Quantitative analysis of directional bias imposed on primary eigenvector estimations in DTI when gradient table correction is neglected

Ali Ersoz[1], Volkan Emre Arpinar[2], and L Tugan Muftuler[2,3]
[1]*Department of Biophysics, Medical College of Wisconsin, Milwaukee, WI, United States,* [2]*Department of Neurosurgery, Medical College of Wisconsin, Milwaukee, WI, United States,* [3]*Center for Imaging Research, Medical College of Wisconsin, Milwaukee, WI, United States*

Target Audience: Researchers and clinicians who are interested in DTI and Tractography techniques.

Introduction: In Diffusion Tensor Imaging (DTI) image misalignments caused by head motion and geometric deformations caused by eddy currents are corrected by applying spatial transformations to the images. It has been suggested that the gradient table should be reoriented using the same motion corrections to ensure that the gradient directions used in DTI estimation are accurate. The effects of gradient table correction on estimates of Fractional Anisotropy (FA) and primary eigenvalue were demonstrated before[1,2]. However, its effects on fiber tracking were studied qualitatively[2] and a quantitative analysis of adjustments to primary eigenvector (PE) has not been presented. In the study presented here, we conducted a quantitative analysis of directional bias imposed on PE when gradient table correction is neglected. We compared this bias with the inherent uncertainty in the estimation of orientation distribution functions (ODF). Although the directional bias in voxels were very small, our results also showed that the effects might accumulate along the fiber tract and lead to inaccurate fiber tracking. The findings were validated using simulations.

Methods: DTI data used for this analysis was selected from a set acquired from 126 children (age: 6-10yrs) for an ongoing study of cognitive development. The study was approved by the Institutional Review Board and written consents were obtained from the parents. A SE-EPI pulse sequence was run on a 3T Philips Achieva system (Best, Netherlands) with 32 gradient directions with b=800 and a single acquisition with b=0 (60 axial slices, 1.75×1.75×2mm^3 voxel size, NEX=1, TR/TE=9290ms/55ms and SENSE=2.4). Total data acquisition time was 6 minutes.

DTI data were processed by FSL 4.1 software package (http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FDT). Head motion and geometric deformations were corrected using 12 parameter affine transformations. The variances of rotation angles used in motion correction were calculated to quantify the amount of motion for each subject. The subject with the maximum amount of motion was selected to analyze the worst-case scenario. Calculations were performed for all voxels in the cingulum (in the cingulate gyrus area) and Corticospinal Tracts (CST) for this subject as well as 4 more subjects. This showed us how motion biased the diffusion estimates in two major tracts in two orthogonal directions. In the voxels of these fiber tracts, we calculated gradient table correction angle (*GTCA*, Eq.1), which is defined as the angle between corrected (e_1) and uncorrected (e_1\`) vectors of the primary diffusion direction. In the first step, we investigated if the angular corrections were larger than the inherent uncertainty in the estimation of fiber orientation inside a voxel (random noise). The FSL program provides estimates of diffusion vector dispersion, which is a measure of this uncertainty. It characterizes how broad the ODF is around the main diffusion vector. It can be transformed into degrees as given in Eq. (2). We compared the dispersion angle and *GTCA* in each voxel and calculated the percentage of voxels that have larger dispersion angles than *GTCA*. This comparison only shows if the directional corrections are below or above the noise level in general. However, it should be noted that even though *GTCA*s might be smaller than dispersion, if they are biased in a particular direction, the effects might accumulate coherently in subsequent voxels along a tract, diverting the fiber tract in the direction of the bias. Since *GTCA* does not have directional information, we calculated the difference vector between e_1 and e_1\` in each voxel to understand if *GTCA*s are randomly distributed or biased along a particular direction. To illustrate this bias we normalized the magnitude of these difference vectors to unity (preserving their angles) and mapped them to points on a unit sphere. Therefore, each point can be described by azimuth and zenith angle. A scatter plot of these angles was generated to illustrate if difference vectors were biased in a particular direction. Color of each dot represents the direction of the difference vector (following the convention used in DTI color maps). If the dots are symmetrically distributed in the plane, there is no bias in that direction; otherwise, the *GTCA*s would be biased. In the simulations diffusion signals were generated using the tensor model and the corrected gradient table obtained from the experimental study. Then PEs were estimated using uncorrected gradient table. For comparison, simplified models of the Cingulum and the CST were generated by assigning PE of tensors in those tracts purely along y and z directions, respectively.

$$GTCA = \min\left\{\operatorname{acos}\left[e_1^T e_1^{'}\right]\right\} \quad (1)$$

$$dispersion_{\text{angle}} = \operatorname{acos}(1 - dispersion) \quad (2)$$

Results and discussion: The histograms of *GTCA* and dispersion angles in the Cingulum and CST are illustrated in Fig.1(a) It is evident that *GTCA* distribution is generally much smaller than the uncertainty in the estimation of primary diffusion direction (random noise). Approximately 90% of the voxels in both fiber tracts had much smaller *GTCA* than the dispersion angle. The remaining 10% of the voxels were on the outer surface of the fiber tracts, where partial volume effects might have resulted in larger *GTCA*. In Fig.1(b), the dots were not symmetrically distributed on the scatterplot showing that a bias was induced in the estimation of the primary diffusion direction in the voxels of that fiber tract. For instance, a bias is clearly seen in 'z' direction for the cingulum voxels (asymmetric distribution of blue dots) and 'y' direction for the CST voxels (asymmetric distribution of green dots). The analyses performed on four other subjects yielded similar results. The results from the simulations were in accord with the experimental results. However, all dots were distributed only around the direction of bias since we selected PE of tensor model along a single direction (no curvature). We can conclude that the uncertainty in the estimated fiber orientation is usually much larger than the correction provided by the gradient table reorientation. However, the small bias observed in Fig.1(b) might accumulate over voxels and deviate the trajectory of tracking.

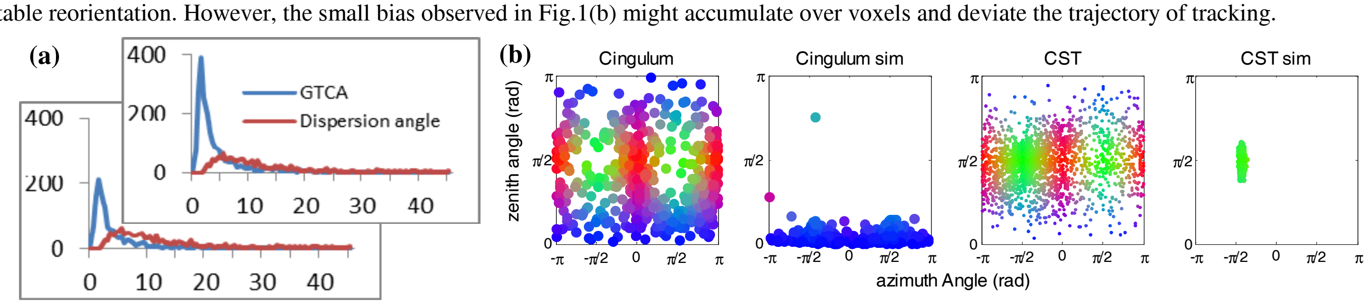

Figure 1. (a) Histograms of *GTCA* and dispersion angle in cingulum (background) and CST (foreground). (b) The distribution of difference vectors calculated by subtracting the uncorrected vectors of the primary diffusion direction from the corrected ones.

References:

[1] L. T. Muftuler, and O. Nalcioglu Proc. ISMRM 17: 3524 (2009) [2] A. Leemans, and D.K. Jones Magn Reson Med 61: 1336-1349 (2009)