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47

Intracellular volume revealed by diffusion-weighted MRI

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Purpose/Introduction: Neuronal volume changes occur throughout development and during different neurologic diseases. Further, apoptotic or oncotic cell death can be distinguished using cell morphology changes (shrinkage vs. swelling, respectively). Several cancers are recognized with MRI based on their unique cellular morphology. This abstract presents findings that it may be possible to estimate mean cell volumes noninvasively.

Subjects and Methods: Semi-permeable cell membranes exert significant restriction effects on water diffusion in nervous tissue. Acquiring diffusion MRI data in multiple diffusion gradient orientations and strengths can effectively sample a three-dimensional space (the q-space). The integral of the resultant MRI signal attenuations estimates the probability for the diffusing particles to return to their initial positions. At long diffusion times, water samples the entire cell volume and the return-to-origin probability can be shown to be the reciprocal of the compartment volume [1]. Here, we employed the simple harmonic oscillator-based reconstruction and estimation (SHORE) technique [2] to estimate apparent intracellular volume (AICV) in 3 human hippocampi autopsy specimens. Each data set contained 330 diffusion-weighted images (150x150x300 μm3) and sampled three-dimensional q-space up to a b-value of 7100 s/mm2.

Results: In the figure, the left panel demonstrates standard diffusion-tensor based parameter maps of T2-weighted signal intensity (S0), fractional anisotropy (FA), mean diffusivity (MD) and color fiber orientation. The right panel demonstrates a map of apparent intracellular volume (AICV). The highest AICV correlates well with hippocampal regions that contain densely-packed pyramidal and granule cell neurons with large dimensions [3]. The AICV map also demonstrates more subtle differences between CA1 and CA3 neuron dimensions. Conversely, regions of densely-packed narrow axons (e.g. the fornix) demonstrate significantly lower AICV.

Discussion/Conclusion: These data suggest q-space diffusion-weighted acquisitions might estimate mean intracellular volumes (and intracellular volume fraction). Even at high spatial resolutions, AICV represents a weighted-average of intracellular volume from different intravoxel cytoarchitectural components (soma vs. neuropil). With further validation this method may offer a unique MRI surrogate marker for in vivo cellular morphology changes, including volume changes in hippocampal pyramidal neurons during epilepsy, post-traumatic stress disorder or Alzheimer's disease [3]. The proposed method also may offer MRI surrogate markers for other organs and disease processes.