

Diffusion Tensor Spectroscopic Imaging of Rat Brains

Y. Bito¹, Y. Kawai², K. Hirata¹, T. Ebisu³, T. Shirai¹, S. Hirata¹, Y. Soutome¹, H. Ochi¹, M. Umeda², T. Higuchi⁴, and C. Tanaka⁴

¹Central Research Laboratory, Hitachi, Ltd., Kokubunji-shi, Tokyo, Japan, ²Medical Informatics, Meiji University of Integrative Medicine, Kyoto, Japan, ³Neurosurgery, Nantan General Hospital, Kyoto, Japan, ⁴Neurosurgery, Meiji University of Integrative Medicine, Kyoto, Japan

Introduction

Diffusion-weighted spectroscopy and diffusion-weighted spectroscopic imaging (DWSI) are expected to provide useful information about tissue microstructures and functions [1]. The diffusion tensor of metabolites is expected to provide more specific microstructures of such neurons; however, only a few studies using diffusion tensor spectroscopy (DTS) [2,3] and no studies using diffusion tensor spectroscopic imaging (DTSI) have been done. The reason that DTSI has not yet been used is mostly that an accurate DWSI technique that overcomes the issues of long measurement time, low signal-to-noise ratio, and large motion artifacts has not yet been developed. To overcome these issues, we developed diffusion-weighted echo-planar spectroscopic imaging with a pair of bipolar diffusion gradients (DW-EPSI with BPGs) and showed its effectiveness in reducing motion artifacts in normal rat brains [4].

In the present study, we developed DTSI using DW-EPSI with BPGs to obtain diffusion tensor (DT) images of N-acetylaspartate (NAA) in rat brains. To the best of our knowledge, the DT images of NAA were measured for the first time. The measured DT images of NAA and DT images of water, hereafter, DTI_{NAA} and DTI_{water}, were analyzed by using a tensor correlation coefficient (TCC), which was defined to estimate the similarity of two tensors, and analyzed by using the difference in fractional anisotropy (FA) of two tensors. The analysis result showed that DT of NAA is similar to DT of water, and that DT of NAA has higher FA than DT of water in most regions except near the base, corpus callosum (CC), and cortex of the brain. Further investigation, from the view of biophysical meaning, is needed; however, this result demonstrates DTSI may become a useful tool for investigating microstructures of nerves.

Methods

A 7-T MRI for a small animal study, equipped with a surface receive coil and actively shielded gradient coils, was used. Three normal male Sprague-Dawley rats, with weights of 248 to 264 g, were measured. The developed DTSI uses DW-EPSI with BPGs [4] with changed amplitude and direction of BPGs to obtain DT. The measurement parameters were TR/TE of 3000/136 ms, spectral bandwidth of 7.24 ppm (128 points), FOV in the x and y directions of 40 mm (16 pixels), slice thickness of 2.5 mm, and number of acquisitions of eight. The pair of BPGs, with δA of 12/12 ms and interval of 30 ms, was added. Diffusion-weighting measurements were done with b -values of 500, 1000, 2000, and 3000×10^6 s/m² in 13 directions, and non-diffusion-weighting measurements were done five times. DT of NAA was obtained by calculating the logarithm of signal intensities of NAA and multiplying it with the inverse matrix of b -tensors. To obtain DT of water, single-shot diffusion-weighted echo-planar imaging with a pair of BPGs was used. The parameters of BPGs were the same as those stated above except for b -values of 333, 667, 1333, and 2000×10^6 s/m². To compare DTI_{NAA} and DTI_{water}, they were resized to have the same spatial resolutions by interpolating DTI_{NAA} and by under-sampling DTI_{water}.

The obtained DTI_{NAA} and DTI_{water} were analyzed by calculating TCC and the difference of FA. The TCC r between DT of NAA A and DT of water Ω is defined as the following equation:

$$r(A, \Omega) = \frac{\sum_{i=1}^3 \sum_{j=1}^3 \lambda_i \omega_j (v_i \cdot w_j)^2}{\sqrt{\lambda_1^2 + \lambda_2^2 + \lambda_3^2} \sqrt{\omega_1^2 + \omega_2^2 + \omega_3^2}},$$

where λ_i and v_i are eigenvalues and eigenvectors of A , ω_j and w_j are eigenvalues and eigenvectors of Ω , and \cdot denotes the inner product of two vectors. According to the above definition, TCC takes -1 to 1, takes 0 to 1 when two tensors are positive definite, takes 1 when two tensors are the same, and takes 0 when two tensors are perpendicular for all eigenvectors (Fig. 1). The FA difference is calculated as "FA_{NAA} - FA_{water}", where each FA is calculated from the corresponding DT.

Results and Discussion

The obtained DTI_{NAA} show radial diffusivity in the cortex and right-left diffusivity at CC in the same manner as DTI_{water} (Fig. 2). A histogram of TCC shows high similarity between DT of NAA and DT of water, and TCC maps show high TCC in most regions, except near the base and CC (Fig. 3). The low TCC near the base may be caused by relatively lower SNR of NAA when a surface coil was settled on top of the head. Maps and a histogram of FA difference show that FA_{NAA} is higher than FA_{water} in most regions, except at CC (Fig. 4). Low TCC and low FA difference at CC may be caused by difference between diffusion coefficients of NAA and water. The mean diffusivity was about 0.14 $\mu\text{m}^2/\text{s}$ for NAA and 0.67 $\mu\text{m}^2/\text{s}$ for water. The difference in these values leads to higher restriction perpendicular to axons at CC for water than for NAA with the same diffusion time, resulting in higher FA of water and lower TCC. FA_{NAA} is higher at the cortex, possibly meaning the DTI_{NAA} is more specific to nervous microstructures.

Conclusion

DTSI using DW-EPSI with BPGs was developed, and DT images of NAA of rat brains were obtained. The obtained DT images of NAA showed similar aspect to DT images of water but showed different characteristics (such as FA) in detail, possibly reflecting specific microstructures of nerves.

References

- [1] Nicolay et al. NMR Biomed 2001;14:94. [2] Ellegood et al. MRM 2006;55:1. [3] Upadhyay et al. MRM 2007;58:1045. [4] Bito et al. ISMRM 2010:24.

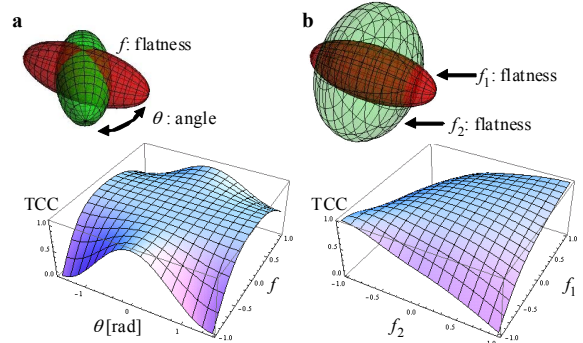


Fig. 1. Typical examples of TCC: (a) same ellipsoids crossing at a variable angle, and (b) ellipsoids with variable flatnesses.

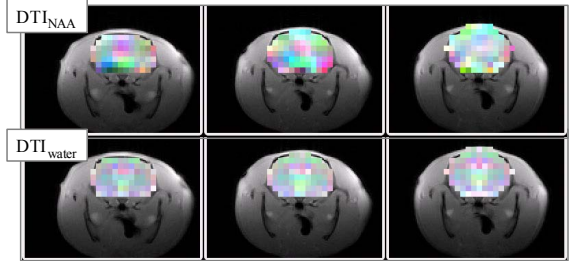


Fig. 2. Color Maps of DTI_{NAA} and DTI_{water} (D_{xx} : red; D_{yy} : green; D_{zz} : blue).

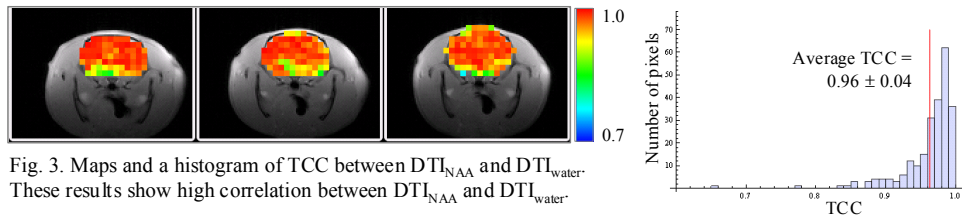


Fig. 3. Maps and a histogram of TCC between DTI_{NAA} and DTI_{water}. These results show high correlation between DTI_{NAA} and DTI_{water}.

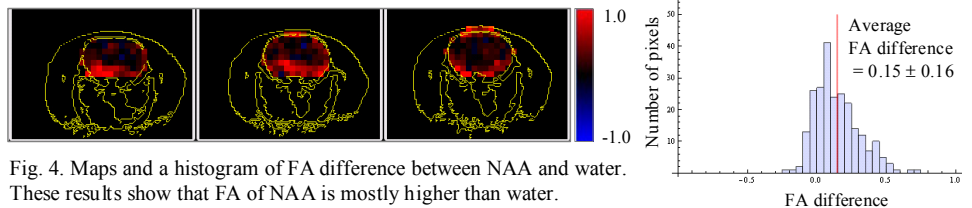


Fig. 4. Maps and a histogram of FA difference between NAA and water. These results show that FA of NAA is mostly higher than water.