Diffusion anisotropy measurement at the crossing fiber by using ga prior h fiber information

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[Introduction]

Magnetic Resonance Diffusion Tensor Imaging (DTI) has been widely used to measure diffusion anisotropy in white matter and those diffusion anisotropy measurement showed clinical usefulness in various fields. Typical diffusion anisotropy index, such as Fractional Anisotropy (FA) are accurate at single fiber but this index has its intrinsic limitation at crossing fiber. It has been shown that high angular resolution diffusion measurement or q-space measurement were able to provide accurate diffusion characteristic measurement at the voxel that includes multi-directional fibers. However these methods requires huge amount of data to decompose crossing fibers, and that makes scan time extremely long. Applying those methods to clinical study is virtually impossible due to such a long scan time. In this study, diffusion properties are estimated from sparse data set to reduce scan time. Fiber directions were estimated by DTI and novel image processing method. Then Multi-directional diffusion-weighted image data set were analyzed with the estimated fiber directions as “a prior” information to measure diffusion properties at the crossing fiber voxel.

[Materials and Methods]

Multi-directional diffusion-weighted image were analyzed by conventional tensor based method to get fiber direction spatial distribution at single fiber. To estimate fiber direction within crossing fiber voxel, we assumed that neuro fiber direction was smoothly curved and its spatial position were almost known for expert neuro radiologist from known anatomical information. Based on that assumption, radial basis function based tensor field interpolation technique (RBF) was used [1] to reconstruct the fiber direction at the crossing fiber voxel. RBF technique reconstructs tensor data set at position x from given data set at position x_i from the following formula.

$$s(\mathbf{x}) = p(\mathbf{x}) + \sum_{i=1}^{N} \lambda_i \phi(|\mathbf{x} - \mathbf{x}_i|)$$

where ϕ is basis function, λ is a weight factor, p(x) is polynomial function and s(x) is interpolated data. As given data set, at least two ROIs were placed in both side of the crossing fiber volume in the fiber bundle to be reconstructed. Two sets of ROIs were placed to reconstruct crossing two fibers. Once the fiber directions were determined by using RFB fiber reconstruction, these directions of fibers were used as a prior known neuro fiber bundle directions. Multiple directional MPG data were fitted to two tensor ellipsoid model.

$$S = S_0(f_1 \exp(-bD_1) + f_2 \exp(-bD_2))$$

where f_1 and f_2 are the volume fraction of each fiber bundle within the voxel. Two diffusion tensor D_1 and D_2 have eigen vectors that was reconstructed by RBF method. Down hill simplex method was used to estimated volume fraction and diffusion coefficient along with the estimated fiber directions. RBF method was performed on origin software (dTV-II) [2] developed by one of the authors.

[Numerical phantom study]

Synthetic crossing fiber models were generated at b value of 1000 mm^2/s and re-sampled to 10, 15, 20, 30 MPG directions. Motion Probing Gradient (MPG) direction were evenly distributed on a unit sphere [3]. Numerical Phantoms that have fibers crossing with 60 and 90 degrees were generated and analyzed. $\lambda1$=0.001, $\lambda2$=0.0001 and $\lambda3$=0.0001 mm_2/s (FA= 0.89, mean DC=0.41) were used for both fiber bundle.

[Volunteer study]

Multi-directional diffusion-weighted images were acquired on 1.5T MRI scanner (SIGNA EXCITE, GE Healthcare). Spin echo EPI type diffusion pulse sequence was used with the following imaging parameters (bvalue=1000 mm^2/s, TR=10s, 128x128, Thickness 3mm, FOV 24cm. 30 MPG direction was used for image acquisition. Image distortion by eddy current was corrected with image based distortion correction algorithm using mutual information analysis. Two given ROI was placed by neuro anatomy expert on Cortico-spinal tract (CST) and corpus callosum (CC) to generate “a prior” fiber directions information in the crossing fiber area.

[Results and Discussions]

Figure.1 shows the synthetic phantom experiment result. Figure.1(a) shows mean diffusion coefficient and figure.1(b) shows fractional anisotropy (FA) for each fiber bundle. Both accuracy and precision increased in meanDC and FA measurement when the number of MPG increased. The cross fiber separation process worked in stable when over 20 MPG direction was used. The Figure.2(a) shows the given ROIs for RBF based crossing fiber reconstruction. ROIs were placed on cortico-spinal tract (CST) and corpus callosum (CC). Figure.2(b) shows the reconstructed crossing fiber bundles. Figure.3 shows the measured diffusion properties at crossing voxel of CST and CC. This result suggests pseudo anisotropy decrease could be recovered by the proposed method in both CC and CST.

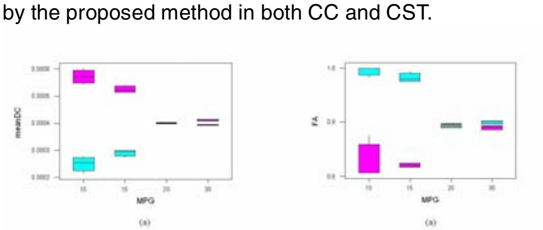
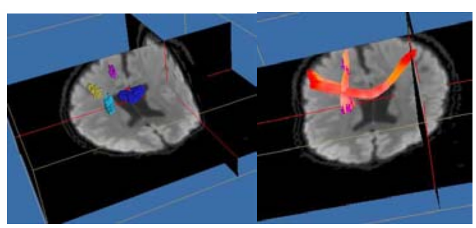


Figure.1 Synthetic phantom result. (a) meanDC measurement (b) FA measurement.



(a) (b)

Figure.2 Given ROI for RBF reconstruction and reconstructed fibers.

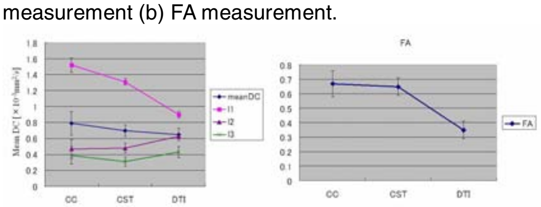


Figure3. Human volunteer result. (a) ADC measurement. (b) FA measurement

[Conclusion]

The proposed method effectively estimated diffusion characteristic at the crossing fiber bundle from sparse diffusion measurement data set.

[Reference]1. Masutani et al, ISMRM 2004, abs#1281, 2. http://www.ut-radiology.umin.jp/people/masutani/dTV.htm 3. MRM. 2003 Nov;50(5):955-65,