Combined eddy-current and EPI-PSF-based distortion corrections in quantification of DW EPI at UHF

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Purpose/Introduction.
Single-shot spin-echo echo-planar imaging (ssseEPI) allows for very fast signal acquisition. However, images are prone to severe geometric distortions due to local variations in the static magnetic field that can reach up to 3cm at ultra high field (UHF) such as 7T. Moreover, the distortions vary according to eddy currents (EC) induced by the diffusion weighting (DW) gradients. Geometric incongruence in DW images may impose significant errors in calculations of diffusion tensors and their derived metrics such as fractional anisotropy (FA), mean diffusivity (MD), major eigenvectors and fiber tracks. Although the point-spread function (PSF) mapping method can correct static geometric distortions very well, the varying DW direction-dependent distortions cannot be properly corrected. In this study, we demonstrate that these *distortions can be effectively corrected by a combination* of EC correction[1,2] and PSF mapping based distortion correction (DiCo) methods[4].

Subjects and Methods.
2 healthy volunteers were studied with a 7T whole-body MR scanner (Siemens AG, Healthcare Sector, Erlangen, Germany) equipped with gradients of up to 70mT/m per axis and a 32-channel phased-array RF head coil (Nova Medical, Wilmington, USA). PSF[3] and DWI scans were sequentially acquired with identical acquisition parameters. The PSF data were acquired with an acceleration factor of 4 in the PSF dimension corresponding to 48 scan. To reduce echo-time (TE) and specific absorption rate (SAR), DWI was performed with a Stejskal-Tanner ssseEPI sequence (TR/TE=8500/59 ms, echo-spacing=0.71 ms, pixels bandwidths 1532 Hz, isotropic voxel size (1.1mm)^3, matrix size 191x191, 85 transverse slices without gap to cover the whole brain, GRAPPA=3 with 81 ref. lines, partial Fourier 6/8 and 80º fat saturation flip angle, TA=15min), consisting of non-DW images with b-value=0 and 30 DW images at b-value=1000 s/mm^2 with non-collinear DW gradient directions.
Image processing consisted of (i) EC distortion correction and registration, (ii) static distortion correction by the PSF method, (iii) calculation of diffusion tensor eigenvectors, eigenvalues and FA-maps[5]. After EC distortion correction of DWIs and registration to the first volume with b-value=0, the static distortion correction was performed with an EPI-PSF kernel obtained from the measured PSF data as described in Ref. 4. For comparison, a reference volume without distortions was calculated from the PSF data and used to create the brain contour (Fig 1). Four FA-maps were computed from DWIs without correction (Fig. 2), with EC correction (Fig. 3), static DiCo (Fig. 4), and combined EC correction and static DiCo (Fig. 5), and then compared with the reference image (Fig.1) to demonstrate the accuracy and efficiency in recovery of anatomical features of the combined method. Steps (i) and (iii) were performed using DTI toolboxes of FSL[6].

Results.
Due to direction-dependent ECs, the varying distortions can lead to inconsistent FA maps. These effects are more pronounced in posterior grey matter and interior white matter (Fig. 2, see arrows and contour plot). As shown in Fig. 3, EC induced distortions can be reduced after EC correction and registration. However, strong geometric distortions, most noticeable as contour deviations, still remain (Fig. 2 and 3, see contour plot). With only static distortion correction, misregistration due to EC distortions can be seen in Fig. 4 (see arrow in transverse image). No residual distortions were apparent after both EC distortion and static distortion corrections (Fig. 5).

Discussion/Conclusion.
This study demonstrates that the proposed distortion correction[4] together with EC distortion correction[6] is effective in eliminating static and gradient direction-dependent distortions in DWIs at UHF, thus unveiling properly positioned fine anatomical structures in the brain FA maps. In order to further increase the accuracy of FA maps, an improved EC distortion correction, based on measured information, should be considered in future work.

References:
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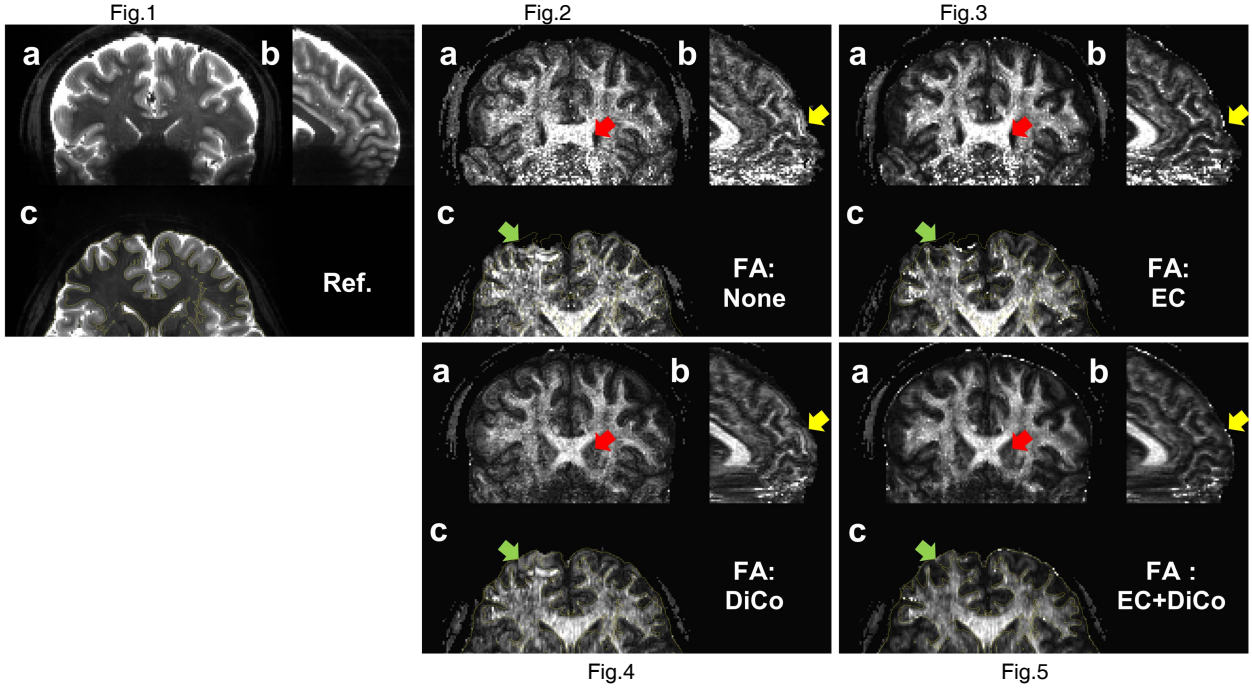

Fig.1. Distortion-free reference images obtained from the measured PSF data. These images serve to create a brain mask and contour. **Fig.2.** FA map created from DWIs without correction. Overlaid contour shows the extent of distortions. Additionally, the most problematic areas are marked with arrows. **Fig.3.** FA map created from EC corrected DWIs**.** The most problematic areas are emphasized with arrows. **Fig.4.** FA map created from DWIs with static DiCo. Misregistration effects due to EC distortions are highlighted by the arrow in the transverse plane. **Fig.5.** FA map created from DWIs with both EC correction and static DiCo.