Motion Correction for Variable Density Spiral MRI Using Sampling Overlap as Inherent Navigators

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INTRODUCTION Variable density spiral (VDS) sampling is advantageous for fast imaging and has been widely used in diffusion and functional MRI [1-4]. However, it can suffer from artifacts when motion occurs between the sampling of multiple interleaves. One potential method to correct motion is to use the sampling overlap around k-space center as inherent navigators for motion information recording, as adopted in PROPELLER [5] and dual-density spiral MRI [6]. In those methods, the sampling overlap around k-space center is fully sampled and can be used to estimate motion. However, for VDS, the fully sampled area is very small and may not allow accurate motion estimation. In this work, we propose to use a larger area as the navigation region to achieve better motion correction for VDS.

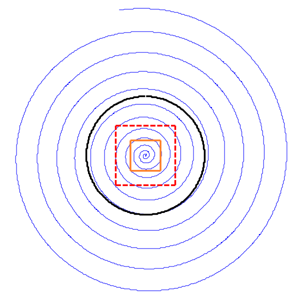

Fig. 1 Diagram of preparing a navigation image. An enlarged calibration area (within the red box) is generated with SPIRiT using the full sampled data (within the yellow box) for initial calibration, then SPIRiT is performed again to reconstruct navigation image from the data within navigation region (within the black circle) using the enlarged calibration area.

METHODS Navigation image preparation: The navigation region (within the black circle in Fig. 1) was defined to be larger than the fully sampled area (within the yellow box), and low resolution images (referred as navigation images) of each spiral interleaf were reconstructed from data within the navigation region. Conventionally, nonuniform FFT (NUFFT) [7] can be used for the reconstruction (NUFFT-based method). However, insufficient sampling around the k-space center will lead to suboptimal motion estimation. In this work, SPIRiT [8] was used for reconstruction of the navigation images (SPIRiT-based method). Due to limited data for calibration, the calibration area which is needed in SPIRiT reconstruction was enlarged iteratively using SPIRiT itself, i.e., an initial navigation image was first reconstructed using SPIRiT with a relatively small but fully sampled calibration area. After that, a larger calibration area (within the red box) was cropped from the k-space of the initial navigation image, and then SPIRiT was performed again to get an improved navigation image using the updated calibration area.

Motion estimation and correction: The k-space data were resampled on polar and Cartesian coordinate from the navigation images, and a motion estimation algorithm for PROPELLER MRI was used to estimate the motion parameters of each interleaf [9]. With the estimated motion parameters, rotation correction was performed by rotating the k-space trajectories, and translation correction was performed by removing the corresponding linear phase shifts in k-space.

Simulation study: Shepp-Logan phantom was used to evaluate the performance of the proposed methods. The interleaf number was set to 16, α (oversampling factor) = 4, FOV = 220×220 mm^2, matrix size = 220×220. Only in-plane random rigid motion was introduced to the k-space data. Specifically, rotation within range of [-5°, 5°], and translation within range of [-5, 5] pixels along x or y direction were simulated. To evaluate the estimation precision, 100 random cases within the specified motion range were simulated and the navigation images were reconstructed using both SPIRiT-based and NUFFT-based methods. To evaluate the results, absolute estimation error, defined as difference between estimated parameters and true parameters, was calculated.

In vivo study: *In vivo* data were acquired with an 8-channel head coil. The imaging parameters are: TR/TE = 2000/70 ms, slice number = 24, slice thickness = 4 mm, and the other parameters are the same as in simulation study. The volunteer was asked to keep still during the first scan (motion-free reference scan), and move his head within a moderate range during the following scans.

Image reconstruction: SPIRiT was used for the final image reconstruction. The kernel size was set to 7×7, and the calibration size was set to 30×30. For *in vivo* studies, off-resonance correction was implemented after motion correction to remove the blurring artifacts caused by long readouts (21 ms in this work).

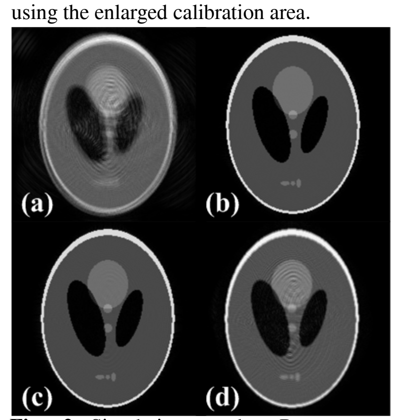

Fig. 2 Simulation results. Reconstructed images (a) without motion correction, (b) corrected with true motion parameters, and corrected with estimated motion parameters using (c) SPIRiT-based and (d) NUFFT-based method.

RESULTS For the simulation study, the estimation errors are averaged across 100 cases and summarized in Table 1. SPIRiT-based method results in smaller estimation error for both rotation and translation. Consequently, the improved motion estimation accuracy leads to minimal artifacts in the reconstructed images, as shown in Fig. 2. NUFFT-based method also suppresses the motion artifacts. However, its residual artifacts are still conspicuous. SPIRiT-based method also produces improved results for *in vivo* study, as shown in Fig. 3.

Table 1 Motion estimation error comparison

Method	Rotation (degree)	Translation in x direction (pixel)	Translation in y direction (pixel)
SPIRiT	0.05±0.04	0.14±0.10	0.12±0.09
NUFFT	0.29±0.23	0.57±0.32	0.83±0.47

DISCUSSION AND CONCLUSION Our results clearly show that using a large navigation region with SPIRiT-based method can efficiently compensate for motion artifacts in VDS MRI. The performance of this method is superior to that of NUFFT-based method. In this work, we chose SPIRiT for reconstruction of navigation images, and other algorithms that can improve the navigation images can also be chosen as alternatives.

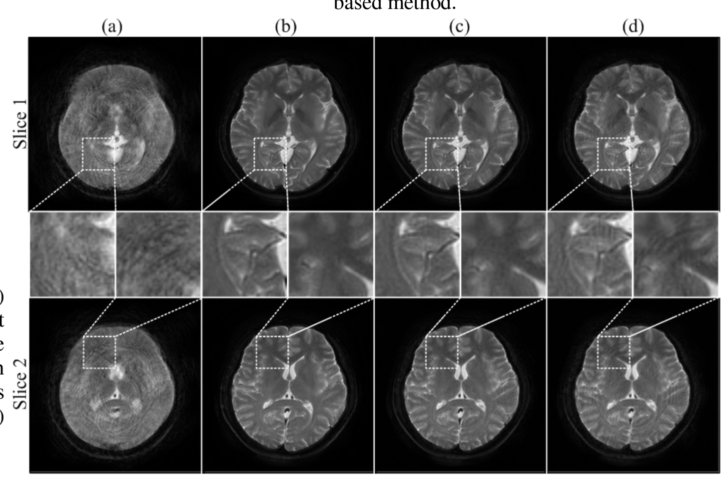

Fig. 3 *In vivo* results. (a) Reconstructed images without motion correction. (b) Reference images. Images corrected with estimated motion parameters using (c) SPIRiT-based and (d) NUFFT-based method.

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