Evaluation of Spatial Normalization in Turboprop-DTI vs. SE-EPI-DTI

H. Peng[1], G. Agam[2], M. Gui[1], and K. Arfanakis[1]

[1]Department of Biomedical Engineering, Illinois Institute of Technology, Chicago, Illinois, United States, [2]Department of Computer Science, Illinois Institute of Technology, Chicago, Illinois, United States

Introduction: Diffusion tensor imaging (DTI) provides important information, in vivo, for the detection of abnormalities in the microstructural integrity of brain tissue. In order to perform voxel-based analysis to a) compare DTI data of the whole brain between cohorts, or b) study the diffusion properties of brain tissue longitudinally, spatial normalization of brains from different subjects, or scan sessions, is necessary. However, conventional DTI data acquisitions by means of spin-echo echo-planar DTI (SE-EPI-DTI) suffer from severe susceptibility-related image artifacts, which are prominent in certain brain regions, such as the brainstem, the frontal and temporal lobes. These artifacts are expressed differently in different subjects, or even in the same subject for different head positioning, and may reduce the accuracy of spatial normalization. In contrast, Turboprop-DTI is relatively immune to image artifacts caused by magnetic field inhomogeneities [1]. In this study, the performance of spatial normalization of DTI data obtained with SE-EPI-DTI and Turboprop-DTI was evaluated.

Methods: *Data acquisition.* Ten healthy human subjects participated in this study. High-resolution T1-weighted MP-RAGE, Turboprop-DTI, two-echo 2D gradient-echo, and SE-EPI-DTI acquisitions were performed for all subjects on a 3T GE MRI scanner (Waukesha, WI). The parameters for Turboprop-DTI were: TR=5s, 16 blades, ETL=8, turbo-factor=5, FOV=24cm x 24cm, 128 samples per line, 36 axial slices, slice thickness=3.5mm, 12 diffusion directions, and b-value=900sec/mm^2. The parameters for SE-EPI-DTI were the same as those in Turboprop-DTI, except in SE-EPI-DTI: TR=5.4s, TE=71.8ms, NEX=4. The scan time for Turboprop-DTI was 18min and 55s. The combined scan time for the SE-EPI-DTI and two-echo 2D gradient-echo sequence was 9min and 26s. The SNR was comparable in SE-EPI-DTI and Turboprop-DTI scans.

Data analysis. Eddy-current-induced distortions in the SE-EPI-DTI diffusion weighted (DW) images were corrected using affine registration (AIR 5.25, Roger Woods, UCLA, CA). Then, phase-maps were constructed from the two-echo 2D gradient-echo scans and were used to correct B_0-related distortions in SE-EPI-DTI [2]. Turboprop-DTI and SE-EPI-DTI FA maps were produced for each subject. Deskulling was performed on all b=0 sec/mm^2 volumes using the brain extraction tool of FSL (Oxford Center for fMRI of the Brain, Oxford, UK). The binary brain masks were then applied on the FA volumes. The Turboprop-DTI and SE-EPI-DTI FA volumes of one subject were used as templates. FA volumes from all other subjects were then normalized to the corresponding FA template using affine and nonlinear regularization (SPM5, Wellcome Department of Imaging and Neuroscience, London, UK). The estimated transformations were applied to the original b=0 sec/mm^2 and DW volumes, and new diffusion tensors were calculated for each subject. The new diffusion tensors were reoriented according to the estimated transformations using the preservation of principal direction (PPD) algorithm [3]. Principle eigenvector coherence (κ) maps were then produced for Turboprop-DTI and SE-EPI-DTI data [4, 5]. Regions of interest (ROIs) were selected on the FA maps in the midbrain, posterior and anterior corpus callosum (PCC, ACC), and forceps minor (Fminor). The mean and standard deviation of the coherence of the principle eigenvector, $\overline{\kappa}$, $\sigma(\kappa)$, were estimated for each ROI for Turboprop-DTI and SE-EPI-DTI data. The significance of any differences in the coherence of the principle eigenvector in the selected ROIs between Turboprop-DTI and SE-EPI-DTI was assessed with a T-test. Only differences with $p<0.05$ were considered significant.

Results and Discussion: The $\overline{\kappa}$ and $\sigma(\kappa)$ in the selected ROIs are shown in Figure 1. In the midbrain, the value of $\overline{\kappa}$ was significantly increased by 8.2% (p=0.0001) for Turboprop-DTI compared to SE-EPI-DTI data. In the ACC and PCC, the increase of $\overline{\kappa}$ for Turboprop-DTI was 0.77% (p=0.3841) and 0.22% (p=0.8349), respectively, compared to SE-EPI-DTI data. In the Fminor, the value of $\overline{\kappa}$ for Turboprop-DTI was increased by 0.69% (p=0.6818) compared to SE-EPI-DTI data. The higher values of κ in the midbrain for Turboprop-DTI compared to SE-EPI-DTI data are also visible in the maps of κ shown in Figure 2. The reason for the increased $\overline{\kappa}$ in the midbrain for Turboprop-DTI data is that, even after correction of B_0-related artifacts in SE-EPI-DTI data, there are residual errors that reduce the accuracy of spatial normalization of brains from different subjects. Furthermore, mean FA maps from Turboprop-DTI data appeared sharper than mean FA maps from SE-EPI-DTI data (Fig.3), suggesting that spatial normalization of FA maps was more accurate when using Turboprop-DTI instead of SE-EPI-DTI data. This may also be due to the fact that Turboprop-DTI is relatively immune to B_0-related artifacts, thus leading to more accurate spatial normalization of FA maps, than SE-EPI-DTI.

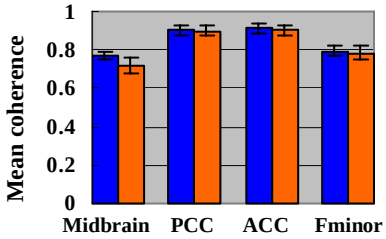

Figure 1. The $\overline{\kappa}$ and $\sigma(\kappa)$ in the midbrain, PCC, ACC, and Fminor for Turboprop-DTI (blue) and SE-EPI-DTI (orange) data.

Several methods have been proposed for reducing B_0-related artifacts in SE-EPI-DTI. Most of them do not completely eliminate these artifacts, or lead to long scan times, or are hard to use. Parallel imaging may reduce B_0-related artifacts and is easy to use. However, parallel imaging with the acceleration factors available today cannot reduce artifacts to the same degree as Turboprop-DTI.

In conclusion, accurate spatial normalization in DTI requires data with minimal artifacts. Turboprop-DTI is relatively immune to B_0-related artifacts, and may lead to more accurate spatial normalization of brains from different subjects, than SE-EPI-DTI, in regions where the latter suffers from magnetic field inhomogeneity artifacts. Furthermore, use of Turboprop-DTI in longitudinal studies allows matching of DTI datasets from different scan-sessions with simple rigid-body registration techniques.

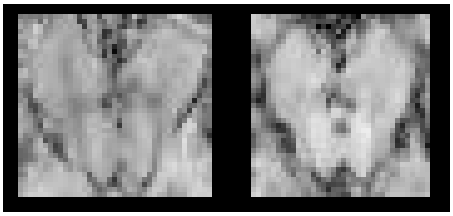

Figure 2. Maps of κ in the midbrain, for SE-EPI-DTI (left) and Turboprop-DTI (right) data.

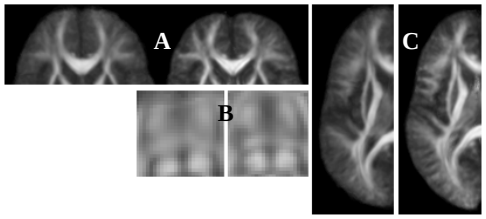

Figure 3. Mean FA maps from SE-EPI-DTI (left image in each image pair) and Turboprop-DTI (right image in each image pair) data. Frames A to C show axial slices of the frontal lobe, brainstem, and right hemisphere.

References: 1) Pierpaoli C *et al., Radiology* 1996;201:637-48. 2) Jenkinson M *et al., Magn Reson Med* 2003;49:193-7. 3) Alexander DC *et al., IEEE TMI* 2001; 20:1131-9. 4) Basser PJ *et al., Magn Reson Med* 2000;44:41-50. 5) Jones DK *et al., Magn Reson Med* 2003;49:7-12.