Magnetization Transfer Prepared Diffusion Tensor Imaging

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Introduction

Diffusion tensor imaging (DTI) (1,2) can provide useful information on white matter anisotropy, and has seen increased utility in assessing brain pathology related to white matter connectivity. However, traditional DTI methods based on FA values do not offer specific selectivity regarding the origin of the connectivity changes. For example, a reduction of FA value can be the results of increased fluid content (e.g. CSF), or axonal losses, or demyelination process. As such, while DTI provides critical information on the outcome of certain brain pathologies such as multiple sclerosis, it does not yet pinpoint the causes of these pathologies. Magnetization transfer (3,4) is widely used to generate contrast based on macromolecule concentrations. For example, it can be used to detect changes in myelination in the brain, as myelin is physically a structure composed of macromolecules. As such, we propose to incorporate magnetization transfer preparations with DTI such that the anisotropy of myelin structure can be investigated. It is hoped that this new method can be used to better differentiate the commonly observed FA decrease in connectivity diseases (e.g. MS) specifically to either loss of myelin (e.g. demyelination) or loss of axonal integrity (e.g. thinning of nerve fibers), without fluid contaminations.

Methods

We present a method by which characteristics of diffusion anisotropy in particular structures in white matter such as myelin can be inferred from tensor changes induced by the addition of a magnetization transfer preparation module to the DTI pulse sequence. Magnetization transfer (MT) effect was obtained by pre-irradiating the volume for a duration of 50ms at 1kHz offset from the Larmor frequency. Two DTI datasets were acquired successively with and without MT preparation on a GE 3T Excite scanner (TE/TR/TI 66.8/4000/50+ ms). Three runs were acquired for each condition. Diffusion weighted images were acquired along 15 directions from a SENSE spin-echo EPI DTI sequence at b=800 s/m^2 [5], using an 8-channel array coil (with a SENSE reduction factor of 2). The 128x128 matrix covered 11 slices with a 5 mm slice thickness.

Diffusion tensor fitting was performed separately for the data volumes obtained in the two different conditions. To simplify the comparison between the two tensors, only the principal eigenvectors of the diffusion tensor were considered. This allows us to perform vector subtraction between the MT and non-MT tensors and obtain a vector which can be used to illustrate the main effect of the MT preparation to the diffusion tensors in the white matter. The difference vectors between the two DTI sets were analyzed on a voxel-by-voxel basis, scaled by the corresponding eigenvalues, with and without MT preparation. As such, this vector change in the main direction (and magnitude) of diffusion induced by the transfer of magnetization represents a coarse approximation of the diffusion tensor associated with macromolecules (e. g. myelin). The rotation angle and direction change of the principal eigenvector after MT preparation were then computed, and overlaid onto the original FA map.

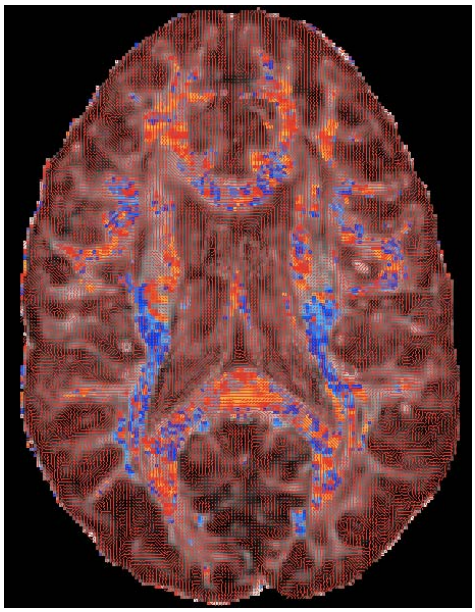

Figure 1 Rotational angle and direction changes as the results of MT preparation, overlaid on FA and principal eigenvector maps. Red indicates a clockwise rotation of 90°, while blue a counter-clockwise rotation of 90°.

Results and Discussion

The changes of rotational angles and directions as the results of MT preparation are color coded and shown in Fig. 1, with clockwise rotation of 90° shown as red and counter-clockwise rotation of 90° shown as blue. It can be seen that most regions with high anisotropy (large fiber bundles, FA > 0.5) exhibit significant directional changes in the difference vector under MT preparation, reflecting the influence of MT on the radial diffusivity of the fibers, orthogonal to the principal eigenvector. This observation is consistent with the radial anatomical structure of the myelin that tightly wraps the axons, reflecting a more dominant radial diffusion.

While the MT preparation leads to low signal-to-noise (SNR) ratio, as seen in our results, it does provide a new means to distinguish among different white matter structures based on their respective macromolecular concentrations. Furthermore, from this preliminary investigation, it appears that the SNR can be sufficient after multiple averages. In comparison to the recently proposed diffusion tensor spectroscopy (5), this method can potentially offer improved spatial selectivity without excessive scan time.

Conclusion

We present here a new method, based on a MT prepared DTI acquisition, that can identify changes in diffusion tensors arising from the macromolecules. It is anticipated that such a new contrast can potentially serve as a marker to detect pathological changes in specific white structures such as demyelination, further enhancing the diagnostic value of DTI in clinical applications.

References

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