# Improvement of Diffusion Spectrum Imaging Using Bi-exponential Diffusion Weighting

Kwan-Jin Jung[1]

[1]*Psychology, Carnegie Mellon University, Pittsburgh, PA, United States*

**TARGET AUDIENCE:** Those to analyze the diffusion spectrum imaging (DSI) and diffusion imaging with multiple b shells

**PURPOSE:** The diffusion of brain tissue is known to follow bi-exponential decay.[1] A wide range of b value is employed in DSI and therefore the bi-exponential diffusion should be considered in the analysis of DSI.[2] A simple method of accounting for the bi-exponential diffusion in DSI has been developed to improve the DSI analysis.

**METHODS:** The exponential diffusion weighting (DW) can be described as exp[-bD(b)] with a diffusion coefficient, D(b), which is dependent on b. Since it is not trivial to measure D(b), another approach is to replace b with $b^*$ which is modeled to compensate for D(b) with a mono-exponential D. If D is determined from a narrow band of b among the DSI data, the effective $b^*$ for the whole range of b can be obtained by using a nonlinear curve fitting through a center point of the b band used for the D calculation and two offsets at the min and max b values as shown in Fig. 1. For DSI with 5 shells (257 DW directions) and max b = 5000, the diffusion tensor, D, was obtained from 39 DW directions within 1700 < b < 2300. Then, $b^*$ was modeled by fitting a cubic curve through 3 points at the center of the b band for the tensor calculation and at two offsets at b=0 and b maximum. The offsets were iteratively adjusted by comparing the image contrast between the acquired and simulated DW images that were calculated using D and $b^*$. The b value in the diffusion vector table for the diffusion analysis was replaced with $b^*$. The tracts through the centrum semiovale with crossing of multiple fiber tracts were compared between the mono- and bi-exponential models using the GQI method in DSI Studio which utilizes b or $b^*$ values for the fiber orientation distribution function (ODF).[3] The tracking parameters were: normalized QA threshold = 0.06, step size = 1mm with a x2 spatial upsampling, termination angle = 40°, and voxel-wise seeding. Two subjects were scanned with DSI and the maximum b = 5000 at 3 tesla with a voxel size of $(2.4)^3$ $mm^3$. The subject's motion and image drift were corrected using the simulated DW images.

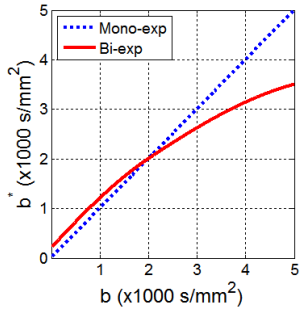


Fig. 1. Adjusted b value (b*) for bi-exponential diffusion. The offsets were 200 and -1500 at b=0 and 5000, respectively.

**RESULTS:** The offsets of b* to match the diffusion contrast (shown in Fig. 2) were 200 and -1500 at b = 0 and 5000 (Fig. 1). At a low b value the brain region with CSF could not be modeled by the bi-exponential diffusion due to partial voluming of brain tissue with CSF. At the high b value, the mono-exponential diffusion weighting resulted in excessive attenuation of the white matter, while the bi-exponential diffusion weighting restored the white matter signal to the acquired image as shown in Fig. 2 and in Table 1. The bi-exponential diffusion weighting had increased the default quality index of the tracking threshold from 0.061 to 0.063. It had significantly improved the corticospinal tracts as demonstrated in Fig. 3, where the relative ratio of the penetrating tract number (yellow tracts in Fig. 3) was increased from 10% to 21%. On another subject the penetration ratio was increased as well by 20%.

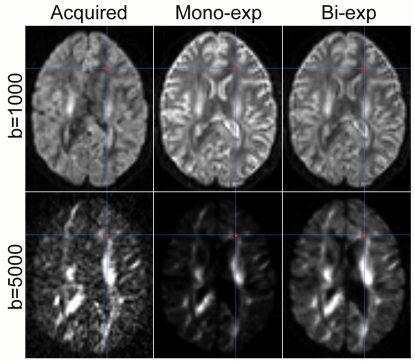


Fig. 2. Image contrast at two b values. The red cubes are for mage intensity measurement of Table 1.

| b | Acq | Mono | Bi |
|---|---|---|---|
| 1000 | 64 | 72 | 62 |
| 5000 | 20 | 9 | 22 |

Table 1. Image intensity in the white matter marked in Fig. 2.

**DISCUSSION:** The bi-exponential diffusion weighting resulted in reducing the sampling radius in the Q-space, which can be understood as reducing the signal amplitude in the Q-space for the mono-exponential diffusion. It is interesting to note that the DSI analysis using the Fourier transform of the Q-space applies the Hamming windowing to reduce artifacts in tracking. The bi-exponential DW might be the physical basis of the Hamming windowing in addition to the reduction of Gibbs artifacts. The proposed method can be applied to the diffusion imaging with multiple b shells when the multiple shells are combined for the enhancement of signal and ODF resolution.

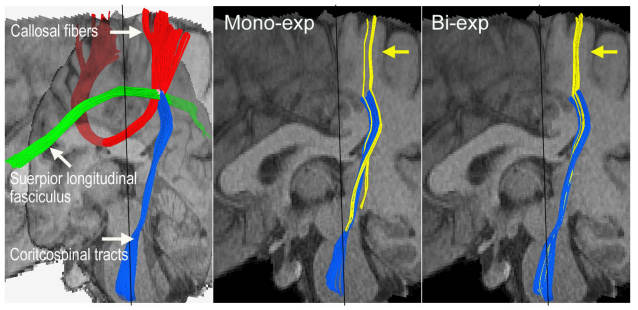


Fig. 3. Tracts through a region in the centrum semiovale. The corticospinal tracts are compared between the mono- and bi-exponential diffusion (marked by yellow arrows).

**CONCLUSION:** The diffusion of the brain tissue was bi-exponential in addition to partial voluming with CSF. A modeling as bi-exponential diffusion in DSI was achieved by adjusting the b values in the diffusion weighting vector table without measuring the bi-exponential diffusion coefficient or tensor. The simple bi-exponential modeling method was confirmed to improve the fiber tracts through fiber crossing regions.

**REFRENCES:** 1. Sehy JV, et al. Evidence that both fast and slow water ADC components arise from intracellular space. Magn Reson Med. 2002; 48: 765-770. 2. Wedeen VJ, et al. Diffusion spectrum magnetic resonance imaging (DSI) tractography of crossing fibers. NeuroImage. 2008; 41: 1267-1277. 3. Yeh F-C, et al. Generalized q-sampling imaging. IEEE Trans Med Imag. 2010; 29-9:1626-1635.