Can Diffusion Tensor Imaging Detect the Degree of Neuronal Cell Membrane Damage in Stroke Patients? : A Patient Study

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INTRODUCTION

Reduction of the apparent diffusion coefficient (ADC) in acute brain infarction has been attributed to various causes; e.g. migration of water from extracellular space into intacellular space [1, 2], decreasing membrane permeability cased by collapse of transmembrane ion gradients [3], decreasing in energy-dependent cytoplasmic circulation or increasing in water viscosity [4, 5, 6], and cell swelling [6, 7]. The ADC and fractional anisotropy (FA) values represent the condition of water molecular diffusion within a voxel which would be highly influenced by integrity of cellular structure. Especially for infarcts involving the white matter, these coefficients may discriminate the structural differences between a normal tissue and infarction.

Our goal of this study is to consider a capability of diffusion tensor coefficients ($\lambda 1$, $\lambda 2$, and $\lambda 3$) as a state changing discriminator on hyper acute- and acute-brain infarction. As an initial consideration, we constructed a numerical diffusion model of a normal and ischemic brain white matter and examined correlations between the structures of white matter and the conditions of water molecule diffusion [8]. We confirmed in this study that one of the reasons for ADC reduction and slight increase of FA at the acute stage of brain infarction occurs by change in membrane permeability and increasing population of the axons that are affected.

In this paper, we attempted to further extend our hypothesis to real life brain infarctions involving the tightly packed white matter bundle. We performed retrospective measurements of diffusion tensor coefficients on patient with hyperacute/acute stage infarction involving posterior limb of internal capsule. From the results, we will consider the changes of diffusion tensor coefficients as the function and structure changing discriminants in hyperacute/acute brain infarction at different stage.

METHODS

Water Diffusivity Changing in Hyper Acute Brain Infraction

Figure 1 summarizes the current knowledge of water diffusivity in stroke [9-13] by using diffusion coefficients (λ, ADC and FA). We categorized the chronological stages of evolution of brain infarction into 4 stages (I to IV). The stage I was divided into two conditions (Ia and Ib) by difference in transverse diffusivity. In Ia, the energy failure and ion pump disorder occur, which would cause reduction in $\lambda 2$ and $\lambda 3$. The water diffusion along the axon will be also restricted, which will result in reduction of $\lambda 1$. At stage Ib, cell swelling by infarction occurs. It will cause the increase of $\lambda 2$ and $\lambda 3$. In stage II, by the larger increase of $\lambda 2$ and $\lambda 3$ than the reduction of $\lambda 1$, increase of ADC and decrease of FA will occur. In stage III, cell membrane will be collapsed which will cause the increase of all diffusion tensor coefficients. Stage IV represents the final phase of evolution which will end up in either gliosis or liquefied tissue.

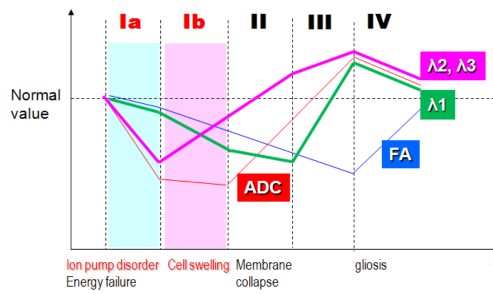

Fig1. A summary of water diffusivity in stroke

Patient Study

Subjects: Forty one adult with hyper acute and acute stroke (15-168 hr) were imaged. The subjects consisted of twenty nine men and twelve women ranging in age from 46 to 89 years, with a mean age of 70.7 years +/- 9.9 [SD]. The study was performed with the approval of the ethics committee at Kyoto Prefectural University of Medicine, and informed consent was obtained from the patient or next of kin.

Image Acquisition: All images were obtained using a 1.5 Tesla whole body scanner (Gyroscan Intera, Philips Medical Systems, Best, Netherlands). All transaxial slices were obtained using a plane parallel to AC-PC line. Single-shot echo-planar imaging (EPI) was used for DTI (repetition time, 6000 ms; excitation time, 88 ms) with a motion-probing gradient in 15 orientations, a b-value of 1000 sec/mm^2, and image averaging of 2 times. Field of view was 230mm. A parallel imaging technique (i.e. SENSE) was used to record 128 x 53 data points, which could be reconstructed to images equivalent to a 128 x 106 matrix. Data were zero-filled to generate images with a 128x128 resolution. A total of 42 slices with a thickness of 3 mm each was obtained without interslice gaps.

ROI Study: Region of interest (ROI) was selected by well trained neuroradiologist (K.Y.) on the lesion of the posterior limb of internal capsule by using MRI analytical software "PRIDE" (Gyroscan Intera, Philips Medical Systems, Best, Netherlands). The ROI was placed upon the most affected regions and upon the sensory or motor tracts, where fibers were expected to have tightly packed configuration. Mean value of ROI was used for analysis. As a comparison of the lesion, we selected bilateral position of same slice. Figure 2 shows the example of ROI selection.

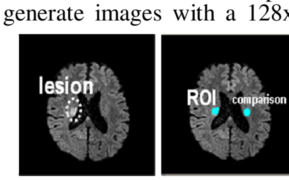

Fig2. An example of ROI selection

RESULTS AND DISCUSSION

Figure 3 shows the results of ROI study. The horizontal axis of the figure indicates the time progression from the onset (1-7 days). The vertical axis shows the frequency ratio of the patients in one time period. The digits on the bar show the numbers of the patients. Within 24 hours from the onset, Ia condition was the dominant form (18 patients). After this initial stage, the ratio of Ib condition had significantly increased. In our study, there was no stage II and more progressed patients in our patient population.

This figure may indicate the natural evolution of membrane condition during the hyperacute stage of infarction. The limitation in our study was that our model can be only applied for infarcts at tightly packed fiber bundles where most of the fibers are oriented in single direction, but would not be applicable to other regions with crossing fibers.

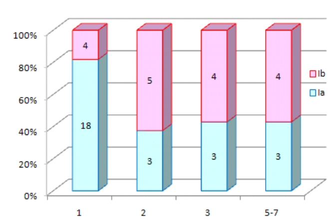

Fig3. Results of ROI study

CONCLUSION

We categorized the hyperacute/acute infarct in four stages. In this paper, we specifically focused on the first stage with sub-categories of Ia and Ib. We were able to observe evolution of the water molecular diffusion condition in such hyperacute/acute stage of infarct involving the posterior limb of internal capsule. The results have indicated that transverse diffusivity may be able to demonstrate the neuronal cellular integrity in hyperacute/acute stage infarction.

References

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