Spatial Normalization of Diffusion Spectrum Imaging Using Large Deformation Diffeomorphic Metric Mapping

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Introduction: Problems of image registration has been well studied in the neuroimaging field. Popular packages addressing this issue include AIR, SPM etc. The general scenario of image registration is to 'normalize' the source image to the template image (or target image) in terms of minimizing certain cost functions. The success of image registration using these methods leads to great progress in group comparison of cortical structure and functions. Recent advance in diffusion MRI permits reconstruction of 3D fiber tractography in the brain, and opens up the opportunity to study the microstructure property of white matter fiber tracts. However, the registration of the diffusion MRI data, especially to align the fiber orientations among different brains, is not readily applicable using current available packages. Alexander *et al.* [1] proposed a reorientation method on diffusion tensor imaging (DTI) dataset. Their method consists of two steps: the DTI dataset is first registered using 3D registration methods, and then the diffusion tensor is reoriented according to the "preservation of principal direction" rule. Although this method is simple and effective, it cannot be generalized to other data sets acquired by high angular resolution sampling schemes such as q-ball imaging (QBI) or diffusion spectrum imaging (DSI). In this study, we proposed a registration method on DSI dataset by considering the fact that DSI dataset is inherently 6D: 3D image space and 3D q-space. Specifically, we generalized the conventional 3D registration to the 6D scenario by implementing Large Deformation Diffeomorphic Metric Mapping (LDDMM) algorithm.

Materials and methods: Two DSI datasets of 203 points in q-space with b-values up to 4500 s/mm^2 were acquired from two healthy subjects on a 3T MRI scanner (Siemens, Tim Trio). Imaging parameters were identical: TR/TE = 9600/130 ms, field of view (FOV) = 200*200 cm^2, matrix size = 80*80, resulting in a 2.5 mm in-plane resolution, slice number = 56, slice thickness = 2.5 mm without gap. Since DSI datasets were huge, in order to reduce the computation time and storage space, three strategies were employed. First, we made use the property of symmetry in q-space, so the original dataset was reduced to 102 points in q-space. Second, a hexa-linear interpolation method was adopted, for points outside the acquired FOV, linear extrapolation was applied. Third, a multigrid algorithm was used. The LDDMM algorithm followed Beg's paper [2] and the parameters are: time steps = 10, smoothing (alpha) = 0.01, smoothing (gamma) = 1.0, integration of velocity field to generate deformation maps used the Euler method.

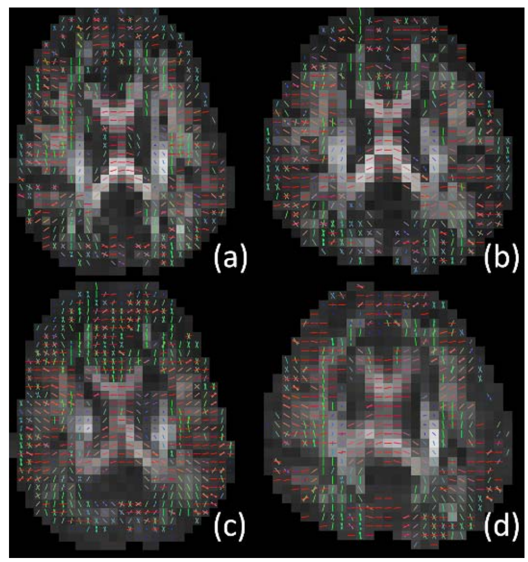

Fig. 1

Results: One selected axial slice is shown in Fig. 1, (a) and (b) are the original GFA images, (c) and (d) are the GFA images transformed from (b) and (a), respectively. Fiber orientation is color coded; red, green and blue represent respectively the left-right, anterior-posterior and superior-inferior directions. Evidently, the morphological details, including brain structures, GFA patterns, and the fiber orientations, are effectively registered. Fig. 2 shows coronal views of the orientation distribution function (ODF) in a region around the corpus callosum, where (a) and (b) are the original ODFs, (c) and (d) are respectively the transformations of (b) and (a). Fig. 2 demonstrates that shapes of the ODFs between corresponding image pairs – (a)(c) and (b)(d) – are well registered, suggesting that DSI dataset can be effectively transformed.

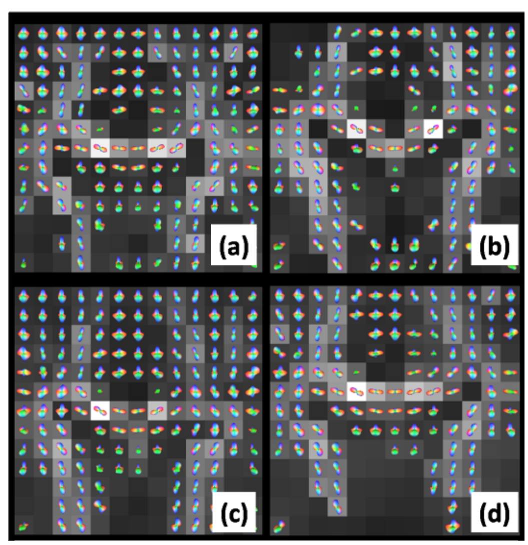

Fig. 2

Discussion: Previous approach addressing the issue of transformation of diffusion tensor images usually resorted to a two-step strategy: 3D registration on the image space first, and reorient the diffusion tensors base on certain algorithm. A natural extension of this approach to the normalization of DSI dataset would be to extract the local rotation matrix from the 3D deformation maps and directly apply the rotation matrix to the q-space samples. Such approach using rigid body rotation is insufficient because it neglects other important effects on fiber orientations such as shear. Different from the previous approach, the present method bypasses the problem of reorientation by performing the transformation with 6D LDDMM on the image space and the q-space simultaneously. The results demonstrate that the proposed method could effectively register DSI datasets and would be an important method in group studies.

References: [1] Alexander D.C. et al., 2001, IEEE Trans. Med. Imag. 20(11), 1131-1139 [2] Beg, M.F., Miller, M.I., Trouvé, A., Younes, L., 2005. Int. J. Comput. Vis. 61 (2), 139–157.