Point spread function mapping for distortion correction of spinal cord diffusion weighted MRI

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Introduction

Diffusion Weighted Magnetic Resonance Imaging (DWMRI) is a promising method to assess axonal integrity in the spinal cord *in vivo* [1]. However, the fast imaging sequences required for *in vivo* DWMRI are sensitive to B0-field inhomogeneities caused by susceptibility differences around vertebral structures and lungs. Those inhomogeneities cause voxel shift that corrupt the anatomical evaluation. Point Spread Function (PSF) mapping is a nobel method developed for correction of single shot EPI [2,3]. By the use of separate reference scan with a phase prewinder before a conventional EPI readout an additional distortion free dimension in k-space is introduced that can be Fourier transformed into the PSF for each voxel. A voxel displacement map is found as the peaks of the PSFs. We demonstrate that PSF mapping can be used as a correction technique for DWMRI of the human cervical spinal cord.

Method

Data acquisition: Diffusion weighted (dw) images were acquired using a Siemens Trio 3T system with a neck and spinal cord phased array coil on three healthy male subjects. Diffusion weighted EPI was used with TE: 86 ms, TR: 4000 ms, sagital image matrix: 96x96x20, GRAPPA acceleration factor 2, voxel size: 1.8x1.8 mm^2, slice thickness 1.8 mm, b=500 s/mm^2 . Total readout time was 33 ms. The dataset consisted of 19 non-dw and 129 dw (non-collinear directions) image volumes. PSF EPI sequence was kindly provided by Dr. Maxim Zaitsev at MRDAC (Freiburg, Germany) and aquired with the same EPI settings and matrix as the diffusion weighted dataset. The PSF reduced field of view factor was set to 4 [2]. *Post processing:* A spinal cord/CSF mask was manually drawn and applied to the raw shift maps from the PSF sequence. The mask border displacement was extrapolated to zero displacement at the ends of each phase encoding line. The mean of the unweighted images was coregistered to the distorted reference of the PSF sequence and the whole dw dataset was resliced to the same space to assure good alignment between the original data and the PSF reference scan. Images where unwarped using cubic spline interpolation. To check for tract consistency, deterministic diffusion tensor tractography was carried out using the Camino toolkit [5]. Two small seed regions where drawn covering the left and right lateral columns at C1. No waypoints where used to constrain tracts.

Results

The PSF peak displacement maps clearly resolved both a larger length scale displacement towards the lower end of the cervical cord (~10 voxels), as well as smaller displacements around intervertebral disks (<2 voxels, see figure 1.A.). The PSF peak displacement map applied to the distorted images could unwarp the shorter scale displacements (white arrows in figure 1.B.) as well as the larger deviation (blue arrows). Some disruptions were still present and could be attributed to outliers in the PSF close to the mask border (green arrow). The tractography gave two well defined fiber tracts in all data sets. Uncorrected images produced tracts terminating in the C3/C4 region whereas corrected datasets produced tracts ending from C5 to the matrix border, indicating a better consistency for corrected images.

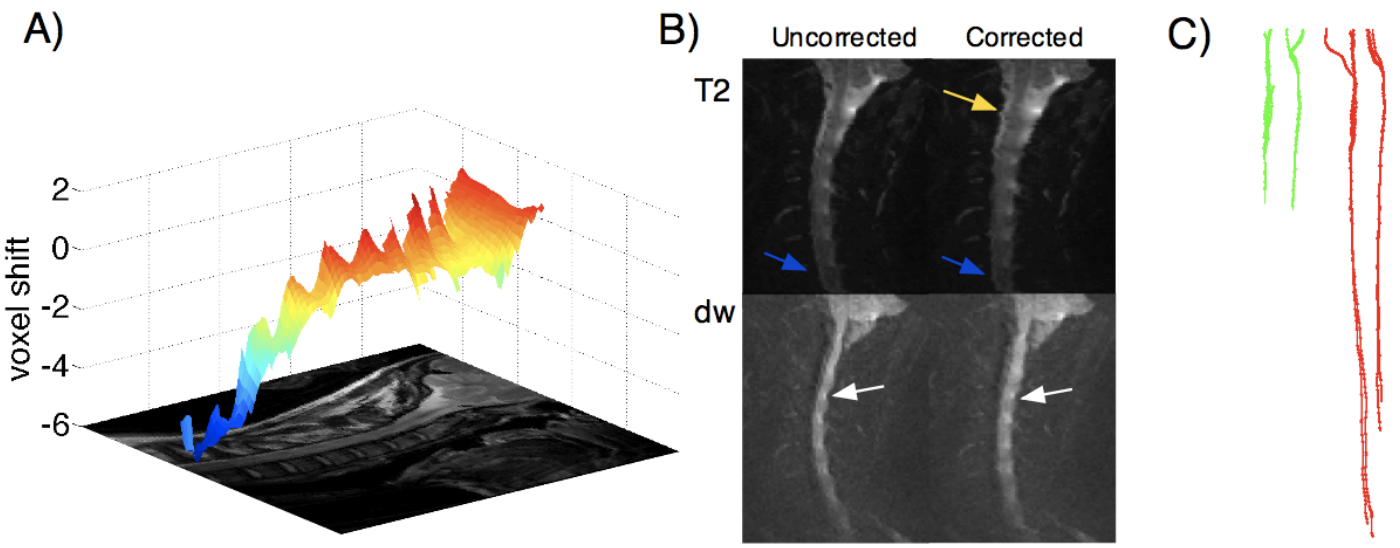

Figure 1: A) Surface plot showing voxel displacements extracted from the PSF peaks (only spinal cord shown) overlaid on corresponding distortion free sagital TSE image. B) Examples of T2 and diffusion weighted images before and after correction. C) Coronal projection of tracts in left- and righthand sided lateral white matter columns. The tracts from uncorrected images and corrected images in green and red respectively.

Discussion

DWMRI of the cervical spinal cord has been combined with PSF mapping for distortion correction of susceptibility related artifacts. It has been demonstrated that the corrected images are more consistent than the original data. However, some problems arise close to the borders of the spinal cord mask. Better masking methods and regularization of the voxel displacement map may help. The method performance is comparable to other methods [4], but the PSF contains more information that might be useful for further corrections, for instance the width of the PSF could be used for deconvolution of partial volume effects in thick axial slices. The proposed method can very well be combined with other sequence based interventions to reduce susceptibility artifacts, e.g. reduced matrix size, shortened readout etc.. Minimizing susceptibility artifacts is crucial for anatomical evaluation, inter subject comparison and tractography.

References: [1] Maier, SE., Neurotherapeutics 4:453-459, 2007 [2] Zaitsev, M., et al MRM 52:1156-66, 2004, [3] Zeng H, et al. MRM 48(1):137–146.19, 2002. [4] Cohen-Adad, J.,et al, 17th ISMRM 2009 [5] Cook, P. A., et al, 2006. ISMRM, Seattle, USA .