# Correction of Bo EPI Distortions in Diffusion Tensor Imaging and White Matter Tractography

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**Introduction**

Diffusion tensor imaging (DTI) is a sensitive method for studying tissue microstructure in *vivo*. The anatomical and geometric correspondence to other neuro- MR images, such as conventional T1-w and T2-w structural images, is necessary for accurate anatomical localization and comparison across subjects. Furthermore, new white matter tractography methods rely on anatomical accuracy to ensure that the tracts are following the proper course as well as correspondence to white matter anatomy in other images. However, DTI data are typically acquired using a set of modified spin-echo EPI acquisitions which are vulnerable to static magnetic field inhomogeneities and consequent image distortion. The amount of distortion (voxel shift) in an EPI image is proportional to the static field inhomogeneity and the temporal spacing of k-space readout lines. In addition, higher field strengths (such as 3 Tesla) provide better SNR but increase the EPI geometric distortions. The geometric distortions in areas with large magnetic susceptibility gradients, such as the sphenoid sinus, temporal lobe and brain stem, can be quite severe. Consequently, it is critical to correct the distortions in DT-MRI for better geometric fidelity. Field-mapping correction methods, based on measured maps of local field strength have been used to correct EPI distortions for fMRI, and are known to be efficient for geometric distortion correction [1,2]. In this study we investigate a field map correction of 3T DTI brain data sets in both humans and macaque monkeys.

**Methods**

DTI data sets and gradient echo field maps were obtained on 42 human subjects (ages 10-42) and 4 adult macaque monkeys with a 3T MRI scanner. DTI was performed using a single-shot EPI sequence with diffusion weighting gradients applied in 12 directions. The following acquisition parameters were used: b-factor: 912 sec/mm$^2$, 128x128 matrix, and 3 mm contiguous slices. High order shimming over the whole brain was applied to make the field as homogenous as possible. For the human studies, 39 axial slices with a 240 mm FOV were obtained. In the macaques, 22-26 coronal slices with a 160 mm FOV were collected. Gradient echo field maps were obtained using a pair of spin-warp gradient echo images at two echo times (TE1 = 8 msec and TE2 = 11 msec). 3D phase unwrapping was performed and the phase difference image was used to estimate the field map $\Delta B = \Delta\Phi/(\gamma\cdot\Delta TE)$. A displacement map was calculated using $\Delta y(x,y,z) = \gamma\cdot\Delta B_o(x,y,z)\cdot FOV\cdot esp$, where esp = the echo spacing. Before static field distortion correction, the raw DW images were corrected for eddy current distortion. Magnetic field distortion correction was subsequently applied to all 13 DW volumes and the diffusion tensor was estimated for each voxel in the volume. Maps of FA, trace{D} and major eigenvector direction were generated. White matter tractography was performed on one data set (both before and after Bo distortion correction) using a streamline algorithm with Euler integration method [3,4]. The propagation of an individual trajectory was terminated when it reached a voxel with FA smaller than 0.2 or when the angle between two consecutive steps was greater than 45°.

**Results & Discussion**

In all cases (both human and macaque brains) the geometric fidelity of the diffusion tensor maps was greatly improved after application of the field map correction. In particular, areas near the ventral orbitofrontal cortex and frontal pole, temporal lobe areas around the temporal bone and inner ear, and the brain stem were greatly improved. An example of typical warp corrections are shown Figures 1 and 2 for human and macaque brains. In the human study example, a registered T1-w image was used to obtain the outline of the brain white matter, which was overlayed on the FA maps both before and after correction (Fig 1 middle & left). Before correction, there is poor alignment between the ventricles, corpus callosum and prefrontal white matter in the FA map. After distortion correction, the correspondence is much improved. Over the entire brain the pixel displacement for correction ranged from -20 pixels (19 mm) to 25 pixels (23.75 mm). Note that corrected data preserves the original tensor information. The image correlations between corrected FA map and segmented white matter for this slice is 0.86 and 0.75. Over 10 subjects, and whole brain volumes the correlation between FA and segmented WM volume was 0.76(after correction) versus 0.66(before correction). Note that the correlation is not a perfect measure because the range of FA values in white matter is large. In the macaque study example, the FA map before correction (Fig 2 – left) demonstrates severe image distortion over the entire brain. After Bo distortion correction, the geometric fidelity of the FA map is significantly better (Fig 2 – right). An example of WM tractography of prefrontal tracts both before and after distortion correction in one subject is shown in Figure 3. Tracts were selected by seeding a coronal plane just anterior to the genu of the corpus callusum (e.g. tracts to frontal pole). After correction (Figure 3 – right panel), the WM tracts appear fuller and more symmetric. After correction, the inferior fronto-occipital fasciculus, fronto-thalamic pathways, and pre-frontal corona radiate projections (seen in sagittal view) are more readily observed in both hemispheres. We expect that tractography results across subjects will be much more consistent after field map correction, particularly for field strengths of 3T and higher. In conclusion, image distortion correction is strongly encouraged for precise tractography, surgical planning, and population-based comparisons, because it provides a more accurate geometric presentation of white matter pathways.

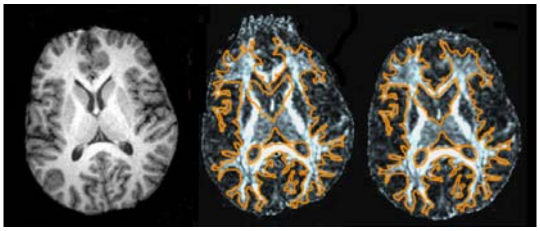

**Figure 1.** left: T1-w image; middle: FA map before Bo correction with WM outline; right: FA map after correction with white matter outline

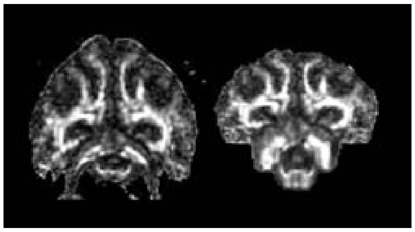

**Figure 2.** FA map of monkey brain left: before; right: after Bo correction

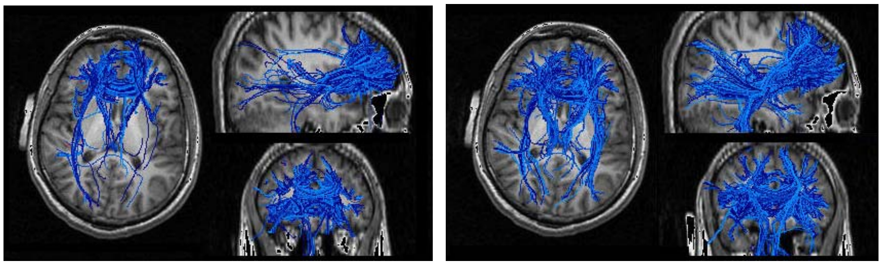

**Figure 3.** left: WM tractography before Bo correction; right: WM tractography after Bo correction

**References**

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