Non-invasive evaluation of vessels by duplex sonography prior to construction of arteriovenous fistulas for haemodialysis

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Abstract

Purpose. The prospective study was aimed at estimating the value of duplex sonography for imaging arteries before arteriovenous fistula (AVF) construction and of evaluating the influence of this method on the outcome of fistula construction.

Methods. A total of 35 patients with end stage renal disease were examined by duplex sonography (DS) before AVF construction, and 27 of them with patent AVF were examined 1, 7 and 21 days after the operation. Filling artery flow was evaluated at 8 and 12 weeks. All AVFs were constructed on the forearm using native veins. Direct measurements of the arterial internal diameter during the operation were also performed.

Results. The mean internal diameter of the arteries (IDA) detected by sonography 2.3 ± 0.62 mm, with a direct measurement of 2.1 ± 0.52 mm (mean ± SD). The correlation coefficient of DS IDA with direct measurement IDA was 0.86. In group A (IDA ≤ 1.5 mm), immediate patency of the AVF was present in 45% (5/11), and in group B (IDA > 1.5 mm) 92% (22/24) (P < 0.001). Before the construction, the mean volume flow through the radial arteries was 22 ± 6.8 ml/min in group A and in group B 46 ± 6.3 ml/min (P < 0.01). If there was conversion of high-resistance triphasic Doppler flow signal to low-resistance biphasic flow signal after release of a fist (group D), the AVF was patent in 95% (21/22), compared with a 46% (6/13) rate of patency in the group without such a response (group C). In 27 patients with patent AVF fistula, arterial volume flow the first day after construction was 138.1 ± 10.1 ml/min in group A and 184.2 ± 12.6 ml/min in group B. After 1 week, the volume flow was 169 ± 11.1 ml/min and 202.4 ± 13.5 ml/min, respectively. After 3 weeks the arterial flow was 274.4 ± 17.3 ml/min, and 366.2 ± 39.6 ml/min, respectively. After 12 weeks, the arterial flow was 438.5 ± 87.7 ml/min in group A and 561.8 ± 131.3 ml/min in group B. The patency rate after 12 weeks was 36% in group A and 83% in group B.

Conclusions. Duplex sonography could be a useful non-invasive method to evaluate arterial vessels prior to AVF construction. The relevant parameters measured by duplex sonography to evaluate the potential patency of the AVF are the arterial internal diameter and changes in the arterial Doppler flow signal.

Key words: arteriovenous fistula; blood velocity waveform; Doppler measurement; haemodialysis

Introduction

Satisfactory blood flow through an arteriovenous fistula (AVF) is essential for adequate haemodialysis in patients with end stage renal disease. AVF should be primarily surgically constructed at the wrist between the radial artery and the accompanying cephalic vein. The most frequent problems with fistulas are lack of immediate patency after construction, failure to mature and inadequate flow during haemodialysis treatment. Preoperative imaging is necessary in patients with arteriopathy, diabetes and in elderly patients with an increased risk of arterial disease [1–2].

The most important factors for the successful outcome of fistula surgery and adequate fistula flow are adequate arterial volume flow, patency and adequate distension capacity of the vein. Duplex scanning is an attractive method for qualitative and quantitative monitoring of vessels that is both non-invasive and safe [2–4,10]. Estimation of volume flow by duplex sonography is inherently inaccurate, but meaningful estimates may be obtained in a relatively large superficial artery. In vessels with relatively small diameter, such as the radial artery, makes errors in estimating the cross-sectional area far greater. Volume flow estimation taken with the shape of the waveform is sufficient for clinical purpose. An alternate or complimentary approach is the study of the Doppler flow waveform with clenched fist and after releasing a fist. Doppler ultrasound with clenched fist shows a high-resistance triphasic flow signal with reversal of flow in early diastole followed by forward flow. After releasing a fist the triphasic Doppler waveform normally changes to a low-resistance biphasic waveform with continuing high flow during diastole, caused by dilatation of
peripheral arterioles and consecutive reduction of the peripheral resistance (Figure 1). Failure of such a response is regarded as a contraindication to AVF construction [2].

The purpose of the present prospective study was to estimate the value of duplex sonography for assessment of arteries before haemodialysis AVF construction. We also prospectively studied the influence of the internal arterial diameter, changes of Doppler waveform after reduction of the peripheral resistance and arterial volume flow detected by duplex ultrasound on AVF patency after surgery.

Subjects and methods

Thirty-five patients (16 females and 19 males) with chronic renal failure, aged 19–74 years (mean 58.7) with end-stage renal disease were examined before AVF construction. The serum creatinine levels ranged from 726 to 1105 μmol/l with mean of 876.3 μmol/l. The construction of AVF between the radial artery and the cephalic vein was planned for all patients. The radial artery was palpated at the wrist before examination with duplex sonography in order to mark the direction and exact position of the vessel. Duplex scanning was performed with Acuson 128 XP/10 (Computed Sonography System, California, USA). A 2-D linear electronic probe L7384 at 7.0 MHz, pulse wave Doppler at 5.0 MHz and colour Doppler at 5.0 MHz was used. The angle of the emitted Doppler ultrasound wave from the probe was adjusted to 60° (56–69°) to achieve the Doppler signal of the strongest intensity. The internal diameter of the vessel was measured using M-mode technique. Transverse examinations were made over the artery and the cross sectional area of the artery was calculated. Time averaged velocity (TAV) was calculated directly from a Doppler spectral waveform by the duplex-scanner system. The volume flow was obtained from TAV and the cross-sectional surface area. Measurements were performed before and 1 day, 1, 3, 8 and 12 weeks after fistula construction in patients with patent AVF. We observed a change in Doppler waveform after the fist was clenched for 3 min and after the fist was reopened. Triphasic high-resistance waveform changing to biphasic low-resistance waveform with a diastolic velocity 20–50% of the peak systolic velocity was considered as a normal reaction. All the ultrasonic imaging was performed by the author to ensure consistency of the measurement procedure.

During surgical construction of AVF, the external diameter (ED) and wall thickness of the radial artery was measured by a micrometer calliper (Mitutoyo, Tokyo, Japan) and the internal diameter (ID) was calculated (ID = ED – 2 × wall thickness). All measurements were performed at three different points along a 3–5 cm length of artery by one observer, who was blinded to the duplex sonographic results. The average values were calculated.

Fig. 1. Doppler signal at clenched fist — high resistance flow (A) and after releasing — low resistance flow (B).
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Correlation between DS-IDA and IO-IDA
Correlation: \( r = 0.86213 \)
\( p < 0.05 \)

Fig. 2. Correlation between duplex sonographic measured internal diameter of artery (DS-IDA) and internal diameter of artery measured during surgery by micrometer (IO-IDA).

Statistical analysis was carried out using Student's \( t \)-test, linear correlation by Pearson and life table analysis. \( P < 0.05 \) was considered to be significant.

Results

The mean (± SD) radial artery internal diameter measured by duplex sonography and during operation was 2.3 mm (± 0.66) (range 1.4–3.2) and 2.1 mm (± 0.55) (range 1.1–2.8) respectively. The correlation coefficient \( (r) \) was 0.86 (\( P < 0.05 \)) (Figure 2).

The difference in mean blood flow (± SD) before surgery and fistula patency after surgery with regard to the artery internal diameter is shown in Table 1.

Table 1. Arterial flow volume measured by duplex sonography (DS) before surgery and arteriovenous fistula (AVF) patency after surgery grouped according to the internal diameter of the artery, measured by DS (\( n=35 \))

<table>
<thead>
<tr>
<th>Arterial flow (ml/min)</th>
<th>Patent AVF</th>
<th>Failed AVF</th>
<th>Success rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A (( n=11 ))</td>
<td>19–31</td>
<td>5/11</td>
<td>6/11</td>
</tr>
<tr>
<td>Group B (( n=24 ))</td>
<td>34–52</td>
<td>22/24**</td>
<td>2/24**</td>
</tr>
</tbody>
</table>

Group A: internal diameter ≤ 1.5 mm.
Group B: internal diameter > 1.5 mm.
*\( P < 0.01 \).
**\( P < 0.001 \).

Table 2. Patency of arteriovenous fistula (AVF) after surgery with regard to conversion of high-resistance Doppler waveform to low-resistance waveform before surgery (\( n=35 \))

<table>
<thead>
<tr>
<th></th>
<th>Patent AVF</th>
<th>Failed AVF</th>
<th>Success of surgery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group C (( n=13 ))</td>
<td>6/13</td>
<td>7/13</td>
<td>46</td>
</tr>
<tr>
<td>Group D (( n=22 ))</td>
<td>21/22*</td>
<td>1/22*</td>
<td>95*</td>
</tr>
</tbody>
</table>

Group C: no conversion of high- to low-resistance flow.
Group D: conversion of high- to low-resistance flow.
*\( P < 0.001 \).

The immediate patency of the AVF based on Doppler flow signal response after reduction of the peripheral resistance is shown for groups C and D in Table 2.

In group A one AVF thrombosed due to a haematoma within 4 weeks of the operation. In group B, one AVF failed 48 days and another 54 days after construction because of serious hypotension in one case and haematoma in another case. Four weeks after construction two patients were lost to follow-up because they were moved to other dialysis centre. The cumulative patency rates of all patients determined by life table analysis are shown in Figure 3. Mean volume flow in the radial artery at the different periods after fistula construction are shown in Table 3.

Discussion

Doppler ultrasound has been shown to yield significant anatomical data that correlates with angiographic stud-
Fig. 3. Cumulative patency rate for 35 AVFs performed in 11 patients with radial artery internal diameter ≤1.5 mm (group A) and in 24 patients with a radial artery internal diameter >1.5 mm (group B) (0* = day of surgery).

In conclusion, our study demonstrates that duplex sonography, a non-invasive method, enables sufficient investigation of the arteries before AVF construction. The internal diameter of the radial artery feeding the fistula has an important influence on immediate fistula patency. Appropriate changes in the Doppler flow waveform pattern after lowering the peripheral resistance has significant predictable value for prompt fistula function. In patients with small radial artery diameter, or without conversion of the Doppler waveform, the AVF should be created at an earlier stage of renal insufficiency. In the case of non-function, the surgeon will have enough time to create the AVF in another location.

Table 3. Mean (±SD) volume flow through the artery before and at different periods of observation measured by duplex sonography in patients with patent arteriovenous fistula (AVF) after surgery

<table>
<thead>
<tr>
<th>Time of observation</th>
<th>Group A (n = 5) (IDA ≤1.5 mm)</th>
<th>Group B (n = 22) (IDA &gt; 1.5 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial flow (ml/min)</td>
<td>mean ± SD</td>
<td>mean ± SD</td>
</tr>
<tr>
<td>Before surgery</td>
<td>28.6 ± 1.8</td>
<td>47 ± 5.4*</td>
</tr>
<tr>
<td>1 day</td>
<td>138.1 ± 10.1</td>
<td>184.2 ± 12.6*</td>
</tr>
<tr>
<td>1 week</td>
<td>169.0 ± 11.1</td>
<td>202.4 ± 13.5*</td>
</tr>
<tr>
<td>3 weeks</td>
<td>272.4 ± 13.5</td>
<td>366.2 ± 39.6*</td>
</tr>
<tr>
<td>8 weeks</td>
<td>394.8 ± 86.1</td>
<td>487.6 ± 95.1*</td>
</tr>
<tr>
<td>12 weeks</td>
<td>438.5 ± 87.7</td>
<td>561.8 ± 131.3*</td>
</tr>
</tbody>
</table>

IDA = internal diameter of artery.

*P <0.05.
†‡ AVF.
‡‡19 AVF.
†††18 AVF.

arterial diameter and immediate fistula patency; the lower the arterial diameter, the higher the risk for the immediate fistula nonfunction. Some authors suggest that primary access should not be performed if the diameter of the artery is ≤1.6 mm [10]. In our study, the risk of AVF failure was increased when the internal diameter of the artery was ≤1.5 mm but even with a success rate of 45%, most of surgeons probably would still try to create an AVF.

Normally, the Doppler flow pattern of the radial artery is triphasic with reversed diastolic flow, so called ‘high-resistance’ waveform. After clenching a fist for 3 min, thereby increasing peripheral resistance, this characteristic of the Doppler waveform becomes more pronounced. After release of the fist resulting in lower peripheral resistance, a change of the Doppler waveform to a ‘low-resistance’ pattern occurs. Blood flow velocity is influenced by two dominant factors: a backward factor, which is the resistance, and forward factor, which is the product of cardiac output and total peripheral resistance [9]. After AVF construction between the radial artery and accompanying cephalic vein, the peripheral resistance for the radial artery feeding the fistula is decreased, as in after the reopened fist. Blood flow through the artery increases and the Doppler waveform changes to a low-resistance flow. Lack of an adequate reaction after releasing a fist indicates that even after fistula construction, the arterial blood flow will not be increased enough for fistula function. Our study confirms that the changes in arterial ‘high-resistance’ flow pattern to ‘low-resistance’ pattern after lowering the peripheral resistance is a satisfactory parameter to assess potential immediate fistula patency.

The volume flow through the radial artery after fistula construction can be calculated by measuring flow velocity and radial artery cross sectional area. In our study, up to nine times increase in volume flow with regard to initial flow was considered 3 weeks after construction in both groups. There was a difference in volume flow with regard to the internal artery diameter at the time of the fistula construction between groups A and B. Patients in group B had adequate AVF flow 3 weeks after construction compared with group A where adequate flow was achieved at 3–8 weeks. After 12 weeks the difference in mean arterial flow between both groups was still present, but blood flow through the AVF was satisfactory for adequate haemodialysis in all patients.

In conclusion, our study demonstrates that duplex sonography, a non-invasive method, enables sufficient investigation of the arteries before AVF construction. The internal diameter of the radial artery feeding the fistula has an important influence on immediate fistula patency. Appropriate changes in the Doppler flow waveform pattern after lowering the peripheral resistance has significant predictable value for prompt fistula function. In patients with small radial artery diameter, or without conversion of the Doppler waveform, the AVF should be created at an earlier stage of renal insufficiency. In the case of non-function, the surgeon will have enough time to create the AVF in another location.

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References


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