3D diffusion tensor MRI with isotropic resolution using a steady-state radial acquisition

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INTRODUCTION

Diffusion tensor imaging (DTI) is a promising method for mapping brain microstructural properties and white matter tractography. Most DTI exams are performed using single shot EPI, which have limited spatial resolution and significant distortions near tissue/skull/air interfaces. Steady-State 3D projection (SS 3DPR) MRI with multiple echoes can image a large volume quickly with 3D isotropic spatial resolution with minimal spatial distortions and reduced motion sensitivity. However, pulsatile brain motion still causes significant signal dropout and artifacts in DW images. In this work, we present a method to synchronize the acquisition to the cardiac cycle, correct linear phase errors due to intravoxel motion, and weight each projection based on its measures of consistency with other data. Our volunteer studies demonstrate substantial image quality improvement.

MATERIALS AND METHODS

A DW SS 3DPR sequence was implemented to acquire four different radial lines per excitation. Diffusion gradients were added immediately after the RF pulse in specific encoding directions. Cardiac gating was synchronized with the acquisition so that data were not collected immediately before and after the R-wave trigger to avoid large displacements during systole.

Even during diastole, large losses of signal and phase variations of projection data were observed and the changes varied significantly throughout the cardiac cycle. To remove linear phase errors along the direction of acquisition, we centered echo peaks and set the phase of the center of k-space to zero [1] This method does not require additional fat suppression to avoid streak artifact around the scalp and works with multiple-channel receiver coils.

Both the area and the center of mass of each projection were used as indicators of the degree of motion corruption. We utilized weighting and density compensation techniques similar to other non-Cartesian correction technique to emphasize excitations with less motion corruption [2]. The assigned weighing factors were used as the initial estimate input for an iterative density compensation method [3, 4].

The volunteer studies were conducted on a 3T GE Signa HD scanner (GE Healthcare, Milwaukee, WI) with an eight-channel phased array head coil. Imaging parameters included TR /flip angle /BW = 17.5 ms/25°/ 62.5 kHz. DWI were acquired using diffusion gradients with $G = 40$mT/m and $\tau = 10$ ms, giving a b-value of ~ 195s/mm^2. A 24 cm spherical FOV was imaged with a readout matrix equivalent to 128*128*128 in 2:40 minutes for each diffusion direction.

DTI images were calculated from DW images acquired with diffusion gradients applied in six noncolinear directions [5]. A full set of DTI images of the entire brain could thus be produced with the seven standard DW image sets with relatively high resolution (1.88 mm) in approximately 18 minutes. Individual 3D images were co-registered each other with SPM5 [6]. Fiber trajectories were obtained using a streamline algorithm and a Runge-Kutta integration method [7]

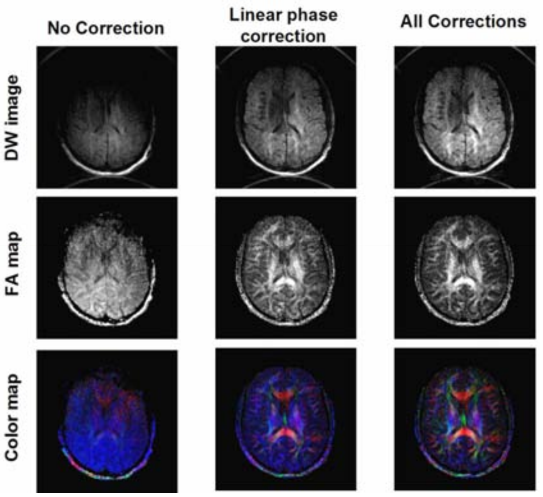

FIG. 1. DW images with RI/LS encoding, FA maps, and color maps of FA represent the effectiveness of linear phase correction and the proposed weighing methods.

RESULTS

Fig. 1. shows the effectiveness of the applied correction method. Before correction, image artifacts with the S/I encoding (indicated by blue in the color map) cause significant overestimation of diffusivity along this direction. Although improved, linear phase corrected DTI maps were still affected by the S/I directional motion. After all correction techniques were applied, the contrast and appearance of both the FA and color maps were improved. Fig. 2. shows the axial, coronal, and sagittal reformatted color maps at difference slice locations. Many of the major white matter tracts are identified and the benefit of 3D isotropic resolution may be appreciated. Fiber tracking results of several major white matter tracts are presented in Fig. 3. The results appear to be in agreement with known anatomy and previous fiber tracking results [7].

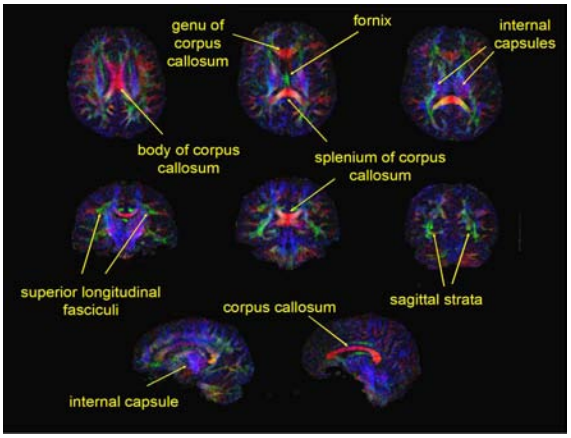

FIG. 2. Whole-brain color maps.Major features of WM morphology are depicted in the axial, coronal, and sagittal planes using the 3D isotropic resolution of this technique.

CONCLUSIONS

DTI with multiple excitations is possible through significant reduction of motion artifacts using a combination of cardiac synchronization, linear phase correction, and weighing techniques. 3D multiple excitation DTI with high isotropic resolution provides comprehensive brain imaging and may be easily reformatted into multiple planes to visualize the complex white matter tracts. Our results show that this technique is a promising method for true 3D volumetric DWI and DTI.

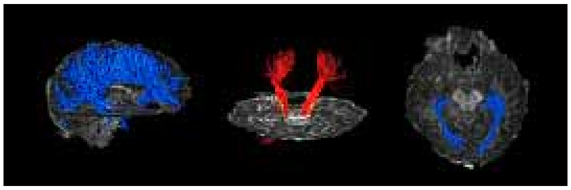

FIG. 3. White matter tractography results. Three-dimensional reconstruction of the corpus callosum (first), pyramidal tracts (second), and optic radiations (third).

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