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Research Article

Magnetic Field Distribution and Signal Decay in Functional MRI in Very High Fields (up to 9.4 T) Using Monte Carlo Diffusion Modeling

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Abstract

Extravascular signal decay rate R2 or R2∗ as a function of blood oxygenation, geometry, and field strength was calculated using a Monte Carlo (MC) algorithm for a wider parameter range than hitherto by others. The relaxation rates of gradient-recalled-echo (GRE) and Hahn-spin-echo (HSE) imaging in the presence of blood vessels (ranging from capillaries to veins) have been computed for a wide range of field strengths up to 9.4 T and 50% blood deoxygenation. The maximum HSE decay was found to be shifted to lower radii in higher compared to lower field strengths. For GRE, however, the relaxation rate was greatest for large vessels at any field strength. In addition, assessments of computational reliability have been carried out by investigating the influence of the time step, the Monte Carlo step procedure, boundary conditions, the number of angles between the vessel and the exterior field B0, the influence of neighboring vessels having the same orientation as the central vessel, and the number of proton spins. The results were compared with those obtained from a field distribution of the vessel computed by an analytic formula describing the field distribution of an ideal object (an infinitely long cylinder). It was found that the time step is not critical for values equal to or lower than 200 microseconds. The choice of the MC step procedure (three-dimensional Gaussian diffusion, constant one- or three-dimensional diffusion step) also failed to influence the results significantly; in contrast, the free boundary conditions, as well as taking too few angles into account, did introduce errors. Next neighbor vessels with the same orientation as the main vessel did not contribute significantly to signal decay. The total number of particles simulated was also found to play a minor role in computing R2/ R2∗.