Can Adiabatic Slice Selection Generate Diffusion Weighting?

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Introduction: It is well known that frequency modulated adiabatic fast passage (AFP) pulses generate a high degree of magnetic spin phase coherence that is proportional to the quadratic power of the pulse frequency (1-3). The Localization by Adiabatic Selective Refocusing (LASER) pulse sequence developed by Garwood *et al* (3) exploits this property to achieve sharply defined excitation profiles in single voxel magnetic resonance spectroscopy (MRS) and imaging studies (4). Following excitation, and in the presence of spatial encoding gradients AFP pulses generate spin phase that is quadratically related to the pulse frequency and therefore quadratically proportional to the spatial coordinate of the spins. The purpose of this study was to determine whether this property of adiabatic slice selection could produce diffusion contrast and therefore measure the apparent diffusion co-efficient (D) in a sample of de-ionized water and a bead phantom containing regions with different microscopic susceptibility. An expression for the diffusion weighting due to the frequency dependent quadratic phase dispersion generated by combining an AFP pulse (chirp pulse assumed (5)) with linear slice select gradients was derived following the method previously described (6):

$$\ln\left(\frac{M(2\tau_{cp})}{M_0}\right) = -bD \quad \text{, where} \quad b = \gamma^2 G^2 \delta^2 \left[\frac{3}{2}\tau_{cp} - \frac{4}{3}\delta + 4\left(\frac{\omega}{\Delta\omega}\right)^2 \delta + 2\left(\frac{\omega}{\Delta\omega}\right)\delta\right]$$

and $M(2\tau_{cp})$ and $M(0)$ represent the image SI with and without diffusion weighting respectively after T_2 correction, τ_{cp}≡ time between two AFP pulses, γ≡gyromagnetic ratio, G≡slice select gradient, δ≡ AFP pulse width, ω≡ resonance frequency of spins during the AFP pulse, Δω≡AFP pulse bandwidth.

Methods: Two phantoms were studied on a 4T Varian whole body MRI with a Siemens Sonata gradient coil using a birdcage transmit/receive radio frequency coil (7.7 cm ID). Phantom A consisted of a 4.5 cm diameter sphere containing de-ionized water. Phantom B consisted of a 2.8 cm diameter tube containing a mixture of 10 μm ORGASOL polymer beads and 2 mmol Gd-DTPA dissolved in 5% agar. The transverse relaxation time T_2 was measured from a single 5 mm slice in each phantom using a conventional spin-echo imaging sequence (TR=2s, TE=40-76 ms in steps of 4 ms). The diffusion coefficient of each phantom was also measured using a conventional spin-echo diffusion imaging sequence (TR/TE = 2s/60 ms, Δ=40 ms, δ=10 ms, G_{diff} = 0.4-3.6 G/cm in steps of 0.4 G/cm). LASER images (5 mm) were acquired using a single orientation excitation (only 2 AFP pulses) version of the original LASER pulse sequence (3) but varying the time between the two AFP pulses (τ_{cp} = 16-38 ms in steps of 2 ms) to allow increased time for spin diffusion/exchange. T_2 time constants were calculated by linear regression plotting ln(image signal intensity (SI)) as a function of TE. The diffusion constant (D) for each phantom was calculated by linear regression of ln(SI) as a function of G_{diff}^2 after correcting for T_2 signal decay. To estimate D from LASER images, ln(SI) after T_2 correction was plotted as a function of τ_{cp}.

Results: Figures 1 and 2 show typical measurement of T_2 and D in both phantoms with linear regression lines superimposed. The average T_2 in phantoms A and B were 449±19 ms (N=4 separate measurements) and 27±4 ms (N=3) respectively and the average D was $2.13\text{x}10^{-3}\pm0.03\text{x}10^{-3}$ mm^2/s (N=3) and $1.43\text{x}10^{-3}\pm0.06\text{x}10^{-3}$ mm^2/s respectively. Following T_2 correction, no signal variation was observed in phantom A as a function of τ_{cp} in the LASER sequence. However, signal variation was observed in phantom B (Figure 3) for both HS1, R10 (3) and HS4, R10 pulses (3). Calculation of the diffusion coefficient for phantom B based on Equation [1] produced values of $2.5\text{x}10^{-3}\pm0.8\text{x}10^{-3}$ mm^2/s and $2.0\text{x}10^{-3}\pm0.5\text{x}10^{-3}$ mm^2/s for the HS1 and HS4 pulses respectively.

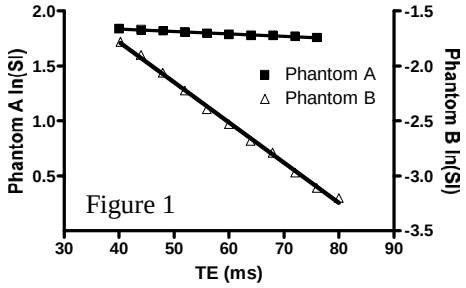

Figure 1

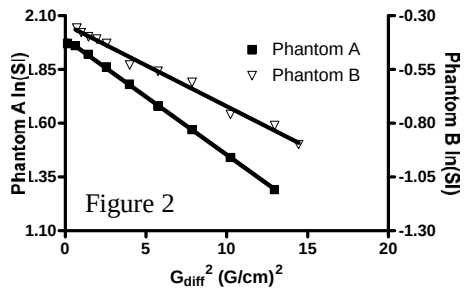

Figure 2

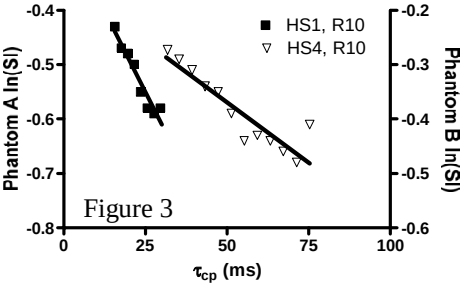

Figure 3

Discussion: Initial experiments were completed to determine whether it is possible to measure the self diffusion coefficient using the phase dispersion generated by the combination of AFP pulses with slice select gradients as occurs in the LASER pulse sequence. A theoretical expression for the expected signal variation was derived. Although signal variation was not observed in a water phantom, potentially because the phase dispersion generated by AFP slice selection was ~10-fold smaller than that generated by conventional diffusion imaging, variation was observed in a phantom containing microscopic magnetic susceptibility gradients. The effect of $T_{2\rho}$ (7) was not estimated, but if present would have resulted in an underestimation of D calculated by the adiabatic phase dispersion method.

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