Susceptibility Distortion Correction for Registration of Perfusion and Anatomical MRI

Ivar Thokle Hovden[1], Ingrid Digernes[1], and Kyrre Eeg Emblem[1]

[1]*Diagnostic Physics, Division of Radiology and Nuclear Medicine, Oslo University Hospital, Oslo, Norway*

Synopsis

Because of its rapid acquisition time Echo Planar Imaging (EPI) is much used in functional studies investigating temporal changes in the brain, such as diffusion and blood perfusion. A common problem with EPI are geometric and intensity distortions in the image caused by tissue-dependent susceptibility as well as other factors contributing to magnetic field inhomogeneities. EPI distortions can be a severe issue when registering EPI to a more detailed anatomical image such as FLAIR.

INTRODUCTION

Our Dynamic Susceptibility Contrast (DSC)-MRI perfusion analysis (1) on glioblastoma patients, is heavily dependent on accurate EPI (low res.) to T1/FLAIR (high res.) mappings, as well as the combination of Gradient Echo (GE) and Spin Echo (SE) images. The most visible EPI distortionsare geometric distortions when comparing a pair of EPI images with opposite phase encoding directions in their k-space acquisitions, where the image with negative phase encoding direction appear as “stretched” along its y-axis whereas the image with the positive phase encoding direction appear as compressed along its y-axis. Existing software such as FSL topup (2) make use of this property to construct off-resonance field maps. The maps can then be used to correct EPI images.

METHODS

In this work, we compare translation-only linear registration from FSL FEAT (3) of positive phase encoded GE and SE EPI to 3D FLAIR, with and without applied FSL topup distortion correction onthe EPI’s. For both GE and SE EPI acquisitions, opposite phase encoded EPI pairs were used tocorrect the respective EPI images. Since the main DSC-MRI is based on positive phase encoded EPI, the registration comparison was done only on positive phase encoded EPI’s.The comparisons were applied on data from n=20 patients, randomly selected from the appropriate baseline data of a larger data set on glioblastoma patients undergoing treatment.Thus, no treatment-related properties were part of the selected data. The registration reporting functionality of FSL FEAT was used to visualize the appropriateness of the registrations (Figure1). For each registration, the X, Y, and Z parameters of the translation matrix were extracted into a data table. The data table was then used to make a box-and-whisker chart, showing min, max, quantiles as well as the median of translational values depending on GE, SE, and X, Y, Z-parameters.

RESULTS and DISCUSSION

Figure 1 shows registration results of positive phase encoded GE and SE EPI (2D slice) volume to3D FLAIR for one of the patients. In each (a)-(d); top row: smoothed EPI image to higher resolution and red contours of high resolution FLAIR image. Bottom row: FLAIR image and red sections showing contours of EPI data. In this patient, at least for the untrained, no glioblastoma is clearly visible. However, the patient underwent consecutive cancer treatment from later stages. The most visible improvement from topup are correction of geometric distortions in air-filled regions and frontal regions such as the eye balls in SE EPI ((c) vs (d) upper row). Figure 2 shows clearly that translation along the Z axis has the most variation in this registration, regardless of whether EPI corrected or not, GE or SE acquisition. It should be considered that the topup corrected EPI’s had one less top and bottom slice, which could affect the registration procedures. It is from prior known that SE have more structural detail than GE and thus should have better conditions for a good registration to FLAIR ground truth if it was appropriately distortion corrected. Corrected GE EPI resulted in larger “whiskers“ in the plot for Z, which could point in this direction. Also, the Z translation variation for corrected GE and SE have more symmetric whiskers. If not interesting, this could be caused by the gradual smoothing of top and bottom Z slice to zero-slice boundary (empty top and bottom slice from topup).

CONCLUSION

EPI distortion correction has been applied on baseline non-treatment data of 10 glioblastoma patients and the corrected volumes have been registrated to FLAIR images. 3 degree of freedom registration allowing only translations is not sufficient to make a clear distinction of the outcome of FSL topup. However, the large Z translations from registration indicates that a relatively large interslice distance along Z in the DSC-MRI EPI introduce EPI voxel Z displacement of a magnitude significantly larger than EPI voxel displacements along Y (or X) that are primarily caused by magnetic susceptibility, when performing 2D slice volume EPI -> 3D FLAIR registrations.

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References

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Figures

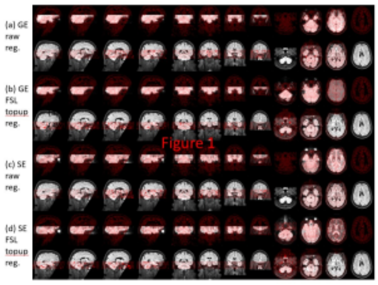

Figure 1

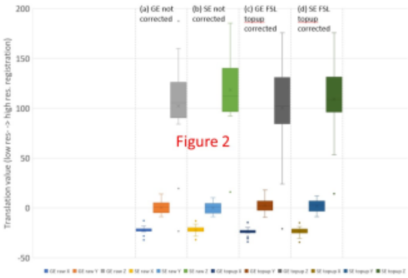

Figure 2