Renal Corticomedullary Differentiation by Non-contrast-enhanced MR Imaging with a Spatially Selective IR Pulse at Various Inversion Times: Comparison with Fast Asymmetric Spin Echo (FASE) and Steady-state Free-precession (SSFP)

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We compared visualization of corticomedullary differentiation between fast asymmetric spin echo (FASE) and steady-state free precession (SSFP) combined with spatially selective inversion recovery (IR) pulse and optimal inversion time (TI). Though the corticomedullary contrast ratio was higher in FASE than SSFP images, visualization of corticomedullary differentiation was significantly better in SSFP images than FASE images obtained with spatially selective IR pulses and optimal TI.

Keywords: corticomedullary differentiation, fast asymmetric spin echo (FASE), kidney, spatially selective IR pulse, steady-state free precession (SSFP)

Introduction

In recent years, renal cortical volume and cortical thickness have been reported as good predictors of progression of chronic renal diseases, and proper measurement of renal cortical thickness requires clear visualization of the renal corticomedullary junction by magnetic resonance (MR) imaging. However, in patients with renal insufficiency, loss of corticomedullary differentiation in non-contrast-enhanced MR imaging has prevented proper measurement of renal cortical thickness or volume.

Non-contrast-enhanced MR imaging with a spatially selective inversion-recovery (IR) pulse has been frequently used to evaluate perfusion in the brain and elsewhere. Spatially selective IR pulses can be applied in any orientation to specify target tissue, and imaging after an optimal inversion time (TI) results in nulling of background signal or target tissue signal. Therefore, this technique can be applied to visualize corticomedullary differentiation based on the substantial differences in $T_1$ values between the cortex and medulla. Our preliminary study showed that non-contrast-enhanced steady-state free-precession (SSFP) MR imaging with spatially selective IR pulses can improve visualization of renal corticomedullary differentiation in normal subjects and thereby facilitate measurement of renal cortical thickness. However, in MR images obtained using a spatially selective IR pulse with optimal TI, the level of contrast between the renal cortex and medulla will depend on imaging sequences. Therefore, it is important to optimize imaging sequences before clinical applications in patients with renal insufficiency. Fast asymmetric spin echo (FASE) and SSFP MR sequences are commonly used for non-contrast-enhanced MR angiography. Both MR sequences enable short scan times and can be combined with such various additional prepulses as fat-suppression, inversion, and/or spatially selective IR pulses. Hence, these MR sequences may be appropriate used in combination with spatially selective IR pulse to visualize renal corticomedullary differentiation. However, no report has directly compared these 2 MR sequences for visualization of renal corticomedullary differentiation. We compared visualization of corticomedullary differentiation in normal kidneys using 2 different MR sequences, FASE and SSFP com-
bined with spatially selective IR pulse and optimal TI.

Materials and Methods

Subjects
Our institutional review board approved this retrospective review of MR imaging data, and informed consent of patients was waived. Study participants included 17 patients (15 men, 2 women; mean age, 33 years; range, 28 to 49 years) who underwent abdominal MR imaging, including non-contrast-enhanced FASE and SSFP sequences with spatially selective IR pulse and various TIs between June 1 and November 30, 2011 for screening of benign abdominal diseases. FASE and SSFP images were obtained as optional sequences for further evaluation of the kidney, e.g., for deformity of the renal contour, based on clinical judgment during each MR examination. Patients finally diagnosed with renal disease, hypertension, or other vascular diseases by clinical investigation were not included in this study.

Imaging technique
All examinations were performed with patients in standard supine position using a 1.5-tesla scanner (EXCELART Vantage Powered by Atlas, Toshiba Medical Systems, Tochigi, Japan) equipped with the Atlas SPEEDER body coil. Before obtaining the images with spatially selective IR pulses and various TIs, we obtained non-contrast-enhanced FASE and SSFP images of both kidneys without spatially selective IR pulse during a single breath-hold in the coronal plane for reference. Parameters for the FASE sequence were: repetition time/echo time (TR/TE), 7000 ms/30 ms; number of acquisitions, one; 90° flip angle; echo train length, 128; receiver bandwidth, 651 Hz/pixel; slice thickness, 7 mm; field of view (FOV), 400 × 400 mm; acquisition matrix, 256 × 256; and acquisition time, 4 s. Imaging parameters of the SSFP sequence were: TR/TE, 4.2/2.1 ms; number of acquisitions, one; 90° flip angle; receiver bandwidth, 977 Hz/pixel; slice thickness, 7 mm, FOV, 400 × 400 mm; acquisition matrix, 256 × 256; and acquisition time, 4 s (Table 1). Fat suppression was applied in both sequences. Parallel imaging was also applied in both sequences with a SPEEDER factor of 2 in the phase direction. After acquisition of the reference image, we obtained non-contrast-enhanced FASE and SSFP MR images of the kidney with spatially selective IR pulses and various TIs using identical imaging parameters during breath holding in the coronal plane. For the spatially selective IR pulse examination, we placed a spatially selective inversion labeling pulse of 130 mm on both kidneys (Fig. 1) to cover the entire kidney. We performed a series of FASE and SSFP sequences with spatially selective IR pulses that were topographically identical using 14 TIs—500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, and 1800 ms.

Table 1. Imaging parameters of fast asymmetric spin echo (FASE) and steady-state free-precession (SSFP) sequences

| Parameter                  | FASE                | SSFP                |
|----------------------------|---------------------|---------------------|
| Repetition time/Echo time  | 7000 ms/30 ms       | 4.2 ms/2.1 ms       |
| Number of acquisitions     | 1                   | 1                   |
| Flip angle                 | 90°                 | 90°                 |
| Field of view (mm)         | 400 × 400           | 400 × 400           |
| Matrix                     | 256 × 256           | 256 × 256           |
| Slice thickness (mm)       | 7                   | 7                   |
| Bandwidth (Hz/pixel)       | 651                 | 977                 |
| Acquisition time (s)       | 4                   | 4                   |
| Parallel imaging factor    | 2                   | 2                   |

Fig. 1. Coronal steady-state free-precession (SSFP) image without a spatially selective inversion recovery (IR) pulse. Parallel horizontal lines show the area where a spatially selective IR pulse is expected to be placed.
Data analysis

Two radiologists who specialize in abdominal imaging retrospectively reviewed MR images. We measured signal intensity (SI) of the renal cortex and medulla using an operator-defined region of interest (ROI) that was either a circle or oval and as large as possible. We drew ROIs on the cortex and medulla on the right and the left kidney in nearly the same location for each sequence. The SI of the renal cortex and medulla in each subject was defined as the mean SI value of the left and right renal cortex and medulla. The ratio of corticomedullary contrast was calculated from mean SI values of the renal cortex (SI\textsubscript{cortex}) and renal medulla (SI\textsubscript{medulla}) as (SI\textsubscript{cortex}/SI\textsubscript{medulla}). In FASE and SSFP images with spatially selective IR pulses, we compared the corticomedullary contrast ratio of the 14 images obtained with the different TIs (500 to 1800 ms) to determine the optimal TI for visualization of the renal corticomedullary junction. We then used a 4-point scale for qualitative analysis to grade visualization of corticomedullary differentiation in FASE and SSFP images with the spatially selective IR pulse obtained with optimal TI (1, poor visualization; 2, fair; 3, good; and 4, excellent). Based on these quantitative and qualitative data, we compared the mean corticomedullary contrast ratio and visualization of corticomedullary differentiation between FASE and SSFP images acquired with spatially selective IR pulse and optimal TI.

Statistical analysis

We used SPSS version 17.0 J for Windows for all statistical analyses and Wilcoxon signed rank tests to evaluate differences in contrast ratio, overall image quality, and visualization grades between FASE and SSFP sequences. $P < 0.05$ was considered significant.

Results

We did not include patients finally diagnosed with renal disease, hypertension, or other vascular diseases by clinical investigation. In FASE with a spatially selective IR pulse, the corticomedullary contrast ratio was highest in images with TI of 1000 ms in 8 subjects (47%) followed by 1100 ms in four (24%), 1200 ms in four (24%), and 1300 ms in one (5%). In contrast, in SSFP with a spatially selective IR pulse, the corticomedullary contrast ratio was highest in images with a TI of 1100 ms in 7 subjects (41%), followed by 1200 ms in six (35%), 1000 ms in two (12%), 1300 ms in one (6%), and 1400 ms in one (6%). The optimal TI for SSFP with a spatially selective IR pulse was significantly longer than that for FASE with a spatially selective IR pulse ($P = 0.008$). The mean corticomedullary contrast ratio was significantly higher in FASE (7.86 ± 1.68) with a spatially selective IR pulse and optimal TI than in SSFP (5.97 ± 1.93) with a spatially selective IR pulse and optimal TI ($P = 0.009$). Conversely, visualization of corticomedullary differentiation and overall image quality were significantly better in SSFP images (average grade, 3.94) with a spatially selective IR pulse and optimal TI than in FASE images (average grade, 3.47) with a spatially selective IR pulse and optimal TI ($P = 0.005$) (Table 2), indicating better delineation of the corticomedullary junction in SSFP with a spatially selective IR pulse and optimal TI (Fig. 2).

Discussion

Our study showed that renal corticomedullary differentiation can be clearly visualized by using 2 different MR sequences combined with a spatial-
ly selective IR pulse. Our results indicated that the ratio of corticomedullary contrast was significantly better in FASE images than SSFP images combined with spatially selective IR pulses and optimal TI. SSFP images are based on a gradient-echo sequence so that the contrast of an SSFP image is determined by the ratio of $T_2$ to $T_1$. In contrast, FASE images are based on a spin-echo sequence, and images acquired with FASE are $T_2$ weighted.\textsuperscript{9–11} The differences in contrast between the 2 sequences ($T_2/T_1$ ratio versus $T_2$ weighted) is likely the reason for the substantially increased contrast ratio between the renal cortex and renal medulla in FASE images and might also explain the observed differences in optimal TI between SSFP and FASE sequences.

Though the contrast between the cortex and medulla was higher in FASE than SSFP images, visualization of corticomedullary differentiation and overall image quality was significantly better in SSFP images than in FASE images obtained with spatially selective IR pulses and optimal TI. This fact indicated that better delineation of the corticomedullary junction can be achieved by using SSFP with spatially selective IR pulses and optimal TI. In FASE images, a $T_2$-blurring effect occurs in the phase-encoding direction that is related to the sampling of multiple echoes per shot when echo times are extended. The $T_2$-blurring effect results in degraded image quality.\textsuperscript{9,11} Conversely, SSFP images can produce a high signal-to-noise ratio because all free induction decay, spin echo, and stimulated echo signals made by consecutive radiofrequency pulses are collected at the same time. These are likely the reasons for better visualization of corticomedullary differentiation in SSFP images than FASE images.

Our results suggested that for patients with mild to moderate renal dysfunction with preserved corticomedullary differentiation, use of the SSFP sequence may be preferable because of its high image quality, whereas the high contrast resolution of FASE might recommend its use for patients with severe renal dysfunction with diminished corticomedullary differentiation. Therefore, in clinical practice, these sequences with different advantages should be used complementarily for the proper measurement of renal cortical thickness or volume in patients with renal dysfunction.

Our study had several limitations. First, the number of patients included in this preliminary single-center study was small. Second, we did not evaluate serum levels of creatinine and GFR, but we did exclude patients with renal disease, hypertension, or other vascular diseases. Future investigations of the relationship of cortical thickness to creatinine level will be necessary. Finally, we did not analyze renal corticomedullary differentiation in patients with renal insufficiency. However, the aim of this preliminary study was to compare FASE

Fig. 2. a. Coronal steady-state free-precession (SSFP) image with a spatially selective inversion recovery (IR) pulse and optimal inversion time (TI; 1200 ms), b. Fast asymmetric spin-echo (FASE) image with a spatially selective IR pulse and optimal TI (1200 ms) in the same patient. The FASE image had a high corticomedullary contrast ratio, whereas the SSFP image demonstrated good visualization of corticomedullary differentiation and high image quality.
and SSFP MR sequences when combined with spatially selective IR pulses and optimal TI to determine which sequence provides better visualization of corticomedullary differentiation in the normal kidney.

In conclusion, both FASE and SSFP MR imaging with spatially selective IR pulses and optimal TI can be used to visualize renal corticomedullary differentiation in normal kidneys without the use of contrast agents. Visualization of the corticomedullary junction was good using SSFP sequence with spatially selective IR pulses and optimal TI, but corticomedullary contrast ratios were high using the FASE sequence with spatially selective IR pulses and optimal TI. These sequences with different advantages should be used complementarily to evaluate corticomedullary differentiation of the kidney.

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