Temporal scaling characteristics of diffusion as a new MRI contrast: Findings in rat hippocampus

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Although computed tomography (CT) is the most commonly employed imaging modality in the diagnosis and management of traumatic brain injury (TBI), magnetic resonance imaging (MRI) offers increased sensitivity and specificity to changes associated with TBI. For example, gradient echo MRI scans reveal more conspicuous information regarding hemorrhagic changes in tissue while reduced apparent diffusion coefficients obtained through diffusion-weighted MRI (DWI) is indicative of traumatic (diffuse) axonal injury (TAI). Indeed, a characteristic feature of TAI is the impairment of axoplasmic transport, which is believed to stem from interruptions in cytoskeletal network. The cascade of changes affecting the brain tissue at different length scales could be monitored by employing quantitative methods devised to probe the relevant length scales. In fact, conventional DWI pulse sequences can be employed to probe hindrances to molecular diffusion by varying the time molecules are allowed to diffuse. Before assessing the TBI-induced changes, however, one needs an understanding of the contrast that could be obtained by variable-diffusion-time DWI acquisitions and its structural determinants. The hippocampus is a particularly important structure in this context as TBI-related cognitive impairment is usually attributed to loss of hippocampal cells.

In this study, we show that characteristics of the diffusion-time dependence of the DWI signal provide a new contrast that could be altered by changes occurring at different length scales. An anomalous diffusion model, inspired by the theory of Brownian motion in fractal and disordered media, is used to measure the temporal scaling (TS) characteristics of diffusion-related statistical parameters, such as moments of the displacement and zero-displacement probabilities, in excised rat hippocampus specimens. To alleviate any bias due to noise in magnitude-valued MRI data, a novel computational procedure was employed that provides accurate estimation of these quantities even when the signal falls below the noise floor. The power-law relationships implied by the theory successfully characterize the TS behavior in all regions of the rat hippocampus. Moreover, the observed contrast appears to provide unique information about the hippocampi's microscopic architecture. The interrelationship between the TS characteristics and diffusion anisotropy is investigated. The findings obtained from DWI acquisitions at multiple diffusion times indicate the robustness of the technique while employing the method on three different hippocampi revealed the reproducibility of estimates.

In conclusion, TS characteristics of the diffusion-weighted signal could be used as a new and useful marker of tissue microstructure. Unlike more conventional quantitative DWI techniques, which provide contrast based on certain physical parameters, our technique goes one step further by characterizing the temporal evolution of these parameters. As such, our approach has the potential for improving the specificity and possibly the sensitivity of the existing methods to a variety of processes and diseases affecting the brain including the above-mentioned changes associated with TBI.