis. Ultrasound is of particular benefit when physical examination is insufficient but has little added value when physical examination is satisfactory.

Therefore, physical examination should be used initially for all patients to evaluate a suitable site for AVF surgery. Patients who are likely to benefit from pre-operative ultrasound evaluation are those with:

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

In summary, pre-operative ultrasound should be used in selected patients to improve AVF outcome.

Conflict of interest statement. None declared.

References

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