EPI distortion correction for quantitative imaging of the mouse brain at ultrahigh magnetic field

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Introduction

Transgenic mice are important animal models to understand disease mechanisms. Functional imaging of the mouse brain, such as resting-state fMRI [1], provides noninvasive and translational way to track disease progression. Echo Planar Imaging (EPI) is an ultrafast acquisition technique widely used in fMRI, diffusion imaging and perfusion imaging. However, it suffers from geometric and intensity distortions caused by static magnetic field inhomogeneity. This issue is especially severe for the mouse brain at ultra-high field due to the large air-tissue interface relative to the small brain. It not only results in localization error, difficulty in spatial normalization, but also biases the quantitative measure of relaxivity, diffusion anisotropy or perfusion. Several correction methods have been proposed and demonstrated successfully in human studies [2, 3]. Whether these methods are effective in small animal imaging at ultrahigh field is not clear. In this study we compared different distortion correction methods and assess their effectiveness in mouse brain at 7T and their influence on T_1 measurement and perfusion quantification.

Methods

6 mice of FVB (n=3) and C57BL/6 (n=3) background, aged between 6 and 12 months were scanned on a 7T scanner (ClinScan, Bruker BioSpin, Germany). T2-weighted structural image was acquired by a fast-spin-echo (FSE) sequence with 0.1x0.1x0.3mm^3 voxel resolution and coil inhomogeneity normalization. T_1 mapping was acquired by inversion recovery spin-echo EPI with inversion time (TI) ranging from 10 to 8000ms, TE=20ms, and 0.28x0.28x1mm^3 resolution. Perfusion imaging was acquired by pseudo-continuous arterial spin labeling (pCASL) with post label delays (PLD) ranging from 0 to 400ms with spin-echo EPI of the same TE and resolution and TR=4000ms. Reversed phase encoding EPI was acquired at PLD=0ms for pCASL and each TI for T_1 mapping. The field map was measured by a dual gradient echo (GE) sequence with TE=1.8ms and 4.85ms, and the same geometry as the EPI.

The T2w FSE image was linearly registered to the GE magnitude image to create a geometrically and anatomically correct gold standard for the EPI. Three correction methods were applied on the EPI data: 1) field map-based using FSL FUGUE [4, 5], 2) nonlinear registration-based using FSL FNIRT [4], and 3) reverse-phase (RP)-based using in-house code on Matlab [2]. The goodness of correction was assessed by a similarity measure, Jaccard index, between the brain mask of the FSE image and that of the corrected image, which were created using 3D-PCNN algorithm [6] with manual editing. T1 maps calculated using corrected and uncorrected TI images, and quantitative perfusion calculated using corrected and uncorrected pCASL images were compared.

Results

At 7T, spin-echo EPI shows significant distortion at the cortex and regions near the ear canals (Fig.1). Both qualitative and quantitative comparisons of the Jaccard index indicate that RP correction outperforms the nonlinear registration and field map-based correction for the mouse brain EPI images (Fig.1 and 2). Application of RP to T1 and perfusion mapping demonstrates that the method is effective and does not create additional large artifacts (Fig. 3).

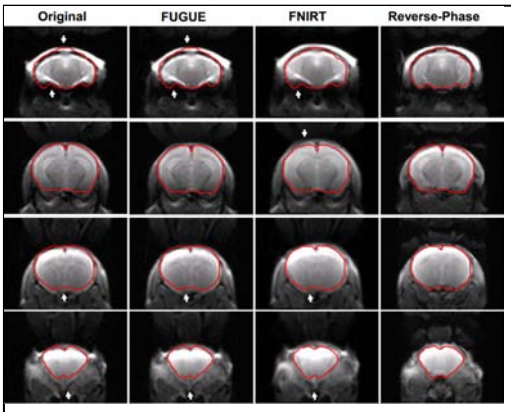

Figure 1: EPI images before and after distortion correction, with the structural image brain contour overlaid (in red). White arrows indicate mismatches.

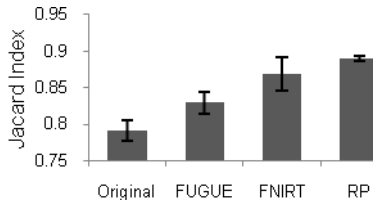

Figure 2: Jaccard index without distortion correction (original) and with different distortion correction methods.

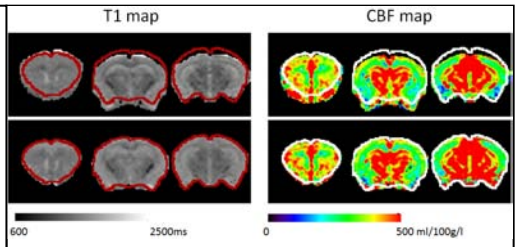

Figure 3: comparison of T1 map and CBF map between original data (top row) and distortion corrected data (bottom row). Brain contours are in red and white.

Discussion

The inferior performance of the field map-based method may be due to errors in the phase unwrapping. Undistortion by nonlinear registration does not require additional image acquisition, but it highly depends on the fine-tuning of the registration parameters, which is subjective and time-consuming. Besides, non-linear registration does not correct for intensity distortion.

Reverse-phase correction adds little acquisition time, and performs more effectively and robustly. One limitation of the technique is for multi-volume data, it is necessary to use one pair of forward-reverse phase images to calculate a warp field and apply the warp to other volumes. This process can lead to inconsistencies among the corrected images, especially in regions with large distortions. Future work will include correction of GE EPI of mouse brain, which will be helpful in preclinical studies using task-based fMRI, resting-state fMRI, or dynamic susceptibility contrast- MRI.

Conclusion

In this study we compared three EPI distortion correction methods on spin-echo EPI of the mouse brain: by field map, nonlinear image registration and reverse-phase-encoding. Our results suggest that reverse-phase-encoding is a fast and robust distortion correction method for the mouse brain at ultrahigh field.

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