

Novel MRI contrast in nervous tissue based on the observation of anomalous diffusion

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INTRODUCTION

Diffusional motion of water molecules in tissue can be observed via magnetic resonance (MR) using different experimental schemes. It is possible to obtain different information from tissue if different parameters of the experiment are varied. It was shown recently that a disordered media model applied to the diffusion-attenuated MR signal obtained from excised tissue specimens is capable of characterizing the diffusion-time dependence of the MR signal accurately [1]. In order to investigate the contrast that can be achieved using this model, we have performed experiments on excised rat hippocampi. Our findings suggest that a previously unavailable contrast can be observed from data collected with different diffusion gradient strengths and diffusion times using the disordered media model.

BACKGROUND AND SIGNIFICANCE

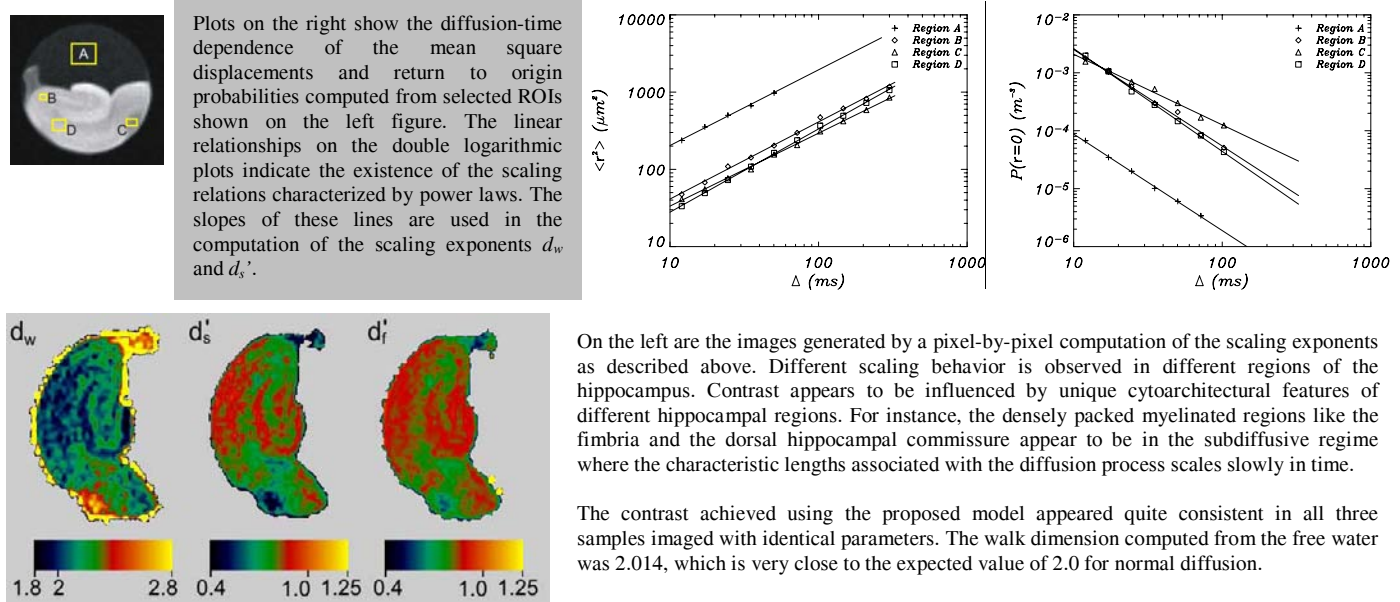
Many biological tissues including the neural tissue have a hierarchical structure that may exhibit significant self-similarity since cytoskeletal proteins, cellular organelles and complicated arrangement patterns of neurons and glia in tissue may present barriers to water molecular motion on different length scales. Sensitizing the MR signal to random incessant movements of the molecules make it possible to probe length scales that can not be resolved by conventional MR imaging methods. Moreover, varying the diffusion time of the MR acquisitions provide a means to observe water diffusion at different temporal or spatial scales. A nonlinear dependence of the mean-square-displacements (MSDs) on the diffusion time gives rise to the well-known phenomenon of anomalous diffusion, which occurs in systems exhibiting fractal behavior.

In fractal environments [2], Brownian motion of particles are restricted in all length scales giving rise to the scaling relations $\langle r^2 \rangle \propto t^{2/d_w}$, and $P(r=0) \propto t^{-d_s/2}$ where $\langle r^2 \rangle$ is the mean square displacement and $P(r=0)$ is the return to origin probabilities for the water molecules undergoing diffusion during time t . The scaling exponents d_w and d_s are called the fractal dimension of the random walk and the spectral (fracton) dimension respectively. The diffusion process is called "normal" if $d_w=2$, where the cases $d_w>2$ and $d_w<2$ correspond to sub- and super-diffusion regimes (anomalous diffusion) respectively. These two scaling exponents are related to the fractal dimension, d_f , through the relationship $d_f=d_w d_s/2$ [3]. In one-dimensional q-space measurements, it is the projection of the propagator onto the axis, whose direction is determined by the diffusion gradient, is measured. Therefore, one effectively has a one-dimensional space, which can be quantified by the effective indices d_s' and d_f' .

METHODS

To investigate the scaling behavior of the diffusional processes in neural tissue, we acquired a series of diffusion-weighted MR images from three excised rat hippocampi with varying diffusion gradient strengths and diffusion times. The imaging parameters were: $B_0=14.1T$, $TR=1000ms$, $TE=12.6ms$, resolution= $(78 \times 78 \times 500)\mu m^3$, matrix size= $(64 \times 64 \times 3)$, $\delta=2ms$. The diffusion gradient strength varied between 0 to 2935mT/m while the q-space acquisition was repeated 10 times with Δ values ranging from 12 to 300ms on a logarithmic scale.

RESULTS



CONCLUSION: The formalism developed to characterize diffusional processes in fractal environments was applied to q-space MRI data collected from excised neural tissue. The functional fits were very satisfactory indicating the appropriateness of the approach. This method can be used to understand the variability of data acquired with different values for diffusion time. The method also provides a novel contrast mechanism that may enhance the utility and specificity of diffusion-weighted MRI/S to better assess the structural changes that occur during development and various neuropathologies.

References: [1] Ozarslan et al., J Magn Reson, doi:10.1016/j.jmr.2006.08.009. [2] Mandelbrot B. *Fractal Geometry of Nature*, Freeman, 1982. [3] ben-Avraham D and Havlin S, *Diffusion and Reactions in Fractals and Disordered Systems*, Cambridge, 2000.