Intravascular ultrasound imaging before and after angioplasty for stenosis of arteriovenous fistulae in haemodialysis patients

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Abstract

Background. Complications of haemodialysis vascular access have emerged as a major cause of patient morbidity. Intravascular ultrasound imaging is a new technical modality providing visualization of the vessel lumen and wall structure in a cross-sectional fashion. Percutaneous transluminal angioplasty has long been used in the treatment of stenoses of arteriovenous fistulae. However, there is no detailed quantitative information on the stenotic lesion and the morphological changes before and after angioplasty.

Methods. Intravascular ultrasound studies were performed in 40 haemodialysis patients with 63 stenoses in arteriovenous fistulae who had percutaneous transluminal angioplasty. The patients were qualitatively and quantitatively evaluated for echogenic patterns and morphological changes before and after angioplasty.

Results. Morphological plaque features in stenotic lesions were classified as 37 soft (58%), five hard (8%), 20 mixed (32%), and one calcified sites. Plaque fractures after angioplasty were detected in 45/63 (71%) instances. The lumen cross-sectional area was found to be dilated approximately threefold (from 3.8±2.4 to 11.1±4.5 mm²) and the external elastic membrane lumen contour, was dilated approximately twofold (from 11.1±5.3 to 19.8±8.1 mm²) after angioplasty.

Conclusion. These results indicate that intravascular ultrasound allows both qualitative and quantitative assessments of arteriovenous fistulae in haemodialysis patients. The results further suggest that the mechanism of expansion of arteriovenous fistulae stenoses by percutaneous transluminal angioplasty involves stretching of the vessel wall as well as plaque fractures.

Keywords: arteriovenous fistulae; haemodialysis patients; intravascular ultrasound imaging; percutaneous transluminal angioplasty

Introduction

The rapid growth of end-stage renal failure programmes worldwide has been accompanied by a tremendous increase in vascular access-associated morbidity in haemodialysis patients. Satisfactory vascular access is the most critical factor in assuring the wellbeing of haemodialysis patients. Adequate blood flow in the arteriovenous fistula (AVF) may have an influence that is vital to the outcome of the dialysis patient. Percutaneous transluminal angioplasty (PTA) has been used in the treatment of stenosis in AVF and accepted as an alternative to surgical revision, it is still the most common intervention [1–5]. Angiography has been the standard method to evaluate the extent of vessel disease. However, angiography provides an image of lumen contour, but does not yield information about the lumen characteristics and vessel-wall structure. Intravascular ultrasound (IVUS) imaging is a new modality that provides visualization of the vessel lumen and wall structures in cross-section. IVUS imaging provided valuable information on the degree of stenosis and the type and extent of atherosclerotic plaques. Several in vitro studies have demonstrated excellent correlation between ultrasound images and the findings of histological investigation [6–12].

However, few data exist regarding the utility of IVUS imaging of AVF in haemodialysis patients [13]. The purpose of this study was to examine the structure and characteristics of the stenotic lesions of AVF, and conduct a quantitative evaluation of the stenotic lesions of AVF before and after angioplasty in vivo.
Subjects and methods

Patients

IVUS studies were performed in 40 haemodialysis patients with 63 stenotic lesion sites, including multiple stenotic lesions, who had undergone PTA. Indications for PTA were the following: (i) insufficient blood flow, defined as the inability to attain a 200 ml/min flow rate during dialysis sessions; (ii) increased venous pressure, defined as a pressure greater than 150 mmHg during dialysis sessions; and (iii) development of arm oedema. In addition, indications for PTA were based on angiographic identification of stenosis of more than 50% compared with a normal reference. Clinical problems before angioplasty included two patients with arm oedema and seven patients who had puncture difficulty. All the patients were undergoing initial treatment with interventional therapy and had native AVF. AVF had been constructed in the forearm in 38 patients and in the upper arm in two patients. Patient age ranged from 25 to 89 years (mean 61 years) and duration of dialysis ranged from 1 to 186 months (mean 29 months). The primary renal diseases were diabetic nephropathy in 20, chronic glomerulonephritis in 12, polycystic kidney disease in two, nephrosclerosis in two, and of unknown origin in four patients.

Intravascular ultrasound

IVUS catheter comprised a 30-MHz transducer mounted on the tip of a 2.9 Fr catheter (Ultra Cross®; Scimed/Boston Scientific, MA, USA). The ultrasound beam was reflected onto a rotating transducer revolving at 1800 r.p.m., creating a 360° real-time image perpendicular to the catheter. Lateral and axial resolutions of this system were approximately 150 μm and 90 μm respectively. The IVUS console was the Clearview Ultra® (Scimed/Boston Scientific) intravascular imaging system. Images were recorded on Super-VHS videotapes. Measurements of lumen diameter and wall thickness were made on-line using the software package built into the instrument. Echogenic patterns and morphological changes of the IVUS images were qualitatively and quantitatively evaluated by two observers blinded to the results of angiography.

Qualitative analysis was performed for echogenic patterns and morphological changes following PTA. Morphological plaque features were classified as soft, hard, mixed, and calcified according to the reports of Hodgson et al. [14]. Briefly, soft plaque ≥80% of the plaque area through the lesion was composed of intimal echoes with less homogenous echodensity than seen in the adventitia. Hard plaque ≥80% of the plaque area through the lesion was composed of dense echoes with a homogenous echodensity greater than or equal to that seen in the adventitia. No calcium was present. Mixed plaque is a plaque having bright echoes with acoustic shadowing encompassing <90° of vessel-wall circumference or a mixture of soft and hard plaque, with each component occupying <80% of the plaque area through the lesion. A plaque fracture was defined as an irregular thin echolucent site increased from 3.9 to 11.1 mm after angioplasty and the minor EEM diameter also increased from 3.5 ± 0.9 to 4.7 ± 1.0 mm after angioplasty (P < 0.0001). The percentage cross-sectional area was measured as the EEM cross-sectional area (CSA). The following measurements were investigated: (i) lumen diameter (mm), (ii) EEM diameter (mm), (iii) lumen CSA (mm²), (iv) EEM CSA (mm²), (v) cross-sectional narrowing = ((EEM CSA – lumen CSA)/(EEM CSA)) × 100. The major and minor diameters of the lumen and EEM were measured according to the reports of Nakamura et al. [15].

PTA procedure

Angiography was performed by puncturing the distal or proximal part of the stenotic lesion of arteriovenous fistulae, or the artery. After delineation of the stenotic lesion, PTA was performed as follows: from the distal or proximal part of the lesion, a 22-gauge thin-wall needle was inserted and the first guide wire was passed through this needle into the vessel. A 5 Fr or 6 Fr sheath with a length of 5 cm was placed, and the patient immediately received 50 units/kg of heparin. Next a 0.014- or 0.018-inch guide wire was passed to the target lesion and angioplasty applied with a high-pressure balloon catheter with a diameter of 4–6 mm and a length of 2 or 4 cm.

Statistical analysis

Statistical analysis was performed by paired Student’s t-test. Data were expressed as the mean ± standard deviation (SD). Differences were considered significant at the level of P < 0.05.

Results

Qualitative analysis

High-resolution real-time ultrasound images were obtained in all patients without any complication. Figure 1 shows intravascular ultrasound imaging obtained from the AVF of a haemodialysed patient. Ultrasound images reveal a triple-layered appearance (echo-reflective intima, echo-lucent media, and echo-reflective adventitia). Figure 2 shows representative angiograms and ultrasound imaging before and after angioplasty. Morphological plaque features in stenotic lesions were classified as 37 soft sites (58%), five hard sites (8%), 20 mixed sites (32%), and one calcified site. In addition, plaque fractures were detected in 45/63 (71%) after angioplasty.

Quantitative analysis

As shown in Table 1, the major lumen diameter at the lesion site increased from 2.3 ± 0.8 to 4.1 ± 0.8 mm after angioplasty and the minor lumen diameter also increased from 1.9 ± 0.7 to 3.3 ± 0.8 mm after angioplasty (P < 0.0001). The major EEM diameter at the lesion site increased from 3.9 ± 1.0 to 5.3 ± 1.1 mm after angioplasty and the minor EEM diameter also increased from 3.5 ± 0.9 to 4.7 ± 1.0 mm after angioplasty (P < 0.0001). The lumen CSA at the lesion site increased from 3.8 ± 2.4 to 11.1 ± 4.5 mm² after angioplasty (P < 0.0001). The EEM CSA at the lesion site increased from 11.1 ± 5.3 to 19.8 ± 8.1 mm² after angioplasty (P < 0.0001).
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Fig. 1. IVUS image obtained from AVF demonstrates the lumen (white arrow) and shows the triple-layer appearance as an echo-reflective intima (Int), echo-lucent media (Med), and echo-reflective adventitia (Adv).

narrowing decreased from $64.8 \pm 14.7$ to $41.9 \pm 12.2\%$ after angioplasty ($P<0.0001$).

Discussion

IVUS imaging can provide detailed information on lumen dimensions and the characteristics of vessel structure and qualitative and quantitative analysis before and after angioplasty. As far as we know this is the first report on quantitative analysis of various parameters, including the diameter and CSA of the lumen and EEM before and after angioplasty, as assessed by IVUS imaging in haemodialysis fistulae.

Veins have thinner walls than their arterial counterparts. Histologically, veins contain an abundance of connective tissue, whereas elastin fibres and smooth-muscle cells occur in smaller numbers. The walls of veins consist of three poorly defined layers: the intima, media, and adventitia. Gussenhoven et al. [8] reported that the walls of veins did not allow ultrasonic distinction between the intima, media, and adventitia.

In our study, the echo pattern of native AVF revealed a triple layer appearance of the hyperechoic intima, the hypoechoic media, and hyperechoic adventitia. This is regarded as a result of arterialization of veins. The phenomenon of arterial blood circulating into veins in vivo exists in saphenous vein grafts for coronary artery bypass surgery and for AVF of haemodialysis patients. Willard et al. [16] reported that a chronically implanted saphenous vein graft demonstrated a variety of pathological changes, including intimal proliferation and atherosclerosis. IVUS can distinguish between the normal appearance of freshly harvested veins and intimal hyperplasia, atherosclerosis, and vein graft wall fibrosis, and reveals a triple-layer appearance. Correlation between the ultrasound examination of plaque morphology and the histological characteristics of the corresponding vessel wall was established. According to these reports, soft echoes are reflective of fibromuscular tissue (intimal proliferation as well as lesions that consist of fibromuscular tissue and diffusely dispersed lipid), and bright and homogeneous

Fig. 2. Representative angiogram and IVUS images before and after PTA are shown. Arrows at lesions indicate which IVUS images correspond to portions A and B. The images trace the contours of the lumen area (inner contour) and the EEM area (outer contour) and trace the lines of the major and minor lumen and EEM diameters. At the lesion A, the lumen area and diameters before PTA did not trace and were assessed inside the catheter as the catheter was wedged. The major and minor EEM diameters increased from 3.6 to 4.7 mm and from 3.2 to 4.7 mm after PTA. The EEM CSA increased from 9.1 to 16.4 mm² and the percentage of cross-sectional narrowing decreased from 91.9 to 37.2% respectively, after PTA. Similarly at lesion B, the major and minor lumen diameters increased from 2.5 to 4.0 mm and from 2.1 to 2.8 mm and the major and minor EEM diameters also increased from 4.0 to 4.8 mm and from 3.4 to 4.8 mm after PTA. The lumen CSA increased from 4.0 to 9.4 mm² and the EEM CSA increased from 10.5 to 17.6 mm²; however, the percentage of the cross-sectional narrowing decreased from 61.9 to 46.6% respectively, after PTA. Moreover, the image revealed plaque fracture at a site between 9 and 10 o’clock. *cephalic vein; **radial artery.
Cross-sectional narrowing imaging. IVUS imaging provided valuable information on histologic and quantitative angiographic assessment of vessel wall characteristics: a correlation with histology.

AVF stenoses by angioplasty is due mainly to vessel wall changes. Our results showed plaque fractures including plaque dissection and intimal flaps as described above. They reported a higher frequency of dissections. This may be due to differences in the choice of balloon catheter used and in the IVUS catheter used. The size of our balloon catheter was usually smaller than that of their report. In our study, however, the mean major EEM diameter of lesions was 3.9 mm and that of the reference sites was below 6.0 mm, and the mean major lumen diameter was also below 5.0 mm. We chose a suitable balloon catheter and could not use a larger balloon catheter because of the risk of complications.

The investigation of morphological changes of angioplasty by ultrasound revealed that the lumen diameter and cross-sectional diameter of the EEM showed significant increases after angioplasty compared with the respective values before angioplasty. Consequently, lumens CSA was dilated by about threefold after angioplasty (from 3.8 ± 2.4 to 11.1 ± 4.5 mm²). It was surprising that the EEM CSA also was dilated approximately twofold after angioplasty (from 11.1 ± 5.3 to 19.8 ± 8.1 mm²). In previous ultrasound examinations of arteries submitted to angioplasty, the vessel CSA of artery was either unchanged or slightly increased after angioplasty [17–19]. These findings strongly suggest that this is a characteristic phenomenon of arterialized venous lesions, and the mechanism of dilatation of AVF stenoses by angioplasty is due mainly to vessel stretch.

We report qualitative and quantitative assessments of the AVF in haemodialysis patients by ultrasound imaging. IVUS imaging provided valuable information on the vessels. Our interest is in the increase of long-term AVF patency in patients undergoing PTA, stent placement and atherectomy or surgical repair. We recommend the clinical use of IVUS combined with angiography.

In conclusion, both qualitative and quantitative assessments of AVF in haemodialysis patients by IVUS are possible, and the viable mechanism of expansion of the stenoses by angioplasty is via stretching of the vessel wall and plaque fractures. This technique may be an important key with regard to the causes of AVF stenosis and restenosis following angioplasty.

References


Table 1. Morphological changes after angioplasty as assessed by intravascular ultrasound imaging (means ± SD)

<table>
<thead>
<tr>
<th>Lumen diameter (mm)</th>
<th>Before</th>
<th>After</th>
<th>P value</th>
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<tbody>
<tr>
<td>Major</td>
<td>2.3 ± 0.8</td>
<td>4.1 ± 0.8</td>
<td>&lt;0.0001</td>
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<tr>
<td>Minor</td>
<td>1.9 ± 0.7</td>
<td>3.3 ± 0.8</td>
<td>&lt;0.0001</td>
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<tr>
<td>Cross-sectional diameter of EEM (mm)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Major</td>
<td>3.9 ± 1.0</td>
<td>5.3 ± 1.1</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Minor</td>
<td>3.5 ± 0.9</td>
<td>4.7 ± 1.0</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Lumen CSA (mm²)</td>
<td>3.8 ± 2.4</td>
<td>11.4 ± 4.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>EEM CSA (mm²)</td>
<td>11.1 ± 5.3</td>
<td>19.8 ± 8.1</td>
<td>&lt;0.0001</td>
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<tr>
<td>Cross-sectional narrowing (%)</td>
<td>64.8 ± 14.7</td>
<td>41.9 ± 12.2</td>
<td>&lt;0.0001</td>
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CSA, cross-sectional area; EEM, external elastic membrane.
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