TECHNICAL NOTE

T₁-weighted MR Imaging of the Female Pelvis Using RADAR-FSE Sequence

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Radial scanning is attracting increasing attention as a method of suppressing motion artifacts in magnetic resonance imaging. We compared the effectiveness of radial acquisition regime-fast spin echo (RADAR-FSE), a method of radial scanning, with conventional FSE in the T₁-weighted imaging setting by scanning Gd-DTPA phantoms and 9 female patients (pelvic imaging). RADAR-FSE suppressed motion artifacts better than FSE but caused streak artifacts and diminished sharpness. Clinicians should be aware of these limitations.

Keywords: radial scan, contrast-enhanced, T₁-weighted Imaging (T₁WI), magnetic resonance imaging (MRI)

Introduction

During magnetic resonance (MR) imaging of the pelvic region, motion artifacts are generated by involuntary movements, such as abdominal wall movement induced by respiration, intestinal peristalsis, and blood flow, as well as by patient motion. Although these movements can be controlled to some extent with the use of an abdominal belt and anticonvulsant, complete control of movement is extremely difficult. Radial scanning, a method of suppressing motion artifact, is attracting increasing attention as a solution to this problem.

Unlike the conventional scanning method, in which the k-space is filled in one direction with equally spaced intervals, radial scanning allows radial filling of the k-space, with the center of the k-space as the axis. Radial scanning is well known as the method used in PROPELLER (periodically rotated overlapping parallel lines with enhanced reconstruction). In this method, acquisition of data on multiple trajectories passing near the center of the k-space enables artifact reduction by both translational and rotational data acquisition styles.¹⁴ Though radial scanning is mainly used for T₂- (T₂WI) or diffusion-weighted imaging (DWI) and its effectiveness has been reported in these modes, there are only a few reports of radial scanning in T₁-weighted imaging (T₁WI).⁵⁻⁸

We examine the effectiveness of radial acquisition regime-fast spin echo (RADAR-FSE), a radial scanning method,⁹,¹⁰ in the T₁WI setting.

Material and Methods

All phantoms and patients were scanned with a 1.5-tesla MR scanner (Echelon Vega, Hitachi Medical Corporation, Tokyo, Japan).

MR imaging

RADAR-FSE combines radial scanning and FSE, which is used to acquire the data on trajectories filling the k-space radially, with the center of the k-space as the axis. This method is similar to PROPELLER (Fig. 1). In the reconstruction process, gridding and Fourier transformation are performed. Unlike PROPELLER, in RADAR-FSE, there is no compensation for subject motion, but its effect is dispersed and artifacts derived from this motion suppressed by radially dispersing the direction of phase encode.
Fig. 1. Illustration of Cartesian scan and radial scan k-space trajectory. a: Cartesian scanning method in which the k-space is filled in one direction with equally-spaced intervals. b: Radial scanning allows the k-space to be filled radially with the center of the k-space as the axis.

Fig. 2. Radial acquisition regime-fast spin echo (RADAR-FSE) sequence k-space trajectory. Blades rotate (with the center of the k-space as the axis) and fill the k-space. The number of echoes acquired per blade is termed the echo factor.

The data on trajectory to be acquired within a repetition time (TR) is determined by echo factor (EF), and a group of trajectories aligned parallel is called a blade (Fig. 2).

In RADAR-FSE, the number of projections is determined by the number of phase matrices, while the number of blades is determined according to EF using the formula: \( \text{projection} \# = \text{blade} \# \times \text{EF} \), where phase matrix \# is the number of phase matrices, projection \# is the number of projections, and blade \# is the number of blades. The number of blades corresponds to the change in EF when the phase matrix is fixed, so the scan time changes if EF changes.

**Phantom study**

To evaluate the contrast of the RADAR-FSE pulse sequence, we imaged phantoms using a brain quadrature-detection (QD) receiver coil and performed the same procedure with FSE as a reference and calculated contrast-to-noise ratio (CNR).

Phantoms were made from diluted solutions of Gd-DTPA (meglumine gadopentetate, Bayer, Osaka, Japan; concentration: 0.1, 0.2, 0.5, 1, 2, 5, 10, and 20 mmol/L) and a normal saline solution.

The fixed parameters for RADAR-FSE were field of view (FOV), \( 26 \times 26 \text{ cm}^2 \); TR, 500 ms; slice thickness 5.0 mm; matrix, \( 256 \times 352 \) (frequency \( \times \) phase); and number of signal average (NSA), 2. EF varied between 3 and 8, which induced changes in echo time (TE): 15 ms when EF was 3 or 4, 14.8 ms when it was 5 or 6, and 20 ms when it was 7 or 8. Scan time was 1 min 59 s when EF was 3; 1 min 30 s when it was 4; 1 min 12 s when it was 5; 1 min when it was 6; 52 s when it was 7; and 46 s when it was 8.

The fixed parameters of FSE were FOV, \( 26 \times 26 \text{ cm}^2 \); TR, 500 ms; TE, 10 ms; slice thickness, 5.0 mm; matrix, \( 256 \times 224 \); NSA, 2; band width (BW), 50 kHz; EF, 3; and scan time 2 min 7 s.

The inter-tissues method (air noise) was adopted as the calculation method for CNR: \( \text{CNR} = \frac{(\text{SI}_a - \text{SI}_b)}{\text{SD}_{\text{air}}} \), where \( \text{SI}_a \) is the signal value of the phantom containing a diluted solution of Gd-DTPA, \( \text{SI}_b \) is the signal value of normal saline solution, and \( \text{SD}_{\text{air}} \) is the standard deviation of air.

**Clinical studies**

Nine women (aged 23 to 74 years, average age 45.1) suspected of having uterine or ovarian tumors gave written consent and underwent scanning of the pelvic region after injection with contrast agent for quantitative evaluation of the image quality acquired with the RADAR-FSE pulse sequence. Two pulse sequences, FSE and RADAR-FSE, were used for imaging, with scan times adjusted so that the modes were equivalent to each other: FSE and RADAR-FSE: FOV, \( 26 \times 26 \text{ cm}^2 \); TR, 500 ms; slice thickness, 6.0 mm; matrix, \( 256 \times 352 \); EF, 3; and NSA, 2. FSE: TE, 10 ms; BW, 50.0 kHz; and scan time 2 min 7 s. RADAR-FSE: TE, 15 ms; BW, 151.6 kHz; and scan time 1 min 59 s.

Two radiologists independently evaluated the significance of artifacts in all images obtained with FSE and RADAR-FSE using a 5-point scale: 0 = severe image artifact (non diagnostic); 1 = moderate to severe image artifact (score between 0 and 2, but
Contrast-to-noise ratio (CNR) of a diluted Gd-DTPA solution (meeglumine gadopentetate, Bayer, Osaka, Japan) phantom filled with saline as a reference substance. In radial acquisition regime-fast spin echo (RADAR-FSE), the smaller the echo factor (EF), the higher the contrast-to-noise ratio (CNR). CNR was higher in fast spin echo (FSE) than in RADAR-FSE in all experimental settings.

We used Wilcoxon’s signed rank test to evaluate differences between FSE and RADAR-FSE because this approach was a qualitative analysis. P-values less than 0.05 were considered statistically significant differences.

Results
Phantom study
CNR was highest when EF was 3, similar when 4 to 7, and lowest at 8. We found that CNR tended to be inversely proportional to EF. In addition, CNR with RADAR-FSE was lower than that with FSE with any EF (Fig. 3).

Clinical studies
Although motion artifact was more suppressed with RADAR-FSE than with FSE, we found streak artifacts with RADAR-FSE (Figs. 4, 5), and sharpness of RADAR-FSE was inferior to that of FSE (Fig. 6). Qualitative evaluation of artifacts and sharpness of images showed that artifacts were suppressed and sharpness deteriorated in RADAR-FSE. RADAR-FSE was associated with significantly fewer artifacts (P<0.05, Wilcoxon’s signed rank test), but poorer sharpness when compared with FSE (P<0.05, Wilcoxon’s signed rank test).

Fig. 3. Contrast-to-noise ratio (CNR) of a diluted Gd-DTPA solution (meeglumine gadopentetate, Bayer, Osaka, Japan) phantom filled with saline as a reference substance. In radial acquisition regime-fast spin echo (RADAR-FSE), the smaller the echo factor (EF), the higher the contrast-to-noise ratio (CNR). CNR was higher in fast spin echo (FSE) than in RADAR-FSE in all experimental settings.

Fig. 4. A 37-year-old woman. a: fast spin echo (FSE). b: radial acquisition regime-fast spin echo (RADAR-FSE) (echo factor [EF] = 3). Whereas motion artifact (arrow) is observed on FSE, motion artifact is suppressed on RADAR-FSE.
Fig. 5. A 23-year-old woman suspected of having a uterine fibroid. A streak artifact is observed on radial acquisition regime-fast spin echo (RADAR-FSE) (arrow).

Fig. 6. A 25-year-old woman. a: fast spin echo (FSE). b: radial acquisition regime-fast spin echo (RADAR-FSE) (echo factor [EF] = 3). Blurring is observed (arrow) on RADAR-FSE.

Discussion

The main focus of this study was to compare RADAR-FSE and FSE, and we found that RADAR-FSE enables acquisition of images with fewer motion artifacts than FSE.

In RADAR-FSE, the CNR decreases as EF, and the number of echoes in the center of the k-space, increases. When EF is 3 and effective TE is 10 ms, 3 kinds of echoes (TE 5 ms, 10 ms, and 15 ms) are mixed, whereas with an EF of 6 and effective TE of 15 ms, 6 kinds of echoes (TE 5 ms, 10 ms, 15 ms, 20
Table. Scores for artifact and sharpness on RADAR-FSE and FSE images

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Observer</th>
<th>FSE</th>
<th>RADAR-FSE</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artifact</td>
<td>1</td>
<td>1.11 ± 0.31</td>
<td>2.33 ± 0.47</td>
<td>0.0077</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.22 ± 0.42</td>
<td>2.11 ± 0.31</td>
<td>0.0077</td>
</tr>
<tr>
<td>Sharpness</td>
<td>1</td>
<td>2.89 ± 0.57</td>
<td>2.00 ± 0.00</td>
<td>0.0180</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.89 ± 0.31</td>
<td>3.00 ± 0.00</td>
<td>0.0177</td>
</tr>
</tbody>
</table>

Data are means ± standard deviations. *Statistically significant for all scores by Wilcoxon's signed rank test.

ms, 25 ms, and 30 ms) are mixed. With RADAR-FSE, the data are usually acquired in centric order, and echoes in the central part of the k-space show only the set effective TE. So, contrast is lower with RADAR-FSE than with FSE because the greater the EF, the lower the contrast.

We were able to obtain images with less motion artifact in clinical cases using RADAR-FSE because artifacts derived from the motion of the abdominal wall or intestinal peristalsis were averaged, thereby suppressing motion artifact. We found RADAR-FSE useful in pelvic MR imaging because in FSE, a conventional Cartesian data collection method, motion artifact appears in the region of interest and affects diagnosis in some cases.

Image sharpness deteriorated in RADAR-FSE compared with FSE, probably caused by blurring from lack of data sampling in the high frequency area of the k-space. Further, image sharpness deteriorated when motion of the subject was significant, presumably from dispersion of the motion effect by placing the direction of the phase-encode radially in this technique. Theoretically, blurring in images from subject motion should be suppressed because RADAR-FSE suppresses the effect of motion. However, because the number of samplings in the imaging protocol was limited in the present experiment, sharpness of images deteriorated while the effect of motion was successfully suppressed.

Conclusion

The use of RADAR-FSE, a method of radial scanning, successfully suppresses motion artifacts caused by involuntary body movements, such as abdominal wall movement induced by respiration and intestinal peristalsis, which enables acquisition of images with fewer motion artifacts than with conventional scanning. Although the effectiveness of RADAR-FSE in the pelvic region was indicated, close attention should be paid to the particular type of artifacts and contrast which are not seen in the conventional scanning method.

References

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