Distortion correction in spinal cord DTI: What's the best approach?

J. Cohen-Adad[1,2], H. Lundell[3,4], and S. Rossignol[2]

[1]INSERM, Univ Paris 6, Pitie Salpetriere Hospital, Paris, France, [2]GRSNC, Physiology department, Univ Montreal, Montreal, QC, Canada, [3]Danish Research Center for MR, Copenhagen University Hospital, Hvidovre, Denmark, [4]Inst. Neurosci & Pharmacol, Univ Copenhagen, Copenhagen N, Denmark

Introduction

Susceptibility artifacts induced by B_0-field inhomogeneities are common issue in echo planar imaging (EPI). They are particularly problematic in the spinal cord region, inducing large geometric and intensity distortions [1]. Although non-EPI techniques could be used instead [2], ultra fast imaging is sometimes a requirement in protocols such as in high angular resolution diffusion imaging of the spinal cord [3]. Two complementary strategies can be used to limit susceptibility artifacts: during acquisition and during image processing. The first one consists in decreasing the duration of k-space filling, which could be achieved using parallel imaging, multishot and reduced field of view techniques [1]. The second strategy consists in correcting images following acquisition. For this purpose, a variety of approaches exist including phase field map [4], reversed gradient [5], point spread function (PSF) [6] and co-registration methods [7]. These methods significantly differ from each other and no study has compared them for spinal cord imaging yet. This is the subject of the present study, with an application to diffusion tensor imaging (DTI).

Methods

Data acquisition. MRI acquisition was conducted on three healthy volunteers at 3T (Siemens) using phased-array spine and neck coils. EPI were acquired using the following parameters: sagittal orientation, TR/TE = 4000/86 ms, 1.8×1.8 mm^2 in-plane resolution, 1.8 mm slice thickness, iPAT = 2. For the reversed gradient method, an additional EPI was acquired by rotating the phase-encoding direction by 180°. For the co-registration method, a turbo spin echo (TSE) image was acquired using the same slice prescription. For the field-map method a phase image was acquired with a twice bigger matrix. For the PSF method we used the implementation as proposed in [6] and adapted to the spinal cord in [8].

Comparing distortion correction methods. The TSE image was considered as *gold standard* for evaluating the efficiency of either methods. A mask was drawn around the spinal cord, where mutual information was computed between the TSE and each corrected EPI. To assess the benefits of distortion correction in the context of DTI, diffusion-weighted EPI data were corrected using the deformation fields (geometric and intensity) generated by all methods. Then, diffusion tensors were estimated and fiber tractography was conducted using standard streamline algorithm [9].

Results

Visual inspection suggested a relatively large variability of efficiency between methods (Fig 1). The reversed-gradient and PSF methods showed relatively good results for both small and large distortion patterns, occurring at inter-vertebral disks and close to the lungs, respectively. The field-map and co-registration methods were sensitive to large distortions, as shown in the lower cervical cord. Results of mutual information confirmed this observation (Fig 2). Results of fiber tractography using the reversed-gradient method demonstrate the benefits of correcting distortions for studying anatomical pathways in the spinal cord white matter (Fig 3).

Discussion

Although very efficient for correcting distortions in the spinal cord, the PSF method is the less straightforward as it is not implemented by default in most clinical scanners yet. Widely used, the field map approach directly relies on phase information, however phase wraps often occur in regions close to the lungs, making this method difficult to apply in the spinal cord. The co-registration method is advantageous when no additional data were acquired – except an anatomical which is often the case in standard protocols. However this method is highly sensitive to the design of mask and parameters tuning. As an alternative, the reverse gradient method produced very accurate estimation of both geometric and intensity distortions, allowing to account for small and large distortions. Moreover this method is low sensitive to parameters tuning and only small amount of time is required to get the negative blips EPI.

References

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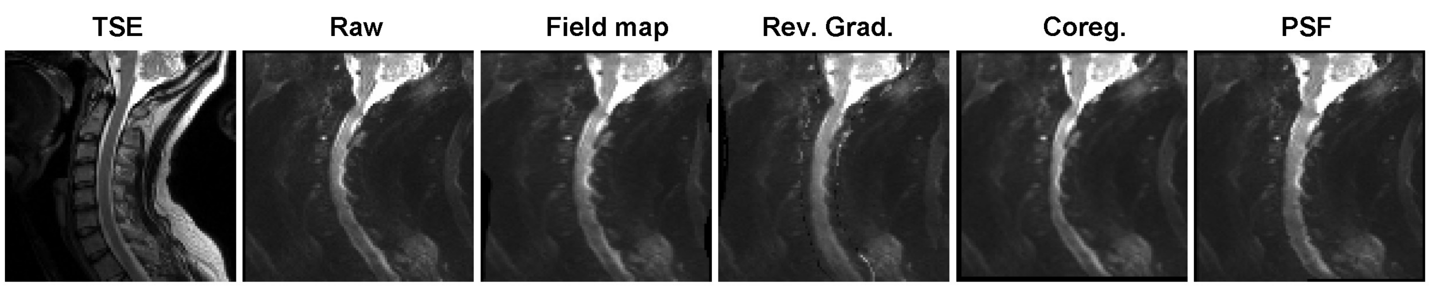

Fig 1. Example of TSE, raw and corrected EPI in one subject. It's interesting to note how each method behaves towards large distortions (lower cord) and small oscillatory patterns (inter-vertebral disks).

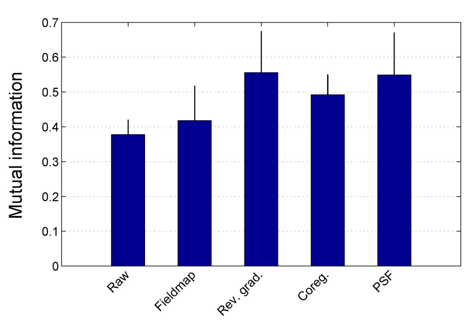

Fig 2. Mutual information between TSE and corrected EPI.

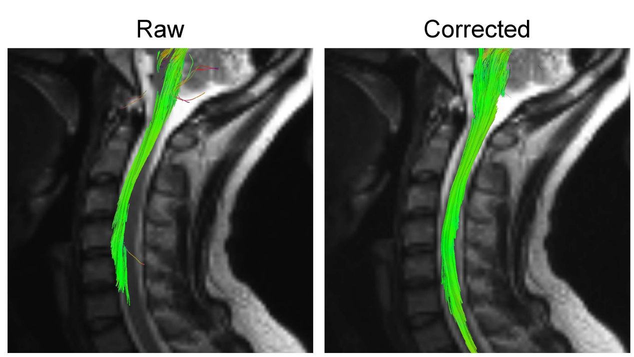

Fig 3. TSE image overlay of fiber tractography derived from raw and reverse gradient-corrected DW-EPI. Diffusion-weighted EPI were acquired with b-value = 500 s/mm^2 and 128 directions. Seed points for tractography were located in the brainstem region. Reconstructed fiber reached C5 and C7 for the raw and corrected data, respectively.