An Efficient Computational Approach to Characterize DSC-MRI Signals Arising from Heterogeneous Vascular Networks

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Introduction: A central assumption in all DSC-MRI studies is that a linear relationship, with a spatially uniform rate constant termed the vascular susceptibility calibration factor (k_p), exists between the CA concentration and the measured transverse relaxation rate change. Given the heterogeneous nature of blood vessels within tissue and the dependence of susceptibility field gradients on vascular geometry this assumption could significantly impact the reliability of DSC-MRI hemodynamic measurements. We propose the use of an efficient computational approach that combines the finite perturber method (FPM) [1] with the finite difference method (FDM) [2] in order to estimate the vascular susceptibility calibration factor for arbitrary vascular tree networks extracted from computer simulation and micro CT based angiograms.

Methods: An efficient computational approach that combines the FPM with the FDM, which we term the Finite Perturber Finite Difference Method (FPFDM), has been developed and used to estimate, the intravascular and extravascular magnetic field perturbations induced by magnetic susceptibility variation between arbitrary shaped mesoscopic scale compartments, and also the associated gradient echo (ΔR_2^*) and spin echo (ΔR_2) transverse relaxation rate enhancement. To initially assess the validity of the approach a simulated 3D vascular phantom consisting of randomly distributed cylinders was used to determine if FPFDM derived GE and SE relaxation rates possess the characteristic vessel size dependency reported in previous studies [1,3].

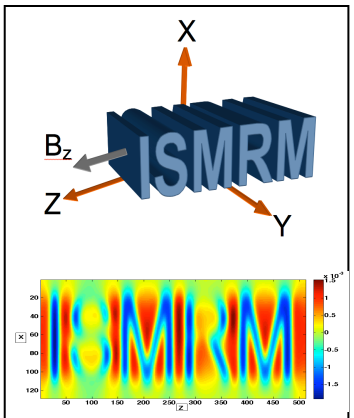

Figure 1: Example 3D structure in a constant magnetic field along Z-direction (top). A 2D slice through the corresponding field perturbation induced by the structure (bottom).

Results: As an example of the FPM, Figure 1 shows the magnetic field perturbation induced by an arbitrary structure. Figure 2 shows that the FPFDM accurately recapitulates the perturber size dependency of ΔR_2 and ΔR_2^*. The dependence of these characteristic ΔR_2 and ΔR_2^* curves on pulse sequence parameter (TE) and field strength (B_0) was also explored and results were in an excellent agreement with previous works [1,3]. For a given set of simulation parameters the FDM method increased the computational efficiency of computing relaxation rates by more than ten fold as compared to Monte Carlo.

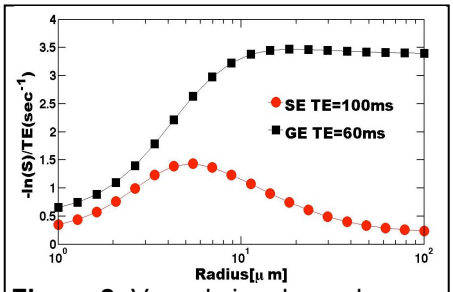

Figure 2: Vessel size dependence of ΔR_2^* and ΔR_2 computed using the FPFD method.

Discussion: The FPFDM uses the FPM to compute field perturbations surrounding arbitrarily shaped structures and replaces the traditional use of Monte Carlo (MC) methods with the FDM to estimate signal relaxation. The use of the FDM instead of the time consuming MC method, which tracks a large number of spins encountering complex tissue boundaries, significantly enhances the computational efficiency of the FPFDM. We are currently using the FPFDM to characterize the relationship between GE and SE relaxation rates and contrast agent concentration for simulated three-dimensional vascular networks constructed to reflect varying vascular features (i.e. branching patterns, diameter, volume- fraction) and for vascular trees extracted from μCT based tissue angiograms (Fig.3). Such data will be used to estimate the extent of k_p heterogeneity across normal and tumor tissue and to assess the reliability of DSC-MRI measures of blood volume and blood flow.

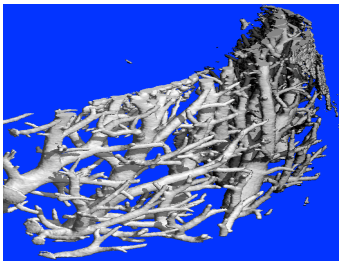

Figure 3: Vascular trees extracted from μCT based angiograms.

References: **[1]** Pathak A P, et al. NeuroImage 40 2008; 1130–1143. **[2]** Junzhong Xu, et al. Phys Med Biol. 2007; 52(7):N111-26. **[3]** Boxerman, J.L., et al., Mag. Reson. Med. 34, 555–566 (1995).

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