Diffusion tensor imaging distortion correction with T1

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Introduction

Diffusion weighted single shot spin-echo planer imaging (DW-EPI) is commonly used for diffusion tensor imaging (DTI). DW-EPI is very sensitive to static magnetic field (B_0) inhomogeneities (such as that near air-tissue boundary) that produce geometric distortion, primarily along the phase-encoding direction. As a result, artifacts are severe in the frontal and temporal lobes due to the sinuses. These artifacts degrade the ability of using diffusion measures (fractional anisotropy (FA), mean diffusivity (MD)) and diffusion tractography to compare patient and control population. Several different techniques (field map, phase reversal, and image based linear and non-linear registration with T_2) were suggested for correcting susceptibility distortion.[1,2,3] However, to apply these correction techniques, additional images (field map, T_2) are required. This is undesirable, especially when scan time is limited. In this work, we examine susceptibility distortion correction using image based non-linear registration along with inverting the intensity of the T_1 image. This method exhibits better performance for geometrical distortion correction in frontal region and an ability to analyze clinical diffusion data without additional collection of images.

Methods

A. Subjects and image acquisition: Twelve healthy subjects (mean age: 36.5±10.7, gender (F/M: 7/5) participated in accordance with Institutional Review Board policies at Emory University. Data were acquired on a 3T Siemens TimTrio scanner using a TX/RX birdcage head coil. DTI data were collected using a DW-EPI sequence with the following parameters: b=1000 sec/mm2; voxel resolution=2×2×2 mm; number of slices=64; matrix=128*128; 64 directions with 2 averages for each direction; TR/TE=9800/95ms. T_1 images were collected in 128 sagittal slices using an MPRAGE sequence with following parameters: TR/TE=2600/3ms; voxel resolution=1×1×1 mm; number of slices=176; matrix=224×256. In addition to T_1 images, T_2 image was acquired from one subject for method comparison.

B. Preprocessing of T_1, T_2, and DTI: FSL (http://www.fmrib.ox.ac.uk/fsl) and TrackVis (http://trackvis.org) were used. T_1 and T_2 data were skull stripped to remove non-brain regions. The intensity of T_1 data was inverted (i.e., the voxel with minimum intensity converted to maximum intensity and vice versa). Diffusion data underwent brain extraction, eddy current correction, and local DTI fitting to generate FA images.

C. Susceptibility distortion correction and validation: Inverse intensity T_1 (and T_2) images were pre-registered to the b_0 image using rigid body registration (FLIRT: degree of freedom 7). These pre-registered images were then used as a reference image for distortion correction using a non-linear registration.[4,5] The b_0 image was then registered to the inverse intensity T_1 and T_2 image using large diffeomorphic registration method (FNIRT). In addition to correction with the T_2 image for one subject, diffusion data of all twelve subjects were registered to the individual T_1 image using normalized mutual information linear registration. Comparison to currently available image based distortion correction methods (non-linear with T_2 and linear using mutual information) to non-linear registration method using the inverse intensity T_1 was performed. To validate the results, the derived FA map (non-corrected, linear corrected, and non-linear corrected) of each individual subject was normalized to the MNI template using a combination of linear (diffusion to T_1 data) and non-linear (T_1 to MNI template) registration, and then the FA variance map of each correction method was calculated.[6] The effects of distortion correction were also evaluated on deterministic fiber tractography. More specifically, TrackVis software was used to analyze tracks in the frontal lobe, one of the regions that suffer from severe susceptibility artifacts.

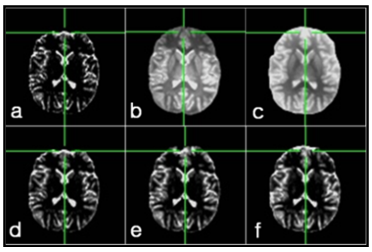

Figure 1. Susceptibility distortion correction results: a) B_0 image, b) T_2 image, c) inverse intensity T_1 image, d) corrected image using linear distortion correction (Normalized MI) e) corrected image with T_2 using non-linear distortion, f) corrected image with inverse intensity T_1 using non-linear distortion correction

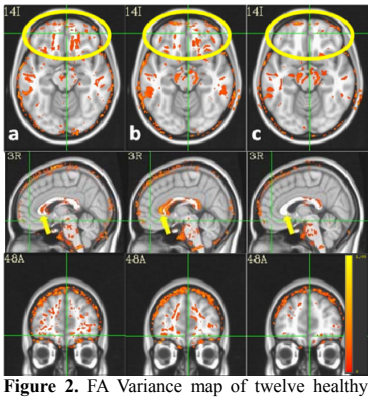

Figure 2. FA Variance map of twelve healthy subjects on the MNI template image: a) uncorrected map, b) linear-corrected map, c) non-linear corrected with inverse intensity T_1

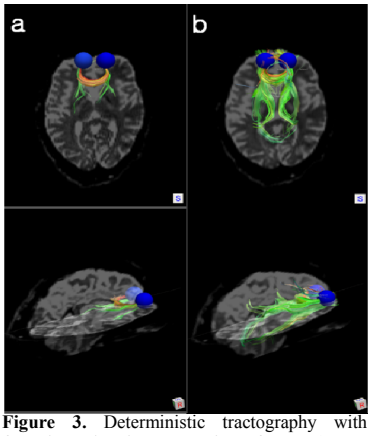

Figure 3. Deterministic tractography with frontal seed using TractVis software (FACT algorithm), a) uncorrected, b) non-linear corrected with inverse intensity T_1

Results & Discussions

Figure 1 presents the distortion correction results of linear and non-linear correction using the T_1 and T_2 images as reference. Linear correction with normalized mutual information did not substantially improve the frontal lobe DTI distortion. Non-linear correction performed significantly better, and for one subject, correction with inverse intensity T_1 and T_2 was very similar. Figure 2 illustrates the FA variance map. As expected, there were several regions with significantly lower variance using non-linear correction compared to uncorrected and linear-correction methods. Importantly, significantly reduced FA variance was seen in the frontal lobe and anterior cingulate (yellow circle and arrows in Fig. 2. Deterministic fiber tractography results are shown Figure 3. By observing the images, it can be seen that, without any correction, tracks are shorter in length and, more specifically, fiber tracks that travel from the anterior to posterior direction (anterior thalamic radiation, inferior fronto-occipital fasciculus) are much more limited. By applying the suggested correction, the fiber length is increased and longer structural connectivity can be observed which are closer to the real anatomy.[7] However, there are several limitations. The corrected images are more blurred than the original images. This may reduce statistical power to detect significant differences between groups. In addition to a blurring artifact, non-linear registration has a high computational cost. In this study, we examined a method to correct DTI susceptibility distortion without the need to collect any additional images (e.g., field map, T_2) using an inverse intensity T_1. The proposed method showed significant improvement in distortion correction compared to a linear method as shown by reduced variance in the normalized FA maps. These results indicate that distortion correction with inverse intensity T_1 images using non-linear registration may be useful when only field map or T_2 data are not available.

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