Multidirectional Distortion Correction for Diffusion Tensor Imaging

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Introduction

Magnetic resonance diffusion tensor imaging (DTI) is sensitive to the anisotropic diffusion of water exerted by its macromolecular environment, and has been shown useful in characterizing structures of ordered tissues such as the brain white matter and myocardium. The essence of DTI involves the acquisition of diffusion-weighted images sensitized in various gradient directions. Therefore, a typical diffusion tensor imaging needs to acquire one base image and 6 non-coplanar diffusion weighted images at the minimum. Because of the large datasets, DTI experiments often use fast imaging sequences to reduce the otherwise lengthy acquisition time. However, fast imaging, such as EPI, suffers from the image distortion because of the field inhomogeneity, imperfection of the gradient waveforms and Eddy currents during the long readout time. Although many methods have been studied and implemented to effectively correct the geometric distortion, the systematical investigations on diffusion directional dependent distortions in DTI acquisition have not been fully developed. As a result, the misregistration among a set of diffusion weighted images will affect the spatial accuracy of the diffusion tensor, ADC, FA, and directional orientation map computation since the diffusion tensor is computed by pixel-by-pixel calculation along different diffusion directions. In this study, a pulse sequence combining conventional phase encoding steps and EPI readout trains has been developed and implemented to collect images continuously at progressing echo times to acquire distortion-free field map for each diffusion direction. Corresponding field maps are subsequently employed to correct a full diffusion tensor dataset of different directions, respectively.

Methods

The sequence development and data acquisition were conducted on a 4T GE Signa Horizon LX system. The phantom images were acquired at TE = 110 ms and TR = 1000 ms with an isopropyl alcohol phantom, whose diffusivity is close to the diffusivity of the human brain, under an imperfect shim. The human data were collected with the same TE and TR under a well-shimmed field. The long TE was used to accommodate diffusion weighting gradients, which were the same at each diffusion direction for both phase-encoded EPI field maps and DTI sequences. For phase-encoded EPI field maps, each individual image was collected within a very short readout window (<1ms) leading to minimal distortion. The field variation map was computed from the image phase evolution at a series of TEs by linear regression, while the image phase was unwrapped pixel-by-pixel with a 1D unwrapping algorithm. The resultant distortion-free field maps were then used to correct specific distortions at different diffusion weighting directions for EPI-based DTI images.

Results

Figure 1 (a) shows diffusion weighted EPI images, corrected EPI images, and field variation maps of the same slice of the isopropyl phantom. Under the imperfect shim, the phase-encoded EPI field maps maintain the spatial fidelity at all diffusion weighting directions, while the diffusion weighted EPI images are distorted prominently along the phase-encoding direction. The corrected images, which are warped from the corresponding EPI images, are close to distortion free images. Figure 1 (b) shows the correction results of a human brain under the well-shimmed field. The frontal lobe which has strong distortion is largely warped back to its original spatial location. It is worth noting that this field map based correction is not compromised by the susceptibility-induced signal losses in the frontal lobe, as opposed to other intensity-based correction methods.

Discussions and Conclusions

The phase-encoded diffusion weighted EPI generates a series of distortion-free images at different TEs. One advantage of this technique is that the phase can be accurately unwrapped in space and time on a pixel-by-pixel basis with a 1D unwrapping algorithm, which is much more reliable compared to 2D or 3D phase unwrapping algorithms, especially in fMRI which has relatively low resolution and larger slice thickness in comparison to high resolution anatomical imaging. Another advantage is that the field maps can be calculated from the least square fitting between unwrapped phase data and TEs. These two critical steps dramatically increase the reliability and robustness of the distortion-free field map computation. Therefore, this reliable and efficient field map computation technique will minimize directional-specific geometric distortion of a full DTI dataset, thereby improving the spatial accuracy of ADC, FA and fiber computation.

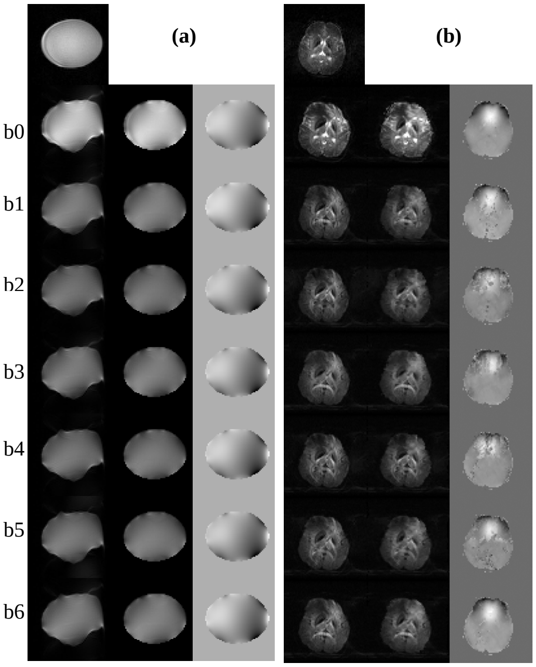

Figure 1: The geometric distortion correction of DTI images. The two images on the top are distortion free images. b0 is the base image of DTI. b1-b6 are images collected under diffusion weighting at different directions. In each image, the 1st column is EPI images before correction, the 2nd column after correction, and the 3rd column the field maps. **(a)** The EPI images are severely distorted under imperfect shimming. The distortion is corrected by the field maps computed from phase-encoded EPI images for each diffusion direction. **(b)** An axial slice of a healthy human subject. The front lobe which has strong distortion is largely warped back to its original spatial location. It is worth noting that this field map based correction is not compromised by the susceptibility-induced signal losses in the frontal lobe, as opposed to other intensity-based correction methods.

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References

1. Song, AW, et al., Measurement of T2* Value Using Phase Encoded EPI. Proc. SMR (1995), p669.
2. Ghiglia DC, et al., Two-dimensional Phase Unwrapping: Theory, Algorithms, and Software. New York: Wiley; 1998. xiv, 493 p.
3. Jezzard, P, et al., Correction for Geometric Distortion in Echo Planar Images from B0 Field Variations. MRM 1995.34:65-73.