Comparison of EPI geometric distortion correction using Field mapping and forward/reverse phase encoding directional EPI scans

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Introduction

Echo planar imaging (EPI) has been popularly employed due to its fast readout paradigm. However, the low bandwidth in the phase encoding (PE) direction leads to spatial distortions invoked by magnetic field inhomogeneities that can be described as a voxel shift in the PE direction. Measurement of spin phase difference from dual echo and calculation of voxel displacement (VD) along PE direction, so called field map (FM) was proposed by Jezzard and Balaban [1] and has been popularly still in use to correct EPI distortion. Since EPI images with forward (for.)/reverse (rev.) PE directions provide voxel shifts in opposite directions, several approaches have been proposed to calculate VD map using the two [2-4]. Recently, a fast and robust EPI unwarping method using 2 PE directional scans, in short, 2PE method here, was proposed which does not require *a priori* information [4]. Since both FM and 2PE methods generate VD maps, the direct voxel-wise comparison of VD maps between FM and 2PE method would provide the comprehensive insight of pros/cons of 2PE. In this study, we compare VD maps from FM and 2 PE methods, and demonstrate their performance and limitation.

Methods

FM method: Gradient refocusing echo (GRE) scan with dual echo acquisition were used to calculate a phase difference, and VD map [1]. Voxel size = isotropic 4 mm, TR = 300ms, TE difference = 2.54ms, 31 slices, and total running time = 1:40

2PE method: In this study, we used the method of Holland et al. [4] as 2PE. For./rev. PE direction EPI scans were used to calculate VD map, which is determined by iteratively minimizing a cost function that reflects the consistency of the unwarped images with for. and rev. PE directions and the smoothness of the deformation [4]. Voxel size = 2×2×4mm^3, TR/TE= 7.8s/92ms, 51 slices and running time = 21.4s

Factors to effect on performance: Since FM measures the phase difference directly, the spatial filtering is commonly (or necessarily) applied on VD map to reduce a noise. In this study, 4mm diameter of full width half maximum (FWHM) inversed background noise weighted Gaussian filtering was applied. While 2PE method does not require a smoothing, the cost function includes the regularization factor ($\lambda 2$ in ref. [4]) which puts a weight for the rapid change of VD. $\lambda 2$ is optimized based on a typical signal to noise of EPI [4].

Data analysis: FM is analyzed using the parts source code of Field map toolbox package (http://www.fil.ion.ucl.ac.uk/spm/toolbox/fieldmap/) and home-built code. 2PE method was analyzed using the scripts provided by the authors in ref. [4]. The for. PE directional EPI image of 2PE scans was unwarped using VD maps from both methods. Since 2PE method employs Jacobian (JC) modulation (mod.) which is not popularly used in FM, EPI image were unwarped with and without JC mod. in both methods for the comparison.

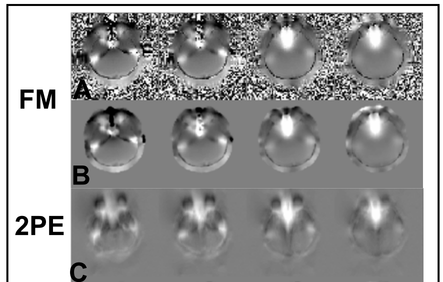

Fig 1. Demonstration of VD maps from FM (A & B) and 2PE (C). The original VD maps are shown in A and C, and the spatial filtering (4mm FWHM) is applied to A and shown in B.

Results & Discussion

Figure 1 demonstrates VD maps from FM and 2PE. It is observed that VD map of 2PE provides a native resolution of EPI within a short running time. Figure 2 compares VD maps of two methods. While voxel-wise comparison of VD in whole brain shows the high correlation between 2PE and FM (r=0.63), shown in Fig.2A.

Fig.2B shows that VD of 2PE is systemically lower than FM, leading to 'not sufficient' unwarping when using 2PE to be compared to FM and 'excessive bluring effect' in the area that the large gradient change of VD is observed, such as between scalp and brain or the front lobe. This result is observed consistently in Fig 3. F and G. The brain edge in unwarped image is shown sharper in FM than in 2PE. It might not be surprising because a cost function of 2PE restricts a smooth deformation, defined the sum of the squares of the gradients of VD, and it's weighted by $\lambda 2$ [4]. This could invoke a large smoothing effect in 2PE where VD varies rapidly, and lose a merit of a native resolution. However, a short scan time and real-time unwarping implementation with DTI [5] would be still promising aspect of 2PE.

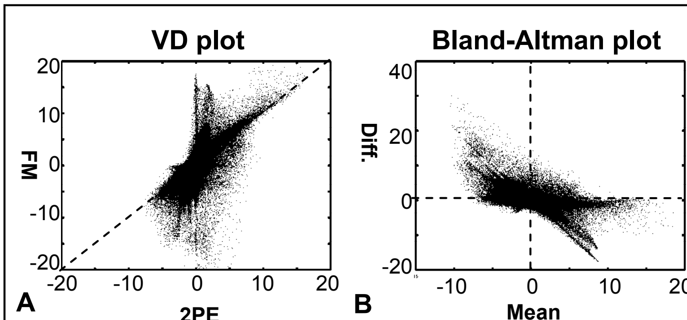

Fig 2. Corresponding Voxel-wise plot (A) and Bland-Altman plot between 2PE and FM (B). In Fig 2.B, x and y axes represent the mean of VDs of 2PE and FM, and the difference of VDs of them (2PE-FM)

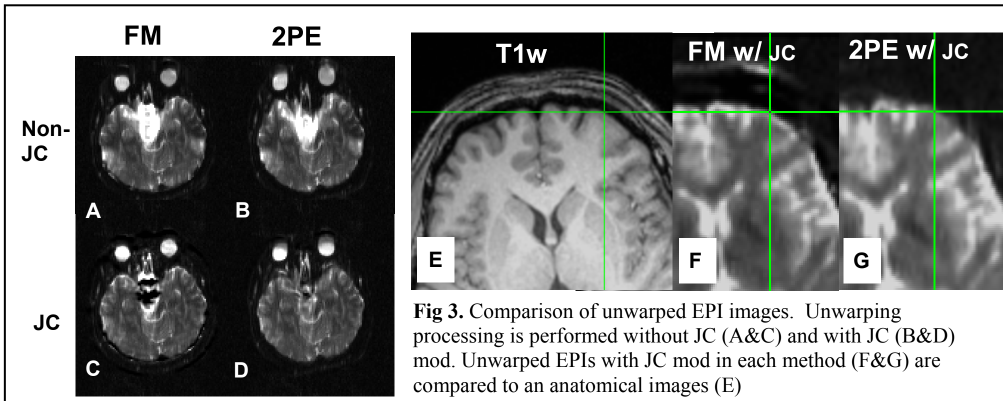

Fig 3. Comparison of unwarped EPI images. Unwarping processing is performed without JC (A&C) and with JC (B&D) mod. Unwarped EPIs with JC mod in each method (F&G) are compared to an anatomical images (E)

Acknowledgements

This work was supported by the Imaging Institute, Cleveland Clinic. Author gratefully acknowledges technical support by Siemens Medical Solutions, and Drs Holland and Dale for providing the codes.

Reference

1. Jezzard and Balaban, MRM, 1995., 2. Anderrson et al., Neuroimage, 2003., 3. Morgan et al., JMRI, 2004., 4. Holland et al., Neuroimage, 2010., 4. Beall et al. ISMRM, 2011.