Comparison of EPI Distortion Correction Methods in Diffusion Tensor MRI

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Introduction

Diffusion weighted images (DWIs) used for Diffusion Tensor (DT) calculation are commonly acquired with Echo-planar imaging (EPI). Unfortunately, EPI is very sensitive to magnetic field (B_0) inhomogeneities, which result in local geometric distortions in regions close to air-tissue interfaces. These distortions degrade the anatomical accuracy of DT-MRI maps and potentially increase their variability in clinical studies [1]. B_0 mapping can be used for EPI distortion correction [2-4]. In a clinical setting, however, the additional data necessary for B_0 mapping are rarely acquired. In this study, we investigate the performance in the context of DT-MRI of an image registration-based method using a cubic b-spline deformable registration algorithm with mutual information metric (BSP) [l] that does not require B_0 field information for correcting EPI distortions.

Methods

Methodological framework. Given that EPI distortions occur in the phase encode direction, one can obtain tensors that are differently corrupted by the EPI distortions by acquiring DWI datasets that differ only for the direction of phase encoding. The local variance of DT-MRI derived quantities computed from DWI datasets acquired with different phase encode directions will be highest in regions that are most significantly affected by EPI distortions. An effective EPI distortion correction strategy should result in a reduction of this local variability.

Experimental testing. Five young subjects (2 male; mean age = 35.95, range 24-48 years old) participated in this study. We acquired four axial DWI datasets in each subject: the phase encoding direction was either anterior/posterior (A/P), or right/left (R/L), and the phase-phase encode blips had either positive or negative sign resulting in either compression or expansion distortion along the A/P and R/L orientation. Data were acquired on a 1.5 Tesla scanner (GE Medical Systems, Milwaukee, WI) with a single-shot spin-echo EPI sequence with the following parameters: FOV = 24x24cm, slice thickness = 2.5mm, no gap, matrix = 96x96 zerofillled to 128x128, 60 axial slices. Each DWI dataset consisted of 2 images with b=0s/mm^2 and 12 images with b=1100s/mm^2 with different orientations of diffusion sensitization. An undistorted T2 weighted scan (T2WFSE) was acquired with a fast spin echo sequence and two gradient echo images with different echo time were collected for B_0 mapping.

All images were co-registered to correct for rigid body motion and eddy current distortion correction and all data sets were registered with a rigid body registration to the T2WFSE [5].

EPI distortion correction methods: Prior to tensor computation, the DWIs of the four datasets for each subject were corrected for EPI distortion using the b-spline deformable registration algorithm (**BSP**) with the T2WFSE as target. EPI distortion correction from the B_0 field data (**B_0M**) was also performed using the PRELUDE and FUGUE algorithms from FSL [6].

Nonlinear tensor fitting was performed for **BSP** and **B_0M** corrected DWI datasets as well as for the uncorrected images (**NOC**) and maps of the standard deviation (**STD**) of the fractional anisotropy (FA) and the trace of the diffusion tensor (TR) across the four datasets were computed.

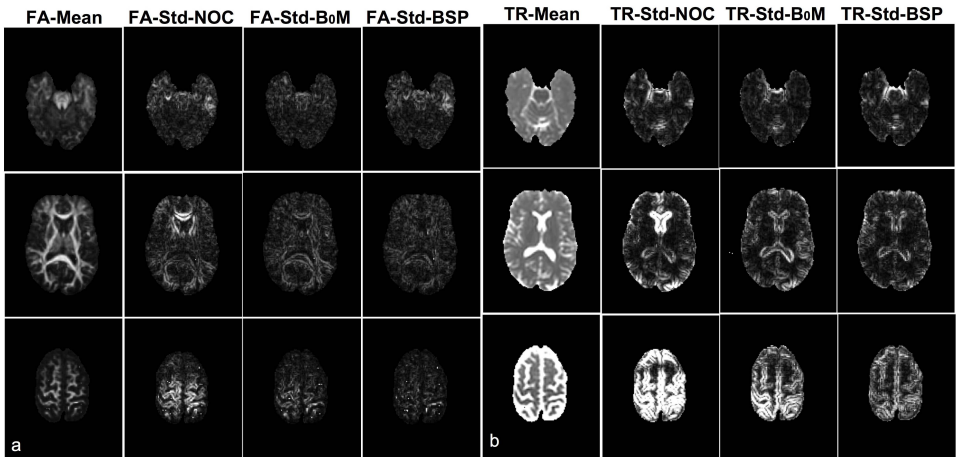

Fig. 1. Standard deviation maps of FA and TR from corrected (B_0M and BSP) and non-corrected (NOC) DWI datasets. Mean FA and TR images from BSP are also displayed.

Results and Discussion

Fig. 1(a) shows STD maps of FA from a representative subject for NOC, B_0M, and BSP (Display range: black=0, white=0.3). The mean FA image from datasets with BSP correction is included as anatomical reference (Display range: 0, 0.95). The STD maps of TR from the same subject are shown in Fig. 1(b) (Display range black=0 mm^2/s white=1.0 *10^{-3} mm^2/s], along with the mean TR map (Display range: 0, 5.0 *10^{-3} mm^2/s). Overall results in the five subjects are consistent with those presented for this subject.

As expected, the local STD of FA and TR in the NOC datasets is highest in regions that are most significantly affected by EPI distortions, such as frontal regions, extending to the genu of the corpus callosum, temporal lobes, and brainstem. More surprisingly in the NOC datasets STD is high also at the top of the brain where susceptibility artifacts are not thought to be prominent. Significant decrease in the regional variability of the FA and TR was observed after EPI distortion correction with both B_0M and BSP. However, BSP consistently provides better correction for rostral regions (e.g. corpus callosum, top of the brain), while B_0M performs better at the base of the brain, including temporal lobes, brainstem, and cerebellum. Factors determining the weaker performance of BSP at the base of the brain may include the relative small size of brain structures in that area, and the severity of the susceptibility artifacts.

Conclusion

Performing EPI distortion correction of diffusion weighted images prior to tensor computation provides maps of quantities derived from the diffusion tensor that are more anatomically accurate. In absence of B_0 field data, successful EPI distortion correction can be performed with a b-spline image registration approach using an undistorted FSE image as target.

References

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