Effects of Coregistration for the Reconstruction of High Angular Resolution Diffusion Imaging

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Introduction

High angular resolution diffusion imaging (HARDI) has been proposed for resolving heterogeneity of white matter fibers within an MR voxel [1]. These methods of HARDI, by using the multi-tensor approach or solving the diffusion orientation distribution function (dODF) of multiple fiber structures within a voxel, successfully elucidated well-known white matter tracts and tract intersections. Also, complementing tractography algorithms for multiple fiber tracking have been implemented to demonstrate the feasibility of describing complex fiber architecture. In most of HARDI approaches, such as diffusion spectrum imaging (DSI) and q-ball imaging (QBI) [2-3], it is necessary to acquire diffusion weighted images (DWIs) with lots of encoding magnetic field gradients along independent directions for further reconstruction of multiple fiber structures. Long acquisition time would lead to image distortion caused by head motion during the scan sessions. In the analysis of diffusion tensor imaging (DTI), the spatial registration of DWIs is a critical step to correct the errors caused by the effects of gradient coil eddy currents and head motion. However, it seems to be ignored in HARDI approaches. In this study, we present that initial coregistration step for the high b-value DWIs might be beneficial for the reconstruction of dODFs and subsequent fiber tractography with experimental data.

Materials and Methods

Imaging: In vivo human brain QBI were acquired in a GE Healthcare Signa 1.5T Excite scanner in Taipei Veterans General Hospital by spin echo EPI sequence with 162 diffusion-encoding directions (4-folds tessellated icosahedrons) at a b-value of 3000 s/mm^2, and one reference image volume containing minimum diffusion weighting (NULL image) was also acquired. Each QBI study consisted of 46 transverse sections was acquired parallel to the anterior commissure-posterior commissure line to cover the entire cerebrum with TR = 17000 ms, TE = 91.2 ms, FOV = 256 × 256 mm^2, matrix size = 128 × 128, yielding voxel size = 2 × 2 × 2.2 mm^3. All diffusion weighted images (DWIs) were duplicated as two datasets: DWIs_coreg and DWIs_raw, for further evaluations between coregistered and non-coregistered QBI. Only DWIs_coreg went through the following coregistration process.

Coregistration: DWIs_coreg were coregistered to the NULL image by the "Coregister function" of Statistical Parametric Mapping 2 (SPM2, Wellcome Department of Cognitive Neurology, London, UK). With this algorithm, the DWIs were aligned with the NULL image by the mutual information cost function.

Reconstruction: Both coregistered DWIs_coreg and DWIs_raw were then utilized to reveal the crossing-fibers within neural architecture by QBI approach. Instead of interpolating data points using radial basis function, the spherical harmonic q-ball reconstruction was applied to estimate fiber ODFs [4], which is analytical, fast, robust to noise and less DWI measurements required to obtain a good angular resolution. The dODFs were derived from the spherical harmonic QBI with harmonic series order =6 and were displayed by surface rendering of 320 triangles. Finally, fiber orientations were determined by estimating the local maximum of ODF in 3D space. Fiber tracking was performed using the multiple fiber assignment by continuous tracking (MFACT) algorithm with a length threshold of ODF 0.85 and a tract-turning angle threshold of 55 degrees [5].

Results

Fig. 1a-d showed the dODF patterns of non-coregistered QBI and coregistered QBI in two selected region of interests (ROIs) in the area including corpus callosum (CC) and cingulum (CG) (a-b), as well as centrum semiovale (CS) (c-d) respectively. Differences between the two results were highlighted by the yellow rectangles. In comparison with Fig. 1b, abnormal fiber profiles within dODF patterns adjacent to cingulum (CG) and CC were shown in Fig. 1a. Conversely, the highlighted dODF patterns in Fig. 1b were displayed with more regular presentation of fiber orientations not only in CG (through plane) but also in the upper part of CC (right-left). Fig. 2a-d presented the fiber trajectories extracted from the same two ROIs in Fig.1 using the non-coregistered QBI (a, c) and coregistered QBI (b, d). The fiber tract of cingulum was delineated completely in Fig. 2b as compared with tracts in Fig. 2a (indicate by the red arrows). Similarly, in comparison with Fig. 2c, Fig. 2d, as well, displayed that the tracts extracted from the CS could propagate to the CC, superior corona radiata (SCR), and cortical spinal tracts (CST), and showed better connections projected to lateral region of brain (indicate by the red arrows).

Discussions

According to the results, it is shown clearly that non-coregistered QBI were influenced more easily by the partial volume effect (PVE) of adjacent microstructures, especially within the region with tract of single orientation, such as CG and CC. In the regions with fiber crossing, the effect seems to be less, but the erroneous estimation of dODF and failed detection of fiber orientation remains obvious. Due to the errors of dODFs, the subsequent fiber tractography with non-coregistered QBI also presented worse reconstruction of fiber trajectories. Error estimated in the initial registration step might lead to subsequent reconstruction. Common registration algorithms still face particular challenges with DWIs because of the poor resolution, low signal-to-noise ratio, particularly in the acquisitions with high b-value. Though it is still difficult to validate the accuracy of estimation of dODF patterns after spatial coregistration of high b-value DWIs, better reconstruction of fiber tracts seems to provide the positive feedback to confirm the effect. Further, experiments with phantom would be necessary to provide a gold standard for validation, and development of appropriate coregistration algorithm for high b-value DWIs might be also important.

Acknowledgements

This study is supported in part by the National Science Council grant, Taiwan: NSC-96-2627-B-010-010 and NSC-97-2752-H-010-004-PAE.

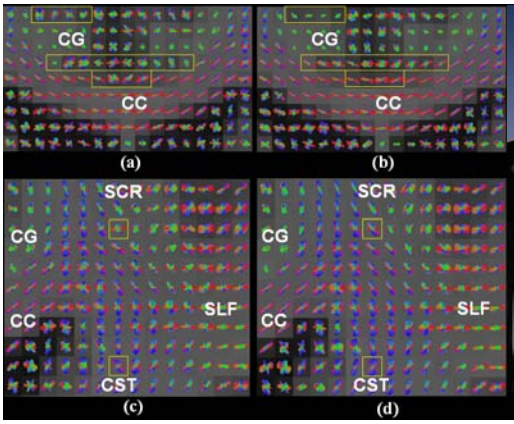

Fig.1 dODF patterns of non-coregistered QBI (a and c) and coregistered QBI (b and d). The differences are indicated by the yellow rectangles.

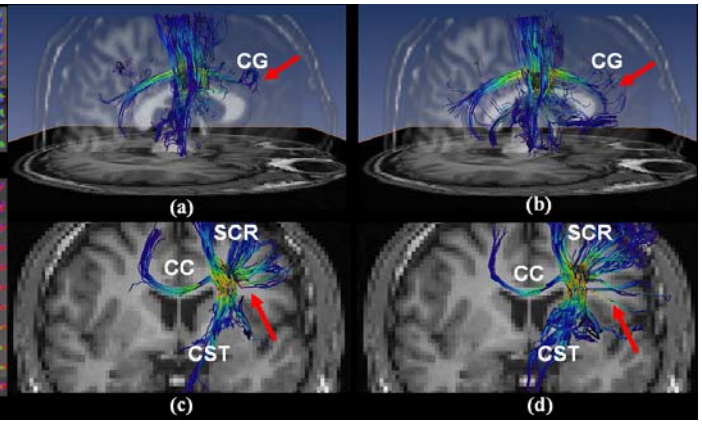

Fig.2 Reconstruction of fiber trajectories by MFACT with non-coregistered QBI (a and c) and coregistered QBI (b and d). The dissimilarities are highlighted by the red arrows.

References

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