TECHNICAL NOTE

Cardiac Cine Parallel Imaging on a 0.7T Open System

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Background: Parallel imaging can be applied to cardiac imaging with a cylindrical MRI (magnetic resonance imaging) apparatus. Studies of open MRI, however, are few. This study sought to achieve cardiac cine parallel imaging (or RAPID, for “rapid acquisition through parallel imaging design”) with an open 0.7T MRI apparatus.

Materials and Methods: Imaging time was shortened in all slice directions with the use of a dedicated four-channel RF receiving coil comprising solenoid coils and butterfly coils. Coil shape was designed through an RF-coil simulation that considered biological load. The auto-calibration of a 0.7T open MRI apparatus incorporated a modified image-domain reconstruction algorithm. Cine images were obtained with a BASG, or balanced SARGE (steady-state acquisition with rewind gradient echo), sequence. Image quality was evaluated with cylindrical phantoms and five healthy volunteers.

Results: Multi-slice phantom images showed no visible artifacts. Cine images taken under breath-hold with an acceleration factor of two were evaluated carefully. With auto-calibration, the images revealed no visible unfolded artifacts or motion artifacts. RAPID thus improved the acquisition speed, time resolution, and spatial resolution of short-axis, long-axis, and four-chamber images.

Conclusion: The use of a dedicated RF coil enabled cardiac cine RAPID to be performed with an open MRI apparatus.

Keywords: *open MRI, parallel imaging, RF coil, cardiac imaging*

Introduction

Parallel imaging is a valuable method of performing cardiac imaging with a cylindrical MRI apparatus,^{1–8} but there are few reports of open MRI.^{9,10} The goal of this study is therefore to obtain cardiac cine images by using parallel imaging with an open 0.7T MRI apparatus. The use of a dedicated four-channel RF receiving coil comprising both solenoid coils and butterfly coils results in shortened imaging time in all slice directions. We have termed this imaging technique RAPID (rapid acquisition through parallel imaging design).

Method

We used an open 0.7T MRI apparatus (Altaire®, Hitachi Medical Corporation, Fig. 1). An open MRI apparatus produces a different magnetic field direction that results in a different RF magnetic field. This requires a multiple array coil (MAC) structure that differs from that used with a cylindrical MRI apparatus (Fig. 2).^{9–11} In the case of cardiac MRI, our approach was to apply RAPID in an arbitrary direction with the limited number of coils. We designed the cardiac-coil shape through an RF-coil simulation that takes biological load into account.^{12,13} This simulation showed that image quality varies strongly with coil shape and imaging-plane angle, and that the optimal shape is two crossed solenoid coils and two butterfly coils (Fig. 3). To remove motion artifacts caused by

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breathing, we used an auto-calibration technique that simultaneously acquires calibration data and reduced FOV data.¹⁴ In order to eliminate incorrect phase components caused by static magnetic field inhomogeneity, we modified the algorithm to make complete sensitivity maps of each coil from the calibration data itself (Fig. 4).

A spin-echo sequence was used for imaging of a cylindrical liquid phantom. Imaging planes were sagittal, coronal or axial sections with two different phase-encoding directions. Balanced SARGE, a coherent-type gradient echo sequence (Fig. 5), was used for cardiac imaging of healthy volunteers with single-phase or multiphase images along three views: short-axis, long-axis, and four-chamber.

Results

Figure 6 shows phantom images in the three sections. No major artifacts are present in the three sections. Figure 7 shows single-phase cardiac

images from each of the three views as obtained by conventional imaging (top row) and RAPID (bottom row). RAPID produced unfolded images in all directions without major artifacts and critical loss in SNR (signal to noise ratio). As is visible in the figure, the conventional and RAPID images have the same contrast in all views. Figure 8 shows coronary MRA (magnetic resonance angiography) images obtained with the two methods. RAPID reduced scan time by half (from eight to four seconds) by using parallel imaging with an acceleration factor of two. Figure 9 compares short-axis views that show the improved spatial resolution provided by RAPID. Conventional and RAPID images were acquired within the same scan time, but the number of phase encodes differed at 100

Fig. 1. Altaire®, a 0.7T open MRI system

Fig. 3. Example of the cardiac-coil structure of an open MRI system. The prototype cardiac coil is rigid and separate.

Fig. 2. Difference in magnetic field directions of two types of MRI apparatus. **A:** Cylindrical (horizontal magnetic field) MRI apparatus. **B:** Open (vertical magnetic field) MRI apparatus. The open MRI apparatus produces a magnetic field in a different direction, resulting in a different RF magnetic field. This requires a different multiple array coil (MAC) structure than that required for a cylindrical MRI apparatus.

Fig. 4. Modified image-domain reconstruction algorithm. The measured data is divided into calibration data and reduced FOV data. Sensitivity maps of each coil are determined without reference data from the T/R (Transmit and Receive) coil.

Fig. 5. Coherent-type gradient echo sequence (Balanced SARGE). RAPID shortened the scan time and improved the time and/or the spatial resolution.

(conventional) and 160 (RAPID). Figure 10 shows that RAPID improved the time resolution by increasing the number of multiphases. Acquisition times for conventional and RAPID images were the same. However, the use of RAPID increased the number of multiphases (from 15 to 25), thus improving the time resolution of cine MRI.

Discussion

In regards to parallel imaging, it is known that the sensitivity distributions of the MAC strongly influence the resulting images.¹ In the case of cardiac MRI, however, we felt that RAPID should be applicable in any direction. Therefore, we designed the cardiac coil so that RAPID can be

Fig. 6. Results of phantom experiment with the prototype cardiac coil. For all sections, images were obtained in two different phase-encoding (PE) directions (the left was obtained with conventional imaging and the right was obtained with parallel imaging accommodating an acceleration factor of two). **A, B:** axial section. **C, D:** sagittal section. **E, F:** coronal section. (2D SE, TR = 1500 ms, TE = 40 ms, slice thickness = 5 mm, data matrix = 256 (freq.) × 128 (phase), FOV = 320 mm (**A, B, C, E**) or 400 mm (**D, F**)).

applied in an arbitrary direction. As for actual cardiac imaging, since the slice of the imaging section is mostly limited to short-axis, long-axis, and four-chamber views, it is important to improve the RAPID coil so that it demonstrates its greatest efficiency in these sections.

Moreover, in order to remove motion artifacts caused by breathing, we used an auto-calibration technique and a modified reconstruction algorithm that forms a reference image for sensitivity distributions by combining images from the cardiac coil. Auto calibration resulted in no visible unfolded artifacts or motion artifacts in the images. Although several auto calibration techniques have been proposed for cylindrical MRI,¹⁵ our results show that the auto-calibration technique is also applicable to open MRI. Since RAPID enables the number of multiphases to be increased (from 15 to 25), cardiac imaging with open MRI becomes more useful.

In this study, we assumed that RAPID provides an acceleration factor of two. However, in order to increase the acceleration factor, we should optimize the cardiac coil with more than four channels.

Fig. 7. Single-phase cardiac images: short-axis view (A), long-axis view (B), and four-chamber view (C). For all views, the top row shows conventional images and the bottom row shows RAPID images with an acceleration factor of two. (2D Balanced SARGE, FOV = 320 mm, TR = 4.4 ms, TE = 2.2 ms, slice thickness = 8 mm, data matrix = 100 (freq.) $\times$ 120 (phase), scan time = 10 s, electrocardiogram gating and breath-holding).

Fig. 8. Coronal MRA of a healthy volunteer during breath-holding. On the left is the conventional image and on the right is the RAPID image obtained with an acceleration factor of two. The scan time was 8 or 4 s, respectively. (2D Balanced SARGE, FOV = 300 mm, TR = 5 ms, TE = 2.5 ms, slice thickness = 8 mm, data matrix = 128 (freq.) $\times$ 128 (phase), electrocardiogram gating and breath-holding).

Fig. 9. Short-axis views of a healthy volunteer. On the left is the conventional image and on the right is the RAPID image obtained with an acceleration factor of two. The number of phase encodes was 100 and 160, respectively. (2D Balanced SARGE, FOV = 350 mm, TR = 4 ms, TE = 2 ms, slice thickness = 8 mm, scan time = 14 s, electrocardiogram gating and breath-holding).

Conclusion

RAPID improved the acquisition speed, time resolution, and spatial resolution of short-axis, long-axis, and four-chamber images. A dedicated RF coil thus enabled cardiac cine RAPID imaging with an open MRI apparatus.

Fig. 10. Multiphase images of a healthy volunteer. Both conventional images (**A**) and RAPID images (**B**) obtained with an acceleration factor of two were acquired within the same scan time. However, the number of multi-phases was 15 for the conventional and 25 for the RAPID. (2D Balanced SARGE, FOV = 350 mm, TR = 3.8 ms, TE = 1.9 ms, image matrix = 128, slice thickness = 8.0 mm, scan time = 15 s, electrocardiogram gating and breath-holding).

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