Quantification of water compartmentation in cell suspensions by diffusion-weighted and T2-weighted MRI

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Introduction: Water molecules in biological tissues partition among various compartments, and are characterized by variability in MR properties such as relaxation times and diffusion coefficients. Hence, the signal in an MR image of a biological tissue generally contains contributions from several water populations. Diffusion in biological tissues is affected by the characteristics of the compartment in which they reside in, the exchange between compartments, and the presence of barriers. The most fundamental differentiation is between the intracellular environment, where water molecules are bound to macromolecules and restricted by cell membrane, and the extracellular environment, where diffusion is an order of magnitude faster, but still may be hindered by impermeable or semi-permeable barriers. Our goal was to obtain a quantitative understanding of the diffusion and T2 relaxation properties of water, in a relatively simple biological system, and to study the origins of changes in MR properties observed in osmotically stressed cells.

Methods: Human breast cancer cells were incubated in isotonic or hypotonic osmotic buffers. Diffusion-weighted magnetic resonance (DWMR) and T2-weighted MR images were acquired during sedimentation over 12 hours. MRI diffusion data were analyzed with three models: The bi-exponential fit, The Karger model for exchange between two freely-diffusing populations, and the Price modified Karger model accounting for restricted diffusion in a spherical geometry.

Results: Non-mono-exponential water diffusion in these two cell suspensions was demonstrated over the entire density range studied. The T2 data indicated two T2 populations having fast exchange, with volume fractions clearly different from those of the DWMR populations, in both cell suspensions. Only the Price model was able to provide an accurate quantitative description for water diffusion characteristics in both cell systems, over a wide range of cell density, independent of experimental parameters. Cell radii and intracellular volume fractions derived from the Price model were in good agreement with results calculated from light microscope images.

When comparing the results from the two cell suspensions, hypotonic stress led to longer trans-membrane water exchange times, higher slow water apparent diffusion coefficient (ADC) component, longer T2 and lower membrane permeability. The relation between the ADC of the fast population, and the volume fraction of the slow population, for the hypotonic cells was consistent with the modeling of Wang for spherical geometry.

Conclusions: This study demonstrates the wide scope of biophysical and morphological information obtainable by DWMRI, including cell dimensions, shape, density, ADCs in the various compartments, and membrane permeability.

Visualization of Diffusion Tensor Imaging Data from Patients with Brain Tumors Using the Method of Tensor Patterns

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Purpose: Brain tumors may infiltrate white matter (WM) tracts. Since Diffusion Tensor Imaging (DTI) has the potential to depict the relation of WM and neuroepithelial tumors the analysis of DTI data is used to guide brain surgery. To allow an effective interpretation we propose the method of tensor patterns using edge contrast, orientation and color to visualize the multi-dimensional information of raw DTI data.

Subjects and Methods: We used the method of tensor patterns, an extension of the tensor splats method. Measurement: 1.5 T (Sonata, Siemens Medical Solutions). Diffusion weighted EPI sequence (TR/TE: 6700/72 ms; resolution: 1.8x1.8x2.0 mm3; EPI: 128; b-value 750 s/mm2, 6 directions) and additional 3D-FLAIR sequence (TR/TE: 6000/354 ms; resolution: 1.1x1.1x1.0 mm3; 160 slices) were applied to four patients (Astrocytoma WHO II, one gemistocytic tumor). Image data processing was performed using an Amira 3.13 research version with DTI analysis and visualization extensions.

Results: The proposed visualization can serve neurosurgeons in providing a framework for interactive analysis of 3D DTI data. Figures are obtained from exploration of a slice within the 3D dataset showing a tumor infiltrating deep WM. We depict anatomical T2 signal (A) using blue color channel whereas the tensor data uses remaining non-blue color space (B; coronal slice E). The image D (magnified section of B) reveals DTI changes exceeding the pathologic T2 signal (C). While coloring provides an overview distinguishing among highly linear and planar diffusion regions, detailed texture shows the dominant diffusion orientation.

Discussion: Tensor splats allow the visualization of complex DTI data information used here to interactively explore peritumoral regions in 3D. Compared to methods based on the extraction of principal directions, it avoids abrupt visual changes between linear and planar structures. This reflects data ambiguity caused by measurement noise and limited resolution. Combined with the ability to display minor changes in tensor information, tensor patterns seem appropriate for visualizing pathological WM changes.

References: