Abstract The aim of this study was to investigate the value of a contrast-enhanced 3D MR angiography in detecting postoperative vascular complications after kidney transplantation in comparison with digital subtraction angiography (DSA). Forty-one patients who underwent a kidney transplantation were examined with MR angiography and DSA. Contrast-enhanced MR angiography was performed as a dynamic measurement with one precontrast and three postcontrast measurements. Maximum intensity projection reconstructions were performed for all postcontrast data sets after DSA. The results were evaluated by two independent observers who were unaware of the DSA results. Twenty-three hemodynamically significant arterial stenoses were identified with DSA in the iliac arteries \((n = 7)\), the renal allograft arteries \((n = 12)\), and in their first branches \((n = 4)\). For a patient-based analysis the sensitivity and specificity, respectively, for observer 1 were 100 and 97\%, and for observer 2, 100 and 93\%. Respective data were 100 and 100\% after a consensus evaluation by two observers. Complications involving the renal veins were detected in 2 cases and perfusion defects of the kidney parenchyma were detected in 4 cases. Contrast-enhanced MR angiography is a reliable method in identifying postoperative arterial stenoses after kidney transplantation. In addition, dynamic MR angiography can be helpful in detecting venous complications and perfusion defects in kidney allografts.

Keywords MR · Angiography · Transplant · Kidney · Gadolinium

Introduction

The gold standard in identifying vascular complications is digital subtraction angiography (DSA). However, DSA is an invasive investigation that is associated with the risk of radiation and nephrotoxicity due to the use of an iodinated contrast agent [1, 2]. Although catheter-associated complications [3] are rare and most of them are minor, 0.14\% of patients require hospitalization [4]. Therefore, there is a need to develop a noninvasive method to examine the vascular system with high diagnostic accuracy [5] and a minimized risk of nephrotoxicity, especially in patients with diabetic angiopathy and renal failure.

Previous studies of phase-contrast (PC) [6] and time-of-flight (TOF) [7] magnetic resonance angiography have shown that both methods are inferior to DSA in imaging the morphology of even large vessels in renal transplants. In addition, ultrasound of the pelvic region cannot replace DSA in all patients after renal transplantation [8].

Recently, contrast-enhanced MR angiography has been shown to be a reliable method in other vascular territories [9] such as in the aorta and in the native renal arteries [10]. Johnson et al. examined nine patients after kidney transplantation with contrast-enhanced MR angiography [7]. In another study, 11 patients after kidney

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and pancreas transplantation were examined with contrast-enhanced MR angiography [11]. Wiesner et al. [12] examined 18 recipients of renal transplants; however, only three arterial stenoses were identified in this study. The largest study about kidney allografts was performed by Ferreiros et al. [13] which included 28 patients and 8 arterial stenosis with promising results. In the current literature there are not many studies with larger populations of patients with kidney transplantation and larger numbers of pathological findings that were examined with MR angiography and DSA.

The goal of our study was to investigate the value of contrast-enhanced 3D gradient-echo MR angiography with short TR and TE in the assessment of postoperative complications after kidney transplantation in a larger patient group, and to compare the results of MR angiography with those of DSA.

**Subjects and methods**

Forty-one patients were examined after kidney transplantation (mean age 42 ± 17.4 years) with contrast-enhanced MR angiography. All patients also underwent DSA. The indication for DSA was allograft failure of the kidney or hypertension. Allograft failure of the kidneys with elevated serum creatinine levels (> 2 mg/dl) was found in 34 patients. Hypertension with elevated blood pressure values (diastolic blood pressure > 95 mmHg, systolic blood pressure > 165 mmHg) was found in 7 patients. Written informed consent to perform MR angiography and DSA was obtained from all patients after the nature of the procedures was fully explained.

**Digital subtraction angiography**

In all patients, conventional angiography was performed using an X-ray system (Integris 3000, Philips, Eindhoven, The Netherlands) with a digital subtraction technique. A power injector was used for administration of the iodinated contrast material, iopamidol (So- lutras 300, Bracco Byk Gulden, Konstanz, Germany). All angiographic procedures were supervised by experienced vascular radiologists.

The DSA was performed by puncturing the common femoral artery and placing the tip of a 4-F pigtail catheter in the distal aorta above the bifurcation. Posterior–anterior and oblique views were obtained by DSA and documented on hard copies. In addition, selective catheterization was performed when necessary.

The DSA results were assessed by two vascular radiologists who were unaware of the MR angiography results, in a consensus reading. The degree of stenosis was categorized with a six-point scale (0 = no stenosis, 1 = stenosis with narrowing of diameter of 1–25%, 2 = stenosis with narrowing of diameter of 26–50%, 3 = moderate stenosis with narrowing of diameter of 51 to 75%, 4 = severe stenosis with narrowing of diameter of 76–99%, and 5 = complete occlusion). Only hemodynamically significant stenoses (> 50% narrowing of the luminal diameter) were included in the comparison with MR angiography.

**MR angiography**

All MR studies were performed on a 1.5-T whole-body system (Magnetom Vision, Siemens, Erlangen, Germany) using a circularly polarized body phased-array coil. For the MR angiography examination, a T1-weighted 3D gradient-echo sequence with a TR of 4.4 ms, a TE of 1.8 ms and a flip angle of 45° was employed. The dynamic examination included four repetitive measurements, each with an acquisition time of 23 s during breathhold and a break of 10 s for one respiratory cycle between the measurements. One measurement was performed before and three measurements after intravenous application of gadopentetate dimeglumine (Magnevist, Schering, Berlin, Germany).

The spatial resolution was defined by a field of view of 500 × 313 mm, a matrix of 512 × 165, a slab thickness of 90 mm, and 30 partitions. The resulting voxel size was 1 × 2 × 3 mm without using an interpolation algorithm and 1 × 2 × 1.5 mm after using an interpolation algorithm. The 3D slab of the MR angiography sequence was positioned in an oblique-coral orientation with a slight anterior–posterior angulation in order to cover the inferior parts of the iliac arteries posteriorly.

The aim of this protocol was to visualize the iliac arteries and the allograft arteries during the second measurement and to obtain information about the venous vessels and the allograft parenchyma during the third and fourth measurements. After subtraction of the pre-contrast data set from the three post-contrast data sets, maximum intensity projection (MIP) reconstructions were calculated over a 90° sector from –45 to +45° around the body axis.

The contrast agent was injected via a MR power injector (Spectris, Medrad, Volkach, Germany) with a flow rate of 2 mL/s at a dose of 0.2 mmol/kg, followed by a flush of 20 mL saline. The transit time was previously determined by an injection of a 2 mL gadolinium test bolus followed by 20 mL saline with a flow rate of 2 mL/s during a dynamic T1-weighted gradient-echo sequence, which included one transverse slice positioned at the level of the distal aorta and 40 measurements at a resolution time of 1 s. The same delay time as determined with the test-bolus injection was used between the second MR angiography measurement and the beginning of the venous injection of contrast material.

**Evaluation of MR angiography results**

The mean values of signal-to-noise ratio (S/N ratio; signal intensity/standard deviation<sub>noise</sub>) of all patients were calculated for the first, second, third, and fourth measurements of the renal allograft artery and vein. The mean values of contrast/noise ratio (C/N ratio; signal intensity-signal intensity<sub>noise</sub>/standard deviation<sub>noise</sub>) of all patients were determined for the first measurement post gadolinium with and without subtraction of the measurement before gadolinium administration in order to find out if a subtraction technique was necessary. For the evaluation of the C/N ratio, four defined arterial vessel segments (common and external iliac artery, renal artery, and segmental arteries) were included.

Two experienced MR radiologists who were unaware of the DSA results evaluated both the MIP reconstructions and the single slices before and after subtraction on a workstation (console workstation of Siemens Vision MR system), first independently and then in a consensus. Five arterial vessel segments were included for the comparison of DSA and MR angiography results: the common iliac artery; the common iliac artery; the anastomosis with the allograft artery; the renal allograft artery; and the first-order branches (segmental renal arteries). In order to evaluate the diagnostic accuracy of MR angiography, sensitivity and specificity were calculated for all vessel segments. The degree of stenosis was