TECHNICAL NOTE

Magnetic Resonance Angiography of the Renal Arteries Using Three-Dimensional Balanced Turbo Field-Echo Sequence with Progressive Spin Saturation

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We developed a new method employing a balanced turbo field-echo (b-TFE) sequence with progressive spin saturation (PSS) for magnetic resonance angiography (MRA) of the renal arteries during breath-holding without the use of contrast agents. We compared our new method with conventional dynamic MRA of renal arteries. For all portions, renal MRA using b-TFE with PSS was clearer to define ($p < 0.002$) than did conventional dynamic MRA. We confirmed that angiography of renal arteries using b-TFE with PSS was more useful than conventional dynamic MRA.

Keywords: *MR angiography, kidney, renal artery, balanced turbo field echo, steady state free precession*

Introduction

Several magnetic resonance (MR) angiographic techniques have been implemented for noninvasive imaging of the renal arteries. They can be divided into some kinds of methods. Those methods are contrast-enhanced MR techniques and flow-based MR techniques such as time-of-flight (TOF)^{1,2} or phase-contrast (PC)³ imaging. We were able to perform the first method during breath-holding (BH) and obtained good images of the renal arteries. Dong Q. et al. have concluded that contrast-enhanced MR angiography can be used to screen for renovascular disease.⁴ However, the relative invasiveness and cost of the intravenous contrast agent used in MR angiography limit the potential of this technique for large-scale screening. Other methods provided successful visualization of only the proximal centimeters of the main renal arteries. However, we were unable to improve the image quality of the peripheral arteries sufficiently for clinical diagnosis, and depiction of the more distal segments of the renal arteries was limited by the conventional imaging technique in a short time without contrast agents.

Consequently, we developed a new method for imaging the renal arteries during BH without the use of contrast agents that utilizes a balanced turbo field echo (b-TFE) sequence with progressive spin saturation (PSS). The purpose of our study was to compare contrast-enhanced MR angiography of the renal arteries with the technique utilizing b-TFE with PSS.

Material and Methods

All MR images were acquired with a Gyroscan NT-INTERA 1.5T MR unit (Philips Medical Systems, Best, Netherlands) equipped with a SENSE (phased-array) body coil, which was used in combination with the breath-holding technique. First, we examined the influence of PSS in the b-TFE sequence. To investigate PSS, we obtained an axial abdominal image of a healthy volunteer by irradiating with the minimum number of RF pulses and evaluated the relationship between the number of start-up RF pulses and the signal intensity. From those results, we estimated the imaging parameters that rendered the renal arteries with a high signal by means of the b-TFE sequence with PSS. Next, we applied our b-TFE sequence with PSS, using optimized scan parameters for patients who were examined with conventional enhanced renal MRA

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simultaneously. All volunteers and patients gave informed consent according to the guidelines approved by the Ethical Committee of the Kobe University Graduate School of Medicine, Japan. We compared the clinically useful peripheral demonstration of the renal arteries obtained with our b-TFE angiography with that obtained with conventional dynamic MRA.

Basic Study

It is known that MR signal intensity decreases with many RF pulses of irradiation; this signal saturation is known as progressive spin saturation (PSS).⁵ To investigate PSS, we produced a special imaging sequence experimentally. The imaging parameters are as follows: b-TFE, TR/TE = 2.5/1.25 ms, FA = 100°, single shot [low-high (centric view order)], scan matrix = 256 × 64, rectangular FOV = 85%, SENSE R = 2.5, and 5 mm-thick single slice by b-TFE sequence. The image was obtained after only 16 RF pulses of irradiation. Moreover, the first RF pulse powerfully affects the contrast for centric view order in k-space. We obtained axial images that included the bilateral kidneys of three healthy volunteers (three men aged 21–24; mean age, 22.0) using the b-TFE sequence while changing the flip angle of the initial excitation RF pulse (FA) and the number of start-up pulses (Nsp). First, we investigated FA, which shows a maximal value for the signal intensity of the blood flow in the abdominal aorta. Next, we measured the signal intensities of the aorta, kidney, subcutaneous fat, and muscle in order to examine the relation between those signal intensities and the Nsp with the FA we had studied previously.

From these results, we determined the optimal scan parameters for renal arterial imaging by means of b-TFE sequence with PSS.

Clinical Study

Our 22 subjects (eight women and 14 men aged 58–74 years; mean age, 68.2 years) were all patients who had undergone testing with conventional enhanced renal MRA. Before the conventional MRA examination, we performed our b-TFE sequence with PSS. We used the 3D b-TFE sequence [TR/TE = 6.1/3.0 ms, FA = 110°, TEF factor = 32, high-low, FOV = 280 mm (rectangular FOV = 85%), thick./gap = 3.0/–1.5 mm at axial 32 slices, scan matrix = 160² (radial scan 100%), in-plane spatial resolution of 1.7 × 1.7 mm, proset (water selective excitation) = 11, and SENSE R = 2.0] within only 17 s BH. Only one saturation pulse was

applied parallel and caudal to the 3D imaging volume to provide suppression of signal from the inferior vena cava (IVC), and we did not use the two saturation slabs over the helum of both kidneys to reduce the signal of the renal vein. We sought to acquire the data under the PSS conditions, performing zero repetitive start-up cycles immediately preceding the imaging portion of the sequence and using high-low (reverse centric view) order in k-space. Next, we examined conventional enhanced renal MRA with the dynamic 3D T₁-TFE sequence [TR/TE = 4.3/1.4 ms, FA = 15°, TEF factor = 128, low-high, FOV = 350 mm (rectangular FOV = 100%), thick./gap = 5.0/–2.5 mm at coronal 25 slices, scan matrix = 256² (radial scan 75%), in-plane spatial resolution of 1.4 × 1.4 mm, SPIR (fat saturation), SENSE R = 2.0, and scan duration = 8.6 s]. Because our MR unit lacked a bolus tracking system, dynamic scanning was started 17 s after bolus injection (0.1 mmol/kg at 1.5 ml/s) of the contrast agent. We obtained the source images of projection by subtracting the mask image from the contrast-enhanced images.

After MIP processing (15 coronal projection at 5° intervals), we compared each image of the angiography, our b-TFE sequence, and conventional enhanced MRA on the display of the MR system. All images were evaluated independently by two radiologists (Y. K., K. S., with 15 and 20 years of experience, respectively, in the interpretation of body MRI) and one radiological technologist (H. K., with 15 years of experience in the operation of clinical MR systems).

We focused our attention on the proximal, middle, and distal portions of the renal artery as well as the more distal branches, such as intra-renal vessels, in order to assess the peripheral demonstration visually with consensus. We evaluated the image quality of each portion of the renal artery on a four-point scale (4 points for “very good,” 3 points for “good,” 2 points for “fair,” 1 point for “poor,” and 0 points when no observation was obtained), and performed a non-parametric statistical analysis (Wilcoxon pairwise signed rank tests).

Results

An FA exceeding 80° was needed so that the signal intensity of the blood flow was maximal and saturated (Fig. 1). Even if the RF pulses continue to be irradiated, the signal of the blood flow in the aorta, for example, does not decrease due to the in-flow effect. On the other hand, the signal decreases when the number of irradiations of the

Fig. 1. When FA exceeded 80°, the signal intensity of the aorta reached the maximum and was saturated. Note: The graph of PVA gel data is described for reference.

Fig. 2 The signal intensity of the aorta did not decrease even when irradiation of the RF pulse continued. On the other hand, the signal decreased when Nsp increased in fixed tissues such as fat, muscle, and kidneys. The difference between the signals of the aorta and fixed tissues increases when the RF pulse was irradiated more than 29 times.

RF pulse is increased in fixed tissue such as fat and muscle. From these results, we recognized that PSS occurred even in the b-TFE sequence (Fig. 2).

The contrast between blood flow and fixed tissues improves when the number of irradiations of the RF pulse exceeds 30. From this result, we established the TFE factor as 32 and used reverse centric order (high-low) in scanning of the renal artery because the 32nd echo is the most influenced contrast in this sequence.

Fig. 3. In all portions, renal MRA obtained by means of the b-TFE sequence with PSS was superior to dynamic MRA ($P < 0.002$). In particular, conventional dynamic MRA was inferior in the proximal and intra-renal portions.

We irradiated a spatial saturation pulse in the inferior part of the imaging slab in order to decrease the signal of the IVC and used a selective water excitation RF pulse (proset 1-1) to further decrease the signal from subcutaneous fat.

In all portions (proximal, middle, distal, and intra-renal), renal MRA by means of b-TFE with PSS was clearer to define ($p < 0.002$) than did conventional dynamic MRA (Fig. 3).

Discussion

We confirmed the influence of PSS with the b-TFE sequence. This takes an influence by the FA of excitation RF pulses, number of irradiation RF pulses, blood flow, and imaging slab.⁵ Therefore, we could not obtain good images if the imaging parameter was not promptly optimized to the applicable blood flow.

In this paper, we investigated the use of the b-TFE sequence in obtaining the optimum parameters for MR angiography in renal arteries. From the basic study, we discovered that the MR signal of fixed tissue is decreased when the number of irradiations of the RF pulse exceeds 30. This result shows that the effect of PSS is effectively available when the TFE factor is established as 32, and reverse centric order is used for the k-space trajectory. The b-TFE sequence has been used conventionally in renal MRA. However, in the conventional method, the spatial saturation pulse is irradiated to reduce the signal of the renal vein⁶ or spin labeling is used to increase in contrast of the renal artery.⁷ When we used PSS with the b-TFE

Fig. 4. Renal MR angiography with conventional dynamic MRA (upper) and b-TFE with PSS (lower). With dynamic MRA, the proximal portion resembled a stenosis (arrow).

Fig. 5. Renal artery obtained with dynamic MRA (upper) and b-TFE sequence with PSS (lower). With conventional dynamic MRA, the ability to display more distal portions, such as the intra-renal artery, is different for the right and left kidneys.

sequence in this report, the high-contrast renal MRA was provided without renal vein, even if we used neither saturation pulse nor spin labeling. We were able to reduce the background signal from fixed tissues in simplistic sequence.

In conventional renal dynamic MRA, the contrast of the vessels was decreased in the proximal and intra-renal portion. We scanned the

coronal section in dynamic MRA, and the proximal portion of the renal artery was done visualization of like a stenosis. On the other hand, b-TFE with PSS sequence provides good MRA, even if the proximal portion, because we scanned the axial section (Fig. 4). In axial section imaging, flexure to the front of a blood vessel in the proximal portion was uneventful.

In conventional dynamic MRA, the time from injection of contrast agent to the start of scanning influenced the image demonstration of the intra-renal artery, and we had difficulty establishing this delay time. However, in b-TFE with PSS, good renal MRA of bilateral kidney was always obtained without contrast agent (Fig. 5).

We have confirmed that the b-TFE sequence with PSS angiography is worth addressing, and it is clearly more useful than conventional dynamic MRA.

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