Effects of Susceptibility Distortion on Fiber Tractography in Diffusion Tensor Imaging

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Introduction:

White matter fiber tractography from diffusion MRI data is widely used in the neuroscience community and in clinical research settings to investigate white matter pathways in the human brain. Diffusion weighted images (DWIs) are generally acquired with echo planar imaging (EPI) and suffer from concomitant field (Zhou 1998) and susceptibility related geometrical distortions in the phase encode direction (Jezzard 1995). It should be noted that these EPI distortions are different from eddy current distortions that are typically corrected in DWI processing. Correction of susceptibility-related distortion requires the acquisition of additional data, either B0 mapping or T2 weighted (T2W) dedicated structural targets, and is not generally performed. In this work we analyzed the effects of these EPI distortions on DTI-derived tractography results. With the exception of a previous ISMRM abstract (Andersson 2004) we did not find literature that investigated this potentially important confound.

Methods:

Methodological framework: If EPI distortions do not significantly affect tractography we would expect tracts computed from diffusion datasets acquired in the same subject with right-left (RL) or anterior-posterior (AP) orientation of phase encoding to be similar. However, if tractography results turn out to be different with different phase encode direction we would expect these dissimilarities to be reduced if the EPI distortion in the DWIs is corrected prior to tensor computation. Data Acquisition: Five healthy subjects were scanned with a 3T MR system (GE Medical Systems) with a single-shot spin-echo EPI sequence. Two DTI scans were acquired for each subject with different phase encode directions (AP and RL). Fast spin echo T2W images were also acquired as anatomical targets for EPI distortion correction. DTI Processing: All DWIs were corrected for motion and eddy-current distortions producing “uncorrected data”. Subsequently, an additional EPI distortion correction step was performed producing “corrected data”. This correction was performed by elastically registering the first b=0s/mm2 image in each DWI set to its corresponding undistorted structural T2W image with B-Splines transformation of grid size 7x7x7. The computed deformation was applied to all DWIs in that set (Wu 2008) using the TORTOISE software (http://www.tortoisedti.org). Tractography: Three anatomical pathways were chosen for analysis: cortical spinal tracts (CST), inferior cerebellar peduncles (ICP), and the cingulum bundle. These pathways were chosen because their anatomical trajectory is well known. Probabilistic tractography was performed using the same ROIs for each subject, for both corrected and uncorrected data, using FSL (Smith 2004). The individual tractography results were combined into a general probabilistic tract representation for the population by registering all diffusion tensors to a common space and applying the transformation to the individual tract probability maps.

Results:

Figure 1 reports the population average tracts for CST and ICP combined for both AP and RL data, corrected and uncorrected versions. The effect of phase-encoding direction is prominent when we examine the uncorrected data. In the presence of different directions of distortions, both the CST and ICP tracts reached different regions of the brain. These tracts were particularly sensitive to distortions in AP direction, which caused the majority of CST to reach anatomically incorrect regions of the brain. The problem was less severe with RL distortion. This can be attributed to the fact that fibers on the inferior aspect of the pons have a large variation of orientation on the AP direction and in the presence of distortions in this direction, they are more likely to go off-track. Additionally, right and left tracts in the population were affected differently from the AP distortion, which resulted in a remarkable loss of tract symmetry. The corrected AP data did not have most of these problems, indicating that EPI distortion correction reduced the likelihood of premature termination of tracts and spurious trajectories. In the corrected AP data, the average CST tracts reach the proper cortical regions and ICP reaches the cerebellum which is its correct anatomical termination. These results show the efficacy of distortion correction for the anatomical accuracy of fiber tractography. Distortion correction also improves consistency: the uncorrected RL and AP data have significantly different trajectory signatures, whereas after correction, the shapes of these average tracts become more similar. Additionally, another improvement with correction for the RL data is the increase in probability of reaching the cortical regions of the brain. This can be observed from the stronger tones of red in the cortical regions in the corrected versions of the RL data compared to the paler tones in the uncorrected case.

Conclusions:

The main finding of this work is that EPI related distortions commonly present in diffusion MRI data acquired on clinical scanners have a profound effect on the quality of tractography. We employed DTI-based tractography but similar effects would be observed with high angular resolution (HARDI) tractography methods. Correction of EPI distortions, originating from susceptibility and concomitant fields effects, should become an essential step in routine processing of diffusion MRIs to be used for tractography applications.

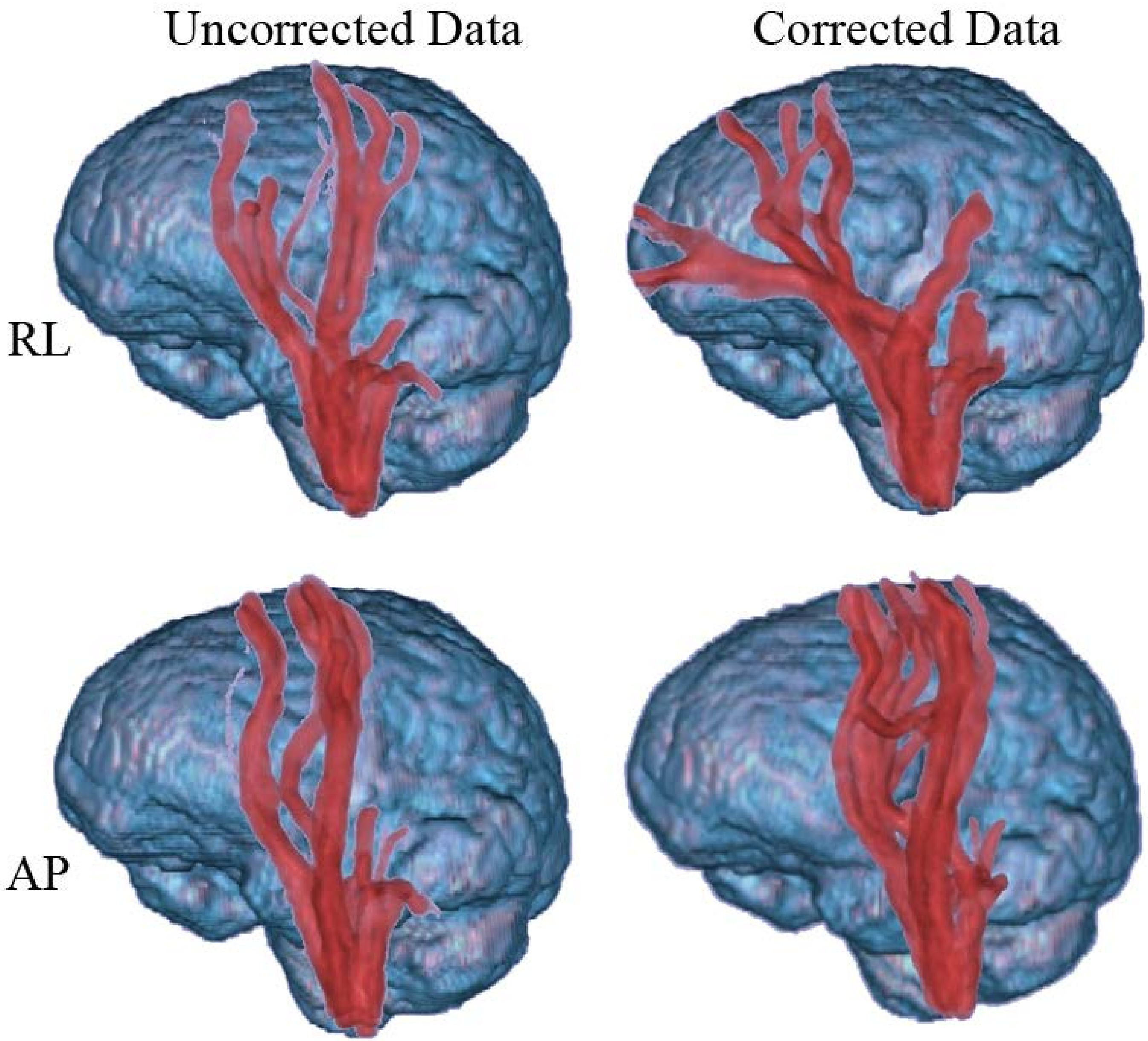

Figure 1: Population average CST and ICP tracts for RL and AP data for both corrected and uncorrected cases. The shade of the red indicates the probability of reaching the voxel from the selected ROIs.

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Categories

- Diffusion MRI (Imaging Techniques and Contrast Mechanism)