

Technical Report

3D Ultrasound imaging—a useful non-invasive tool to detect AV fistulas in transplanted kidneys

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Abstract

Background. A precise, non-invasive, non-toxic, repeatable, convenient and inexpensive follow-up of renal transplants, especially following biopsies, is in the interest of nephrologists. Formerly, the rate of biopsies leading to AV fistulas had been underestimated. Imaging procedures suited to a detailed judgement of these vascular malformations are to be assessed.

Methods. Three-dimensional (3D) reconstruction techniques of ultrasound flow-directed and non-flow-directed energy mode pictures were compared with a standard procedure, gadolinium-enhanced nuclear magnetic resonance imaging angiography (MRA) using the phase contrast technique.

Results. Using B-mode and conventional duplex information, AV fistulas were localized in the upper pole of the kidney transplant of the index patient. The 3D reconstruction provided information about the exact localization and orientation of the fistula in relation to other vascular structures, and the flow along the fistula. The MRA provided localization and orientation information, but less functional information. Flow-directed and non-flow-directed energy mode pictures could be reconstructed to provide 3D information about vascular malformations in transplanted kidneys.

Conclusion. In transplanted kidneys, 3D-ultrasound angiography may be equally as effective as MRA in localizing and identifying AV malformations. Advantages of the ultrasound method are that it is cheaper, non-toxic, non-invasive, more widely availability and that it even provides more functional information. Future prospective studies will be necessary to evaluate the two techniques further.

Key words: AV fistula; kidney transplantation; magnetic resonance angiography; renal biopsy; three-dimensional ultrasound

Introduction

The follow-up of kidney transplants includes biopsies of these organs in a number of circumstances. Recently, AV fistulas have been acknowledged as a complication of renal biopsies in up to 9% of the procedures performed [1–3]. As soon as there is a clinical suspicion of a haemodynamically relevant AV fistula, imaging procedures are applied which are either associated with a risk of nephrotoxicity, e.g. contrast-media application during angiography [4], or are not widely available and expensive, e.g. gadolinium-enhanced nuclear magnetic resonance imaging (MRI).

Three-dimensional (3D) imaging techniques in ultrasonography are now more commonly available and are already used in gynaecology and angiology [5,6]. Yet, we use two-dimensional duplex ultrasound techniques which we supplement by 3D viewing information, as suggested by Bendick *et al.* [7] and Bonilla-Musoles *et al.* [8].

We wish to present the techniques used in our division by reporting the case of a patient with a post-biopsy AV fistula of a transplanted kidney. We retrospectively examined angiographic gadolinium-contrast enhanced MRI as compared with 3D ultrasound techniques to help to define the need for a corrective intervention.

Patients and methods

We studied 3D imaging techniques in patients who had a kidney transplant in the past using two techniques. We performed an ultrasound examination of the kidney using a machine capable of the standard technique with a multifrequency sector array probe at 3.5 MHz. To obtain a picture series for 3D reconstructions, we performed a manual sweep technique within the region of interest. The 3D reconstruction was achieved either by integrating up to 15 pictures of flow-directed energy mode (Logiq 500 MR3, GE Medical Systems), or we currently use a data management subsystem to reconstitute up to nine energy mode pictures three-dimensionally which are selected out of loops of up to 111 pictures (Aloka DynaView SSD-1700 and DMS 1700).

The ultrasound examination was compared with gadolin-

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ium-enhanced MRI angiography (MRA) as routinely performed by the radiology department.

In order to elucidate the technique, we describe the case of an index patient. A 26-year-old man with end-stage renal failure due to mesangio-proliferative glomerulonephritis diagnosed 7 years earlier received his first kidney transplant 2 years ago after spending 13 months on chronic intermittent haemodialysis. The acute phase after transplantation was complicated by a delayed graft function which was assessed by renal biopsy. This showed evidence of tubular necrosis without rejection. Within the next 2 weeks, repeated ultrasound examinations revealed a reduced perfusion of the upper third of the kidney and evidence of an AV fistula which was most likely due to the biopsy performed in the same region some days before. The renal function remained stable, with a creatinine of 140–150 $\mu\text{mol/l}$ for the next 2 years.

Results

In the index patient, a gadolinium-enhanced MRI was performed by the radiology department which showed a regular perfusion of the renal vein and artery. At the upper pole of the kidney, a spurious aneurysm (Figures 1 and 2) could be demonstrated without evidence of an early venous drainage. Although the vein which drains this region was enlarged, the main renal vein was of normal size (Figures 1 and 2). The Standard ultrasound technique showed a transplanted kidney without severe morphological abnormalities apart from the dilated venous drainage from the upper pole; however, regular resistance indices were derived from this area. The cranial segmental artery was identified



Fig. 1. A gadolinium-enhanced nuclear MR scan using the phase contrast technique in the early arterial phase of the perfusion of the transplanted kidney. The large inguinal vessels, the renal artery and the arterial feeder vessel, the aneurysm formation and the rapid premature venous outflow are visible. The renal parenchyma provides almost no signal.



Fig. 2. A gadolinium-enhanced nuclear MR scan using the phase contrast technique in the late arterial and early venous phase of the perfusion of the transplanted kidney. The large inguinal vessels, the renal artery and the arterial feeder vessel and the venous outflow are still visible. Since the renal parenchyma is contrasted, the fistula formation is less visible compared with Figure 1; however, the right iliac vein already is contrasted.

as exhibiting an increased diastolic flow rate which could suggest the feeding blood flow towards the aneurysm. The application of a sweep technique using the flow-directed energy mode with 15 picture reconstructions allowed us to identify the draining vein, the interlobar arteries which were slightly displaced by the enlarged vein (Figure 3) and the aneurysm itself (Figure 4). We were able to recognize the feeder artery (Figure 4); and the turbulent flow through the fistula switching into a slower venous outflow (Figure 4).

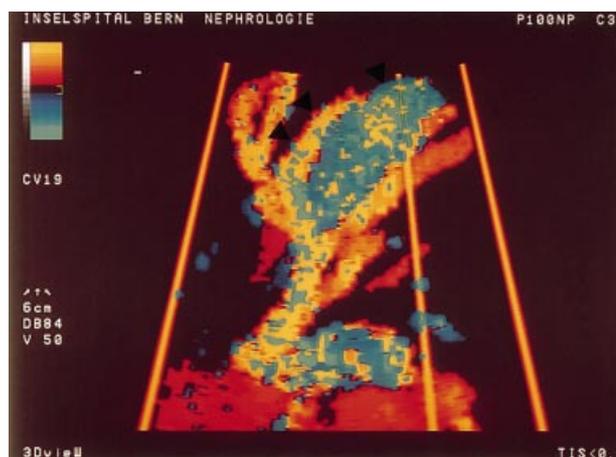


Fig. 3. A 3D reconstruction of a series of flow-directed energy mode pictures taken from the same patient. The use of a sweep technique with 15 picture reconstructions allowed us to identify the draining vein, and the interlobar arteries which were slightly displaced by the enlarged vein.



Fig. 4. Using the same technique as in Figure 3, we additionally could recognize the feeder artery and the turbulent flow through the fistula switching into a slower venous outflow.

In further patients, AV fistulas were detected by conventional duplex techniques which were supplemented consecutively by a 3D non-flow-directed energy mode visualization of the vascular malformation using nine picture 3D reconstructions.

Discussion

Three-dimensional techniques in ultrasonography are becoming more sophisticated as technical progress allows large quantities of data to be processed in shorter periods of time. Applications of 3D ultrasound techniques have been described for the kidney [9]. These and other 3D approaches have basically focused on measuring the kidney volume using devices which rotate to differing extents around one or two axes. Evaluating this technique in comparison with MRI showed a good correlation between the values obtained by the two methods with respect to the volume measured [10], and were improved further using an electromagnetic localization system [11,12]. Enhanced 3D techniques allowed the visualization of structures of <10 mm which provide an ideal tool for the follow-up of pregnancies to detect fetal abnormalities at an early stage [5]. Carotid plaque formation was also measured reliably by 3D ultrasound imaging [13].

Three-dimensional vascular imaging became available with the introduction of energy-mode Doppler ultrasonic angiography. Two-dimensional scans were used after digitization to reconstruct 3D images [14]. Recently, Yao *et al.* [6], in a study performed on carotid arteries, reported excellent reproducibility and small intra- and interobserver variability on 3D ultrasound imaging when compared with carotid angiography. This report confirmed the results of the study by Benedick *et al.* [7] showing an accurate assessment of carotid stenosis when compared with angiography in 53 out of 61 vessels. Stenoses above 60% were identified correctly in all cases.

We believe that the transplanted kidney is a favourable target for application of this new technique, as demonstrated here in a case of a vascular abnormality in a transplanted kidney following renal biopsy. To control for complications of a method, as is kidney biopsy, which frequently is applied in situations with already compromised renal function, a non-invasive, non-toxic, but cost-effective procedure seems to be favorable for initial diagnosis as well as for repeated follow-ups.

No data are available currently to support the use of this new method in nephrology. In pilot experiments, we could demonstrate that it can be applied sensibly in renal transplantation to detect vascular malformations. The 3D reconstruction process was performed on structures suspected to be AV fistulas or if duplex signals or Doppler spectra indicated a further investigation. Prospective studies are needed to compare ultrasonographic angiography with the sensitivity and specificity of the MRA method. However, even this technique for vascular imaging in renal transplantation depends upon the accuracy of the individual reconstruction procedure, although the reported results of ultrafast, contrast-enhanced two-phase 3D-MRA are promising [15]. Angiographic procedures which include the application of iodinated contrast media should be reserved only for distinct clinical questions and no longer be performed as the method of choice to detect vascular malformations in transplanted kidneys.

A limitation of 3D ultrasonographic imaging may be that its accuracy and performance depend on access to the structures to be investigated. Kidneys *in situ* in obese patients will definitely pose a problem with this method. However, dialysis fistulas which are usually very easily accessible in a subcutaneous localization may be a future application.

In summary, the advantages of the ultrasonic 3D technique are that it: (i) is non-invasive, (ii) is non-toxic, (iii) is inexpensive, (iv) provides an almost real-time functional and 3D high resolution picture of vascular structures, and (v) has the potential of being widely available. However, even though the sensitivity, specificity and reproducibility still remain to be proven prospectively, this technique opens up a new horizon in post-transplant, post-biopsy management.

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