Rician noise corrected and multi-component analyzed diffusion signal decays for human brain tissue in-vivo at high b-values

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Introduction

The diffusion decay of water in brain tissue over an extended range of b-values shows a behavior consistent with a multi-exponential model $S(b)=\Sigma_i S_i \exp(-bD_i)$. Better understanding of this behavior requires the removal of Rician noise bias from the voxel signal decay for a magnitude image. A new Rician noise correction scheme combined with multi-component analysis based on the non-negative least squares (NNLS) algorithm [1] was developed to analyze the water diffusion signal decays in order to examine restricted diffusion in human brain tissue *in-vivo* at high b-values and short diffusion times.

Methods

The diffusion experiments were done on a Siemens Symphony 1.5 T imager using the Twice Refocused Spin Echo (TRSE) diffusion pulse sequence [2] with EPI acquisition (figure 1a). Diffusion decays with 96 b-values up to a maximum of 12,500 s/ mm^2 for the maximum gradient amplitude of 28.8 mT/m were measured. The diffusion time of this sequence was about 50 ms. The sequence was modified to work over a range of diffusion times (6 - 54 ms) with the highest possible b-values (figure 1b). The images were acquired with NEX=50 at TE=200 ms and TR=500 ms. These measurements were validated on a water phantom before they were used on human subjects. A single transverse slice (5 mm) was selected above the ventricles of the brain. The diffusion-sensitizing gradient was employed in the readout direction (RL). The images were processed using IDL 6.1. The ROI's were selected in the white matter with the pixels=20 and the ROI in the background required for noise correction are presented in figure 2.

Results and Discussion

The decay curves were analyzed using NNLS after Rician noise correction. At all diffusion times there was a diffusion coefficient at approximately $0.9\text{x}10^{-3}$ (79%) mm^2/s and another at about $0.07\text{x}10^{-3}$ (19.8%) mm^2/s. For some diffusion times a small contribution at about $1\text{x}10^{-2}$ mm^2/s was also detected. Figures 3 shows the decay curve fit to the measured results of a diffusion experiment on human brain for 96 b-values and the signal decays over the diffusion times from 19.8 to 53.8 ms using 16 b-values up to the maximum 12,500 s/ mm^2 averaged over 8 human subjects. The decays show a small variation in slope due to the time dependence of the slow diffusion coefficients (figure 4). The results from the experiments of the studied regions in human brain are comparable with analytical results of restricted diffusion behavior and water exchange in tissue using the Tanner-planar equation combined with Karger theory [4,5] for a human model .

Conclusion

Reliable diffusion information such as diffusion coefficients and their relative contribution requires the removal of Rician noise bias from the signal decay. The developed procedure has allowed us to observe a small diffusion time dependence of the slow diffusion coefficient which has not previously been reported.

Figure 1

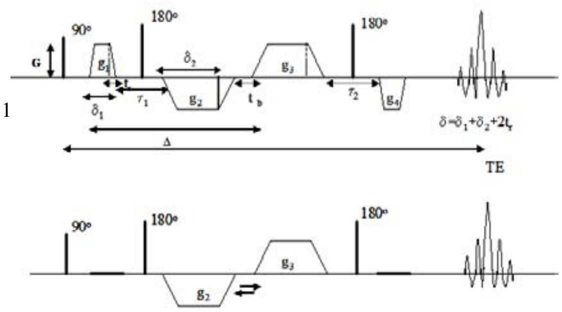

Figure 2

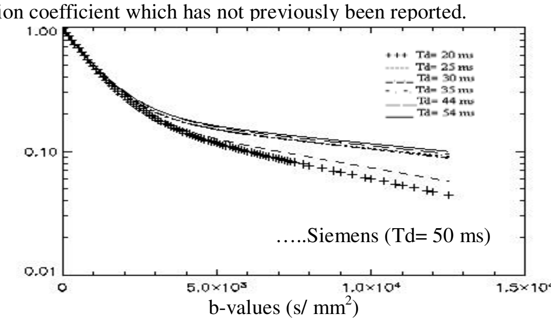

Figure 3. Diffusion decays averaged over 8 human brain vs. diffusion time by NNLS.

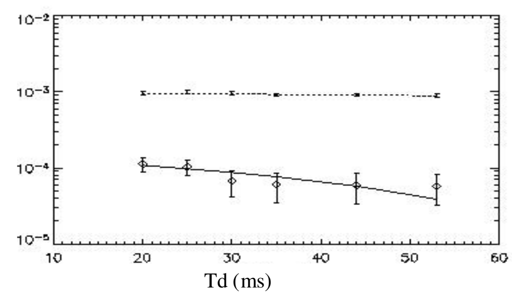

Figure 4. The fast and slow diffusion coefficients of the studied regions in human brain vs. diffusion time.

References: (1) Whittall K.P., MacKay A.L.; Quantitative interpretation of NMR relaxation data, J Magn. Reson., 84, (1989). (2) Heid O.; Eddy current nulled diffusion weighting, Proceedings ISMRM 8th, (2000). (3) Tanner J. E., Stejskal E.O.; Restricted Self-Diffusion of Protons in Colloidal Systems by the Pulsed-Gradient, Spin-Echo Method, J. Chem. Phys., 49, No.4 ,1968.(4) Karger J., Pfeifer H., Heink W.; Principles and applications of self diffusion measurements by nuclear magnetic resonance, Adv. Magn. Res., 12, 1- 89 (1988).