Suppression of Image Artifacts Arising from Magnetic Field Inhomogeneity in Continuous Moving Table MRI

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Introduction

Continuously moving table (CMT) magnetic resonance imaging (MRI) has become very popular in recent years [1, 2]. The CMT MR imaging is susceptible to artifacts arising from the nonlinearities of magnetic field gradients and the inhomogeneity of static magnetic field. The nonlinearities of magnetic field gradients cause spatially dependent blurring and distortion in reconstructed images, but it was found that these artifacts can be suppressed in the image reconstruction process [3]. However, the effects of the magnetic field inhomogeneity on CMT MR imaging has not been investigated. In CMT MRI, each echo is acquired at a different table position, so phase error caused by inhomogeneity is distributed inconsistently in hybrid k-space in which the Fourier transferred echoes are located for image reconstruction. Therefore the magnetic field inhomogeneity may cause different artifacts or distortions from those of the conventional fixed table MRI. It is important to understand the artifacts and distortions arising from the inhomogeneity and to develop an image reconstruction algorithm that is robust enough to be used in the clinical applications.

In this study, we evaluated the effects of the magnetic field inhomogeneity in CMT MRI by using computer simulation. In the reconstructed images obtained in the simulation, different artifacts or spatial distortions arose depending on the inhomogeneity terms, but we were able to suppress the artifacts using a phase correction technique we developed. CMT images were also acquired in experiments on phantoms and volunteers without dynamic or high-order shimming. We confirmed from the phantom images that artifacts in the experimental results were similar to those in the simulation results. Furthermore, the artifacts in the images acquired in the experiments were successfully suppressed by the phase correction.

Method

Raw data of CMT MRI were calculated by two-dimensional computer simulation with magnetic field inhomogeneity factored in. The inhomogeneities parallel to the direction of table motion affect image quality differently from the case of fixed table MRI. Thus we evaluated inhomogeneity terms of z, z2, and xz where z was the direction of table motion. The amplitude of the inhomogeneities were: ±0.5 ppm at 1.5T in the corner of sub-FOV for the term of z, and 1 ppm for z2 and xz. The subject model was an ellipse where spin distribution is uniform. In the simulation, the subject model was moved in the z-direction every time one point of data was sampled during echo readout, and T1 and T2 effects during the scan were ignored. Imaging parameters for the computer simulation were as follows—table velocity: 1 pixel/TR, matrix size of sub-FOV: 64x64, number of phase encoding cycles: 2, readout direction: z.

In the image reconstruction, phase errors in the raw data were corrected in order to suppress the artifacts. The simulation results show that field inhomogeneity results in discontinuity of the z-kx space data at the turning point of the phase cycle (Fig. 1), which results in image artifacts. The method to remove this discontinuity is as follows: data are extracted from two lines (s1 and s2 in Fig. 1) at the turning point, and s1 and s2 are transformed into projections in the slanting direction of the kx-axis by inverse Fourier transform. Then the phase of the two projections are corrected to be the same so that the discontinuity is removed.

CMT images were obtained in phantom and volunteer experiments on a 1.5T horizontal system for comparison with the simulation results. The coronal multi-slice images were obtained using RSSG (rf spoiled steady state acquisition with rewound gradient echo) pulse sequence. Only first-order shimming at the first bottle of the phantom or at the head of a volunteer was performed. Imaging parameters for the phantom experiments were as follows—TR/TE: 90/6 ms, sub-FOV: 350 mm (x) x 230 mm (z), table velocity: 20 mm/s, pixel size: 2.7x2.7 mm. Imaging parameters for the volunteer were as follows—TR/TE: 90/6 ms, sub-FOV: 350 mm (x) x 205 mm (z), slices: 10 mm x 10, and the others were the same as those of the phantom.

Results and Discussion

Figure 2 shows the results from the computer simulation. An image without inhomogeneity is shown in Fig. 2a for comparison. Images with inhomogeneity of terms z, z2, and xz are shown in Fig. 2b, 2d, and 2f respectively. These images after phase error correction are respectively shown in Fig. 2c, 2e, and 2g. Figures 2b, 2d, and 2f show that different artifacts arise in accordance with the terms of the magnetic field inhomogeneity. The position where the artifacts arise is around the z position where the phase encoding cycle changes to the next step. The artifacts can be suppressed completely by the phase correction, as shown in Fig. 2c, 2e, and 2g. However, the inhomogeneity term of z2 causes distortions in the x direction as shown in Fig. 2e.

Figure 3 is a slice from a series of multi-slice images obtained by the phantom experiment (a) without and (b) with phase correction. Images were obtained without dynamic shimming, so artifacts arise at the position where the phase encoding cycle changes to the next step, which was similar to the simulation results. The artifact pattern is about the same as that of Fig. 2f, where the inhomogeneity term of xz was present. In Fig. 3b, it is clear that the artifacts are suppressed by the phase correction as effectively as in the case of the computer simulation. Figure 4 shows one of the volunteer images. Although only first-order shimming at the position of the head was performed, image artifacts arising from field inhomogeneity are successfully suppressed by the phase correction.

Conclusion

We described here artifacts or distortions in CMT MR images arising in accordance with the magnetic field inhomogeneity using computer simulation. We successfully developed a reconstruction algorithm for CMT MRI using the simulation results, which was stable in the presence of field inhomogeneity. This reconstruction will make CMT MRI more robust for clinical applications.

References

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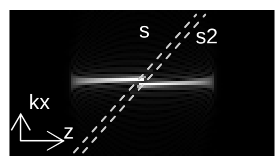

Fig. 1: Data in z-kx space obtained by simulation with the inhomogeneity term of xz.

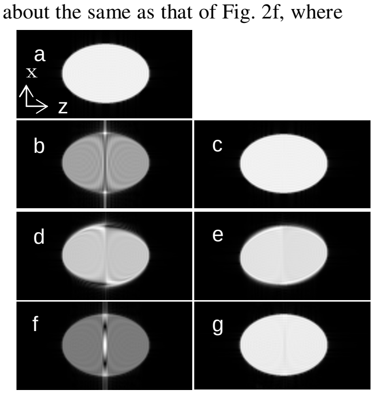

Fig. 2: Images obtained by computer simulation (a) without and (b-g) with field inhomogeneity. Images are reconstructed without the phase correction (left column) and with the correction (right column). Inhomogeneity terms are (b, c) z, (d, e) z2, and (f, g) xz.

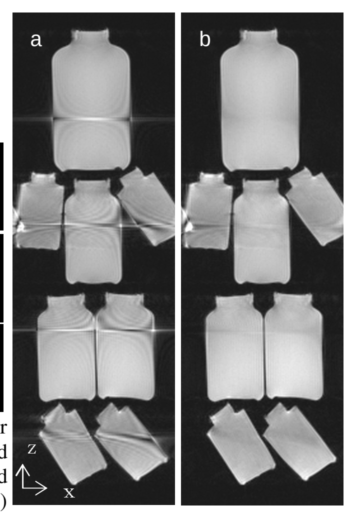

Fig. 3: Images obtained by phantom experiments (a) without and (b) with phase correction.

Fig. 4: Volunteer image obtained only with first-order shimming at the head.