Utility of Bi- and Stretched-Exponential Diffusion-Weighted MR Imaging Models Using High b-Values in Assessment of Stroke

Shiteng Suo[1], Zengai Chen[1], and Jianrong Xu[1]
[1]*Department of Radiology, Ren Ji Hospital, School of Medicine, Shanghai Jiao Tong University, Shanghai, China, China*

Targeted audience:

Scientists and clinicians interested in stroke diffusion-weighted MRI.

Introduction:

Diffusion-weighted imaging (DWI) is useful for the assessment of acute/subacute ischemic stroke. [1] The ischemic lesions present hyperintensity on DWI and a reduced apparent diffusion coefficient (ADC) value. Recently, many reported diffusion studies in brain tissues found in high *b*-value regime, the diffusion pattern no longer follows the mono-exponential behavior. [2-5] Both bi- and stretched-exponential models have been suggested to depict the non-Gaussian diffusion features. The bi-exponential function is based on a "two-compartment" model including two separate diffusivity components called "fast" and "slow" diffusion coefficients; [6,7] the stretched-exponential model has been employed to describe the degree of intravoxel heterogeneity of the DWI signal. [8,9] The goal of the study was to investigate the value of bi- and stretched-exponential models using high *b*-values for clinical stoke assessment.

Materials and Methods:

In this IRB-proved study, 48 patients (age range 34 to 83 years; mean 60.4 years) diagnosed with acute/subacute ischemic stroke (6 h-2 weeks from symptom onset) in the middle cerebral artery territory were enrolled. The admission National Institutes of Health Stroke Scale (NIHSS) scores were 7.60±5.85 (range 2-25) and the discharge NIHSS scores were 7.29±6.35 (range 0-19) after thrombolytic therapy. All patients underwent MRI including multi-*b*-value DWI examination on a 3.0-T scanner (HDxt, GE Healthcare, Waukesha, WI). Axial DWI was performed by using a single shot SE-EPI sequence at 11 *b*-values (b = 0, 20, 50, 100, 150, 200, 500, 800, 1000, 1500, and 2000 s/mm^2) with three orthogonal gradient directions. Parameters for DWI included: TR/TE = 6000/88 ms, FOV = 26 × 26 cm^2, acquisition matrix = 192 × 192, 18 slices, NEX = 2, and parallel imaging technique using acceleration factor = 2. 3D time-of-flight MRA was also conducted to confirm the relevant vessels. Voxel-by-voxel curve-fitting method using the Levenberg-Marquardt algorithm was employed to fit the signal $S(b)$ as the bi- and stretched exponential function of the *b*-value: $S(b) = S_0 \bullet [f \bullet \exp(-b \bullet D_{fast}) + (1-f) \bullet \exp(-b \bullet D_{slow})]$; $S(b) = S_0 \bullet \exp(-b \bullet DDC)^{\alpha}$. In addition, the standard ADC was also calculated by using a conventional monoexponential fit with all *b*-values: $S(b) = S_0 \bullet \exp(-b \bullet \mathrm{ADC})$. Regions of interests (ROIs) were placed on the ischemic lesion and contralateral healthy region. Diffusion maps for each case, and the corresponding mean and standard deviation of each parameter within the ROIs were generated for statistical analysis.

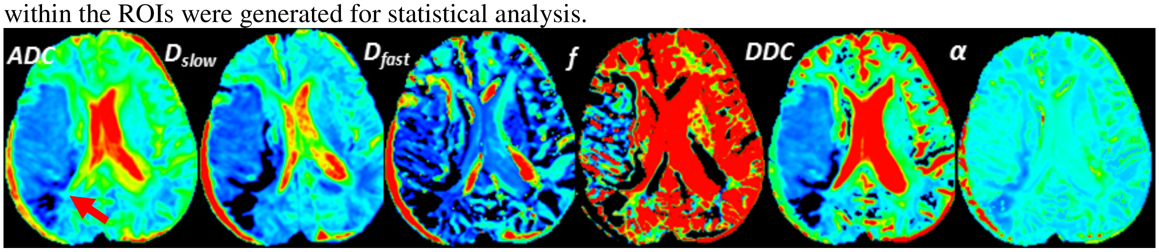

Fig. 1: One example of a 58-year-old male patient diagnosed with acute stroke, and the ischemic lesion was indicated by the red arrow on the ADC map.

Results and Discussion:

A total number of 48 ischemic lesions and corresponding contralateral healthy regions were evaluated. The diffusion parameters for all cases are summarized in Table 1. The Wilcoxon signed-rank test showed significant differences in *ADC*, D_{slow} and *DDC* (all $P <$ 0.001), in f ($P < 0.001$) and in α (P =0.046) between ischemic and contralateral regions. However, no significant difference was observed for D_{fast} ($P = 0.139$). These results indicated that water diffusion in acute/subacute stroke was more hindered in ischemic lesion than normal brain tissues and the slow diffusion compartment play a key role; as well, the lesion tended to have a more heterogeneous microstructure. Using ΔNIHSS ($\mathrm{NIHSS}_{discharge}$-$\mathrm{NIHSS}_{admission}$) as a clinical marker for the neural function restoration after thrombolytic therapy, *ADC*, D_{slow} and *DDC* all showed significantly inverse correlations with ΔNIHSS (Spearman correlation analysis, r = -0.446, P = 0.001; r = -0.398, P = 0.005; r = -0.450, P = 0.001), which suggested that a more restricted diffusion in ischemic lesion predicted a worse prognosis.

Conclusion:

The preliminary results suggest that the bi- and stretched -exponential model can help better describe the complex behavior of water diffusion in acute/subacute stroke, and may provide more detailed and useful metrics for lesion assessment and prognosis.

Table 1. The mean values and standard deviations derived for all diffusion parameters.

	ADC ($\times10^{-3}$ mm^2/s)	D_{slow} ($\times10^{-3}$ mm^2/s)	D_{fast} ($\times10^{-3}$ mm^2/s)	f	*DDC*($\times10^{-3}$ mm^2/s)	α
Ischemic lesion	0.49±0.14	0.37±0.10	3.60±1.03	0.18±0.07	0.46±0.18	0.81±0.05
Contralateral tissue	0.83±0.16	0.63±0.11	4.18±1.90	0.28±0.07	0.95±0.33	0.83±0.05
P value	< 0.001	< 0.001	0.139	< 0.001	< 0.001	0.046

References:

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