Correction of Eddy Current Distortions in High b-value and High Angular Resolution Diffusion Imaging
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Introduction Diffusion tensor imaging (DTI) technology has a significant limitation in resolving intravoxel orientational heterogeneity within white matter of brain. Such limitations have prompted the development of high angular resolution diffusion imaging (HARDI) methods capable of resolving intravoxel fiber crossings, such as Diffusion Spectrum Imaging (DSI) and Q-Ball Imaging (QBI) [1]. However, because most of the HARDI techniques require high to ultra-high diffusion sensitizing gradients (b>4000 s/mm²), the capability of HARDI to provide valid and reliable information about tissue structures can be affected adversely by eddy current artifacts. One widely used post-processing algorithm, Iterative Cross-Correlation (ICC) [2], estimates distortions in DW images by cross-correlating them with an undistorted baseline image in terms of scaling, shear, and translation along the phase-encoding direction. One serious limitation of the original ICC algorithm, however, is its inability to correct image distortions at high b-values. The contrasts of cerebrospinal fluid (CSF), gray matter, and white matter in images acquired with high diffusion weighting differ greatly at different diffusion weightings or different diffusion gradient directions. Here we describe a new algorithm to detect eddy current distortions by modeling the distortion with the known x, y, and z components of diffusion gradients exclusively from DW images with close diffusion gradient directions.

Materials and Methods Five young adults (3 males and 2 females) were scanned on a Siemens 3T Trio Tim MRI system. HARDI data were acquired using a single-shot spin-echo echo planar sequence with the following parameters: TR = 10000ms, TE = 110ms, 128 diffusion gradient directions, 51 axial slices for whole brain coverage, FOV = 240mm × 240mm and matrix = 96 × 96, 2.5mm in-plane resolution and 2.5mm slice thickness. Three of the subjects were scanned with a single 5000 s/mm², 128 diffusion gradient directions, 51 axial slices for whole brain coverage, FOV = 240mm × 240mm and matrix = 96 × 96, 2.5mm in-plane resolution and 2.5mm slice thickness. One serious limitation of the original ICC algorithm, however, is its inability to correct image distortions at high b-values. The contrasts of cerebrospinal fluid (CSF), gray matter, and white matter in images acquired with high diffusion weighting differ greatly at different diffusion weightings or different diffusion gradient directions. Here we describe a new algorithm to detect eddy current distortions by modeling the distortion with the known x, y, and z components of diffusion gradients exclusively from DW images with close diffusion gradient directions.

Results and Discussion The ICC algorithm on human data did not give high correlation coefficients in co-registering the same slices with far-away diffusion gradient directions, when the diffusion weight was higher than 3000 s/mm² (Figure 1). In the QBI analysis, tractography performed on images corrected by our method shows fiber tracks with smoother contours and higher number of tracked fibers than the fiber maps constructed without correction (Figure 2). The average length of tracked fibers also increased significantly (<0.0001) after our correction was applied. In contrast, the correction using the original ICC method did not result in a statistically significant improvement. This result demonstrates the effectiveness of the proposed algorithm. In conclusion, the proposed method for eddy current distortion correction is both accurate and feasible in the real-world setting. The method not only circumvents the difficulties of prior correction algorithms that are associated with large contrast differences across high b-value DW and non-DW images, but also eliminates the requirement of acquiring additional images specifically for distortion correction.

Figure 1. Correlation coefficients of ICC between DW images of human subjects depend on the spatial angle difference of diffusion gradients and gradient strength (b values in the unit of s/mm²).

Figure 2. Representative fiber tracking results constructed from the QBI data of a human brain, with and without the eddy current correction proposed in this study.