Normalization of Diffusion Tensor Images Using Parameters from Normalizing Scalar Anatomical Images

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Introduction

Multi-subject analysis of diffusion tensor images (DTI) is potentially helpful in increasing the detection sensitivity of mild white matter injury. Spatial normalization of DTI, which is necessary in multi-subject analysis, is however much more complicated than normalization of scalar images because all tensor indices including principal directions and fractional anisotropy should be preserved or properly adjusted [1,2]. Several algorithms were proposed to normalize DTI employing methods such as iterations [2]. Here we propose a DTI normalization approach based on the use of normalization transformation matrix obtained from normalization of scalar T1 images. In addition, we applied the tensor deflection tractography [3] to the images before and after DTI normalization to validate the effectiveness of our method.

Theories

The diffusion tensor is a second-rank tensor satisfying the rotational coordinate transformation relationship from coordinate *S* to *T*:

$$\tilde{D}_t = M\tilde{D}_s M^{-1} \quad (1)$$

where *M* is the rotation matrix. Spatial normalization of images from source (position vector *X*) to target image (position vector *Y*), on the other hand, can be expressed in matrix multiplication form using an affine matrix *A* (which is a function of position *X*) plus a translation operation as:

$$\vec{Y} = A(\vec{X}) \cdot \vec{X} + \vec{C} \quad (2)$$

In general, *A* can be factorized as $A = Q \cdot S \cdot U$ for rigid-body transformation (*Q*), scaling (*S*), and shearing (*U*), respectively. Note that since *U* does not satisfy Eq.(1) as a rotation matrix *M* does, spatial normalization of DTI cannot be performed using scalar image normalization procedures. It has been shown that image scaling has no effects on the diffusion tensor and could hence be discarded, while the effect of image shearing on the diffusion tensor is essentially similar to another rotation operation representing the angular relationship between the principal directions of the diffusion tensor before and after the shearing [2]. Thus the DTI spatial normalization procedure can be divided into two steps both satisfying Eq.(1): The rigid-body transformation *Q* which can be performed using existing coregistration tools, and the shearing *U* which can be done with existing deformation tools. Both are available in the widely available software package SPM99.

Materials and Methods

MR imaging experiments were performed on a 1.5T system (GE Signa CVi, Milwaukee, WI). A 13-direction EPI DTI protocol was adopted for acquisition with b-value of 1000 s/mm^2. Slice thickness was 5 mm with in-plane resolution of 0.86x0.86 mm^2. 30 slices were obtained covering the whole brain. 3D T1-weighted images (124 slices) were also acquired with voxel size of 0.98x0.98x1.1 mm^3. Fitting was performed to derive the diffusion tensor parameters.

Scalar image registration and normalization was performed using SPM99. The b = 0 EPI images in DTI were coregistered to T1 images to obtain an affine matrix from b0 to T1. Subsequently, this matrix was applied to the tensor components coregistration. The original T1 images were then normalized to a T1 template, from which the normalization parameters could be obtained to derive the transformation matrices using the deformation toolbox in SPM99. Finally, we used these matrices to normalize the diffusion tensor field and resliced the DTI with matrix size of 121x145x128 with 1.5 mm isotropic voxel size suitable for tractography using the tensor deflection (TEND) algorithm [3]. Thus the spatial normalization of the tensor field was accomplished using existing tools originally designed for scalar image normalization. To illustrate the importance of tensor field normalization, we also performed DTI normalization but treating the diffusion tensor parameters as scalars, with the result compared with that from our proposed method.

Results

Figure 1a shows the axial fractional anisotropy (FA) map (left) obtained from the original DTI and the corresponding TEND tractography in a coronal view (right) for one subject. Initial seeding areas for tractography were marked out in purple on the FA maps. Fig.1b shows the same result while normalizing DTI as a scalar image, and Fig.1c using our proposed method, respectively. Note that since images from one single subject were shown in Fig.1, the ideal normalization procedure should not change the tractography results. The white matter tracts associated with the corona radiata as tracked by TEND tractography (red) showed similar results in Figs.1a and 1c, while Fig.1b showed tract deviation to the region of corpus callosum. The results indicated that our proposed method was able to preserve the original information about fiber orientation and connectivity.

Discussion

The directional information, just like all the anisotropy indices of the diffusion tensor, should be taken into account in spatial transformation of DTI [1]. The normalization strategy should be carefully chosen in order to avoid, e.g., tractography errors as shown in this study. The method proposed in our work is unique in that it makes use of a widely available software, namely SPM99, for computationally economical operations compared with other more complicated approaches [2]. Results from our study suggested that our method may be a good alternative if multi-subject DTI analysis is desired.

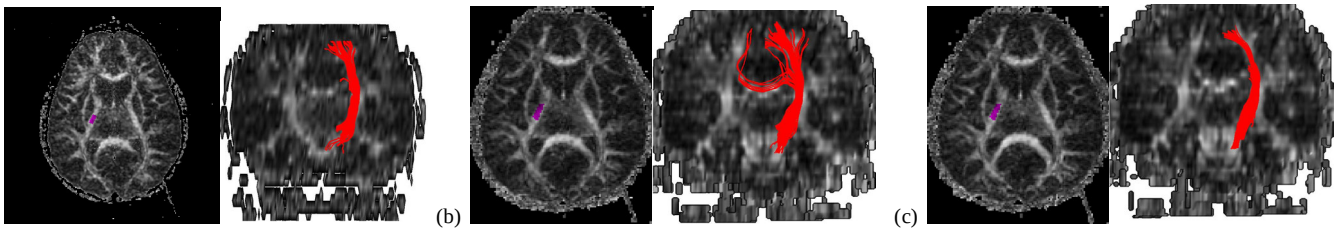

Figure 1. Three sets of images obtained from the same subject showing typical axial FA map (left) and the corresponding TEND tractographic result overlaid on a coronal FA map (right). (a) Images obtained from the original DTI. (b) Images obtained by normalizing DTI when normalizing DTI as a scalar image. (c) Images obtained using the proposed method. Initial seeding areas for tractography were marked out in purple on the axial FA maps. The white matter tracts associated with the corona radiata (shown in red) showed similar results in Figs.1a and 1c, whereas Fig.1b showed tract deviation to the region of corpus callosum.

References

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