Assessment of Dynamic Averaging From Transverse Relaxation in the Rotating Frame ($T_{2\rho}$) During Adiabatic HSn Pulses.

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Introduction

Conventional techniques used to access dynamic averaging (DA) include Carr-Purcell spin echo (SE) and on/off-resonance $T_{1\rho}$ methods. $T_{2\rho}$ relaxation has not been investigated probably because of the experimental difficulties associated with measuring $T_{2\rho}$. During the application of the adiabatic pulses, the time-dependent effective field $\boldsymbol{\omega_{eff}(t)}$ affects the $T_{2\rho}(t)$ by changing the axis of quantization. During the pulses in the adiabatic CP sequence known as CP-LASER (1,2), magnetization precesses in the plane approximately perpendicular to $\boldsymbol{\omega_{eff}}$ **(t)** (2); thus the time-dependent transverse relaxation in the double rotating frame (TDRF) is *mainly* responsible for the MR signal decay. This work was focused on the time-dependent Hamiltonian $H=h/(2\pi)E(I,t)$ case, e.g. the interaction energy of the nuclear magnetic moments with the time-dependent externally applied magnetic field. This approach includes dipolar relaxation and DA (during the adiabatic pulse) components, as represented by the following Eq: $R_2^{\dagger}=R_{2\rho}^{dd}(t)+R_{2\rho}^{DA}(t)$. In this work water-glycerol samples with high viscosity (30%/70% by volume), as well as the cerebral metabolite Creatine/Phosphocreatine (tCr, 3.03 ppm) in human brain were investigated as a function of the τ_{cp} (interpulse time interval of the CP-LASER sequence) with HS1 and HS4 pulses.

Methods

Transverse relaxation times of water in glycerol (30%/70%) were measured at 4.7T using localized spectroscopy based on the CP-LASER technique. TE of the sequence was incremented by increasing of the number of HS*n* pulses in the CP-train. The CP-train was composed of 3-ms-long HS*n* (n=1or 4*)* pulses with an adiabaticity factor R of $AT_p/20$ (pulses length T_p=0.003 s), using various delays between pulses. The modulation functions of HSn pulses differ with the choice of *n*. Three different RF amplitudes (ω_1^{max} =2.5, 5, 10 kHz) were used for the $T_2^{\dagger}$ measurements of water in glycerol. $T_2^{\dagger}$ of brain tCr were also measured at 7T. Four healthy volunteers participated in the studies. Interleaved acquisitions were performed with the HS1 and HS4 pulses (R=20) in the CP-train as a function of τ_{cp}.

Results and Discussion

During the adiabatic pulses the magnetization undergoes precession around the rotating $\boldsymbol{\omega_{eff}(t)}$ and remains approximately perpendicular to $\boldsymbol{\omega_{eff}(t)}$ when the adiabatic condition is satisfied. Transverse dipolar relaxations of a system of two equivalent nuclei of a spin I in the TDRF were considered by Blicharski (3). Under the experimental conditions of $\omega_0 >> \omega_{eff}$, one obtains:

$$1/T_{2\rho}^{dd}(t)=1/(40\,k_{dd})[3(3\cos^2\theta-1)^2+30\,\sin^2\theta\cos^2\theta\,J(\omega_{eff}(t))+3\,\sin^4\theta\,J(4\,\omega_{eff}(t))+(20-6\sin^2\theta)\,J(\omega_0)+(8+12\sin^2\theta)\,J(4\omega_{eff}(t))] \quad (1)$$

where $1/k_{dd}=(h/(2\pi))^2 2I(I+1)\,\gamma^4 r^{-6}$, r is the inter nuclear distance, $h/(2\pi)$ is the Planck's constant, γ is the gyromagnetic ratio of the protons, and τ_c is the rotational correlation time. Integration over the pulse length was performed to calculate the averaged relaxation time: $T_{2\rho}=1/T_p\int_0^{Tp} T_{2\rho}(t)dt$. We found that the DA contribution during the pulse can be described by the Eq.2: $R_2^{DA}\sim F(\vartheta)\Delta\omega k^{DA}/(k^{DA}+B(\omega_{eff}(t)))$, where $B(\omega_{eff}(t))$ and $F(\vartheta)$ are the time dependent functions, that are specific to the adiabatic pulse used. The relaxation rate during the interpulse time intervals is presented by the following Eq. 3: $1/T_2'= ((R_{2\rho}^{dd}(t)+R_{2\rho}^{DA}(t))-1/T_2)\,T_p/\tau_{cp}+1/T_2$, where the contribution of DA as a function of the delay time can be described by the general model for the DA (4): $1/T_2=\Delta\omega^2\tau_{cp}\,\alpha\beta x\,\{1-b\,x\,\tanh[1/(bx)]\}$; $x=\tau_{d,ex}/\tau_{cp}$; $\tau_d=r^2/D$. Here D is apparent diffusion coefficient, $\tau_{d,ex}$-is the correlation time for diffusion or exchange and $\Delta\omega$ is the chemical shift difference between exchangeable protons or background susceptibility gradients.

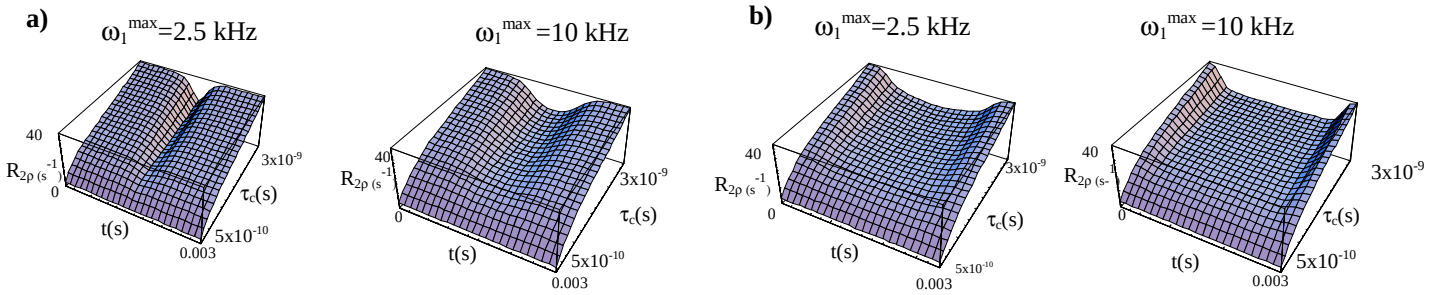

Figure 1 Calculated transverse relaxation rates ($R_{2\rho}^{dd}$) in the TDRF during the a) HS1 and b) HS4 pulses as a function of the rotational correlation time (τ_c) and time during the pulse. The pulse parameters used for calculation were: pulse length T_p=0.003s, R=20, ω_1=2.5kHz.

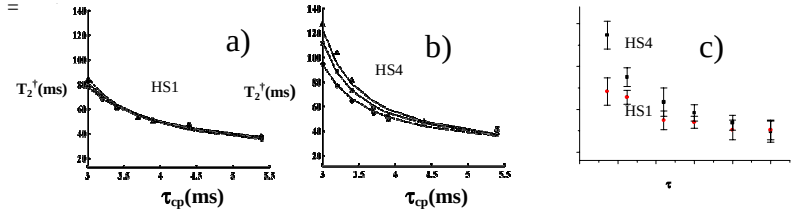

Figure 2. (a) $T_2^{\dagger}$ measurements of water in glycerol as a function of the τ_{cp} and the ω_1^{max} with HS1 pulse; (b) same as (a), but using HS4 pulses in the CP-train of CP-LASER. The superimposed dashed lines are the theoretical simulations according to Eq. (3). The results of the simulations are: τ_c=1.12x10^{-10} s, τ_{ex}=0.1 ms; (c) $T_2^{\dagger}$ measurements of tCr as a function of τ_{cp}.

There was no significant difference between $T_2^{\dagger}$ measured with HS*1* pulses using ω_1^{max} 2.5 kHz or 10 kHz. On the other hand, $T_2^{\dagger}$s measured with the HS4 pulses exhibited significant increase when ω_1^{max} increased. Analysis of the experimental data indicate that the dominant contribution to the MR signal decay in CP-LASER is DA, and during the pulse is governed mainly by the time-dependent $T_{2\rho}^{DA}(t)$ term. This approach provides the possibility to assess MRI contrast based on DA. The contribution of the time-dependent $T_{1\rho}(t)$ was neglected due to the fact that the magnetization precesses in the plane perpendicular to $\boldsymbol{\omega_{eff}(t)}$. The time-dependent $T_{2\rho}$ relaxation process also provides sensitivity to dipolar interactions of the slow moving spins (τ_c>5*10^{-9} s). In such cases, interleaved measurements of $T_2^{\dagger}$s using adiabatic pulses with the different modulation functions may be used to determine the rotational and diffusion/exchange correlation times of the spins of interest.

References 1), Michaeli et. al, MRM, **47**, 2002, p. 629; 2) Garwood et. al, JMR, **153**, 2002, p155; 3) Blicharski, Acta Physica Polonica, 1971, **A41**, p 223; 4) R. Brooks, et al., MRM **45**, 1014-1029 (2001).

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