Effects of duration of the diffusion-encoding gradient (δ) and/or diffusion time interval (Δ) in diffusion weighted MRI: assessing ADC and Kurtosis in human brain

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[Introduction/Purpose] The signal intensity of DWI is varied with restricted and unrestricted diffusions in vivo. Strength of diffusion is controlled by a duration of the diffusion-encoding gradient (δ) and/or diffusion time interval (Δ) of MPG pulses (Fig. 1). The purpose of this study is to evaluate the effect of various δ or Δ in DWI.

[Materials/Methods] Five healthy volunteers and 5 patients with brain metastases from lung cancer were enrolled. This study was approved by our institutional review board. Informed consent was obtained from all subjects in advance of the MRI study. ***In healthy volunteer study***, DWI were obtained with a 3 T MR system (MAGNETOM Trio, A Tim system, Siemens, Erlangen, Germany) with repetition time = 5000 ms, echo time = 175 or 165 ms when δ (10 ~ 40 ms) or Δ (50 ~ 120 ms) was varied, respectively, matrix size = 140 x 140, field of view = 230 x 230 mm^2, bandwidth = 1700 Hx/Px, slice thickness = 5 mm, number of average = 3, and b factor = 0, 100, 500, 1000, 2000 s/mm^2. The ADC values and kurtosis (K) of white matter, gray matter, pyramidal tract, and CSF were estimated from the following equation [1] using linear least square estimation;

$$\ln\left(\frac{S_{(b)}}{S_{(0)}}\right) = b \times ADC + b^2 \times ADC^2 \times \frac{K}{6}$$

where $S_{(b)}$ and $S_{(0)}$ were signal intensity in DWI with various b factor and b = 0 s/mm^2, respectively.
In clinical study, DWIs with 50 and 120 ms of Δ were obtained before surgery, and the estimated ADC and K in the lesion were compered.

[Results] ***Healthy volunteer study***: When applying various Δ, in white matter, K increased with increase of Δ (Fig. 2). On the other hand, there were no significant change in gray matter, pyramidal tract, and CSF. There were also no significant changes in the ADC values and K in all regions against to various δ.
Clinical study: The difference between Δ= 50 and 120 ms in estimated K was greater than that in ADC (Fig. 3). In the other patients, similar tendencies were obtained. However, DWIs with b = 0 and 1000 s/mm^2 and ADC images were visually similar between Δ = 50 and 120 ms (Fig. 4).

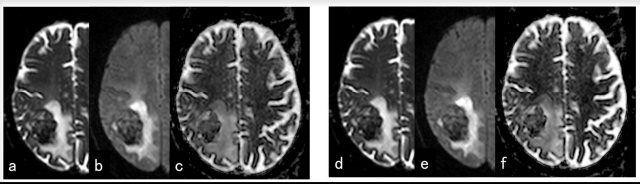

Fig. 4 DWI with b = 0 s/mm^2 (a, d), b = 1000 s/mm^2 (b, e), and ADC images (c, f) in a patient with metastatic brain tumor.
(a, b, c) and (d, e, f) were obtained with Δ = 50 and 120 ms, respectively.

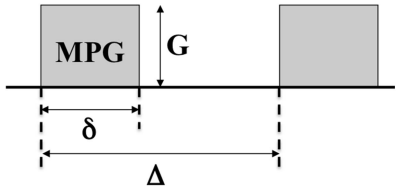

Fig. 1 Schematic model of a duration of the diffusion-encoding gradient (δ) and/or diffusion time interval (Δ) of MPG pulses.

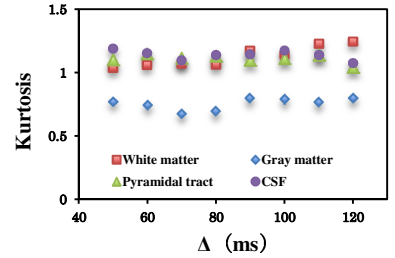

Fig. 2 The estimated kurtosis values with various Δ in healthy volunteer.

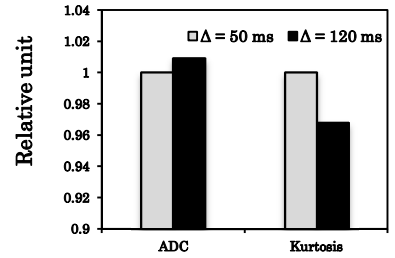

Fig. 3 Comparison of the estimated ADC and kurtosis in a patient shown in Fig. 4, in which the data was shown as relative value when the estimated value with Δ = 50 ms was taken as 1.

[Discussion] Our results suggested that the effects of Δ, using variable range in clinical MR system, was greater than that of δ. Using the ranges of δ and Δ applied in this study, in white matter, the diffusion might be restricted more than in gray matter, pyramidal tract, and CSF. Therefore, the K of white matter was affected by Δ greater than that of others'. On the other hand, in pyramidal tract or CSF, it was suggested that the effects of unrestricted diffusion was significant. Although there was no significant change in ADC, there was a tendency for an increase of the K in healthy volunteer. Additionally, in clinical study, the difference in K was greater than that in ADC comparing between Δ = 50 and 120 ms. These finding suggested that the optimization of Δ might lead usefulness in clinical diagnosis using kurtosis.

[Conclusion] The ADC and kurtosis might be affected by duration of the diffusion-encoding gradient and/or diffusion time interval MPG pulses, and it suggested that the optimized Δ might be useful to diagnose and to assess the treatment effect of brain disease using kurtosis.

[Reference] 1. Jens H. Jensena and Joseph A. Helperna. MRI Quantification of Non-Gaussian Water Diffusion by Kurtosis Analysis, NMR Biomed. 2010; 23(7): 698–710.