Automated Correction of EPI Geometric Distortions Applied to Diffusion Tensor Imaging

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Introduction

Single shot diffusion weighted EPI (SS DW EPI) is commonly used for diffusion tensor imaging (DTI). SS EPI is very robust against motion artefacts and allows to perform DTI within reasonable measurement times. EPI, however, is prone to geometric distortions, which depend on the local magnetic field. Susceptibility-induced distortions scale with the main magnetic field strength, making it difficult to interpret the DTI results at fields of 3T and above. Parallel imaging offers a limited remedy there by reducing distortions in proportion to the acceleration factor. Several distortion correction techniques have been proposed; nevertheless none is used routinely in the majority of DTI examinations, probably because of the limited stability of those techniques and the need for operator input. At this juncture a recently introduced distortion correction method, based on the point spread function (PSF) mapping[(1)], offers a number of advantages: it is robust, stable and operator independent[(2)]. At our institution the PSF-based correction is used routinely in all fMRI studies for a period of several years without a single failure reported. The purpose of this study was to adapt the PSF mapping distortion correction package to the DTI protocol and to evaluate the effect of the corrections on fibre tracking results.

Methods

Measurements were performed on a Magnetom Trio 3T scanner (Siemens Medical Solutions, Germany). A standard double refocused spin echo DW EPI sequence was modified to allow for arbitrary number of diffusion encoding directions (ED) and interleaved inversion recovery preparation for the CSF suppression. Imaging parameters were: in-plane resolution 2×2mm^2, 53 gapless slices, thickness 2.5mm, TR/TE 104/9300ms, matrix 128×104, phase encoding direction A-P, b-factors 0 and 1000mm^2/s, 61 ED, 7 non-weighted scans were distributed evenly throughout the 10min 30s measurement. Prior to the DTI a distortion-mapping scan was acquired with the same geometric and encoding parameters. The original PSF mapping sequence[(2)] was modified to enable optional spin echo or double refocused spin echo contrasts. The acquisition time for the reference scan was 3½min. PSF reconstruction resulted in the noiseless distortion map and the reference image for motion correction. Distortion correction of DTI images was applied online on the scanner. In order to avoid dynamic range problems no intensity correction was applied. Optionally, motion correction based on the non-DW scans was performed with the reference from the PSF acquisition; motion parameters were assumed to remain constant between the non-weighted scans. Offline DTI analysis was carried out using the in-house developed software running under Matlab (The Mathworks, USA).

Fibre Tracking (FTr) using the Fact algorithm[(3)] was performed on both uncorrected and distortion corrected data sets with the identical tracking parameters. FTr was started in all voxels with fractional anisotropy (FA) >0.2 and was stopped if FA dropped below 0.15 or the angle between the highest eigenvector directions in the adjacent voxels exceeded the stop angle. To evaluate the sensitivity of tracking results to geometric distortions stop angles of 35º, 45º and 53.1º were used.

Results

Distortion correction was found to perform well also in such critical regions as orbito-frontal areas and parietal lobes. Distortion corrected images were in a good agreement with high-resolution anatomical images. The comparison of regional apparent diffusion coefficient, *D*', and FA values, which had to be performed manually because of the altered geometry, discovered no significant differences between the corrected an uncorrected images. The colour-coded FA maps used to identify fibre tracts are shown in Fig.1. As seen, the position and the extent of the corticospinal tract differ significantly between the uncorrected and corrected images. As seen from Fig. 2 fibre tracking in uncorrected and corrected datasets showed qualitatively different results, e.g. the frontobasal cortex was only reached in distortion corrected data. For the corrected data the total number of fibres detected in corticospinal tract was increased by 9% and the volume of the tract (number of pixels visited) by 12%, respectively. Whole brain fibre tracking with different stop angles showed that in corrected data the total number of fibres increased by 2.5%, 1.6% and 0.8% for 35º, 45º and 53.1º, respectively. The mean length of fibres was increased by 3.6% with insignificant differences for different stop angles.

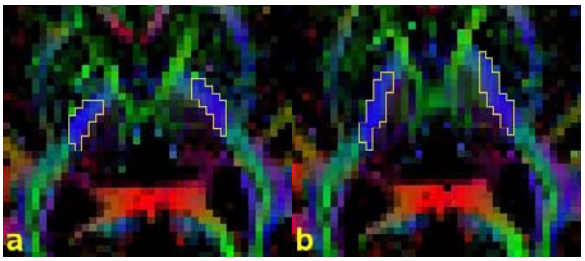

Fig. 1. *Transversal colour coded FA maps on the level of the internal capsule. (a) Uncorrected image with the ROI in the posterior limb of the internal capsule marking the corticospinal tract (yellow line); (b) distortion corrected image with the same tract marked. In corrected images the tract appears to be notably stretched.*

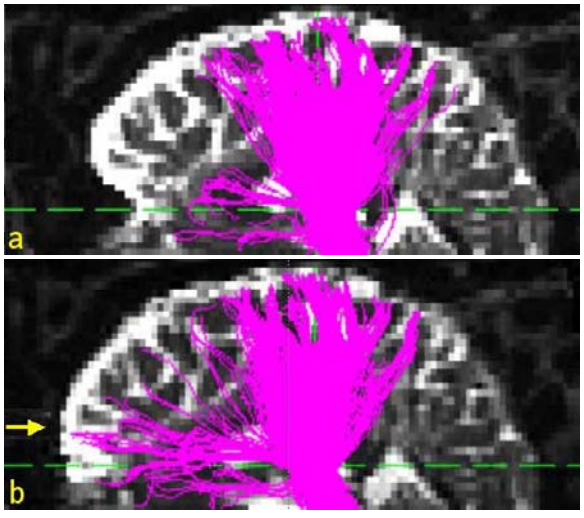

Fig. 2. *Sagittal T2w echo planar images through the midline with overlaid fibres. (a) Uncorrected image, (b) distortion corrected image. Detected fibre tracts are projected on the plane of the image and plotted in magenta. Note, that fibres of the frontopontine tract (arrow) are only detected in the distortion corrected data.*

Discussion

PSF-based distortion correction is a stable and robust technique, which does not require intensive computations and operator input. The correction routines are fully integrated into the scanner software, allowing for distortion correction to be performed on the fly during the image reconstruction. Measurement time for the reference scan can be further shortened if parallel imaging is used for the PSF acquisition[(2)]. Important to note, that distortion correction is applied on the pixel basis and does not affect diffusion tensor directionality, in contrast to e.g. brain normalisation. Motion correction, which is optionally included into the online image reconstruction, serves not only the purpose of realigning the actual DTI data to the distortion correction map, but also allows to detect and treat appropriately the cases of excessive subject motion, which are not always detectable from the DTI analysis alone.

Eddy currents (EC) induced by the strong diffusion encoding gradients are known to cause additional distortions in echo planar images. Ignoring these effects, if they are significant, while applying distortion correction may cause further mismatch between images acquired with different diffusion encodins. However, for the double refocused spin echo weighting scheme the EC induced distortions were found to lie in subvoxel range.

Bearing in mind that DTI analysis based on distortion corrected data provides more anatomically meaningful results without signs for any adverse effects it is perfectly acceptable to extend the routine DTI protocols by incorporating the PSF reference scan.

References

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