Quantitative Investigation of Rotating-Frame Intermolecular

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Introduction

The spin-locking technique was introduced into the conventional CRAZED experiment in this work [1,2]. The concept of rotating-frame intermolecular double-quantum (iDQC) spin-lattice relaxation, $T_{1\rho,DQC}$, was proposed and evaluated quantitatively for the first time. The results show that $T_{1\rho,DQC}$ may provide a new contrast parameter that can be useful in the MR imaging applications.

Methods

A modified CRAZED pulse sequence shown in Fig.1 was used to investigate the behavior of the rotating-frame spin-lattice relaxation time, $T_{1\rho,DQC}$. In such an experiment, the *n*-th echo doesn't appear at the *n* times of the interval between the two RF pulses as usually found when the low-power, spin-locking pulse (labeled as "T_{SL}" in Fig.1) is in effect. When the amplitude of spin-locking pulse is strong enough to lock the observed spins, echoes will appear at the n times of τ with respect to the *n*-quantum coherence. A mixture of zero- and double-quantum coherences (when n=0 or ±2 is used) survives at the end of T_{SL} and both are modulated by the corresponding multiple-quantum relaxations [2,3]. Considering the iDQC case, the complex magnetization originating from iDQCs (n=±2) is given by

$$M^{+}_{DQC}(t_2) = iM_0\left(\frac{2\tau_d}{t_2}\right)J_2(-t_2/\tau_d)e^{-T_{SL}/T_{1\rho,DQC}}e^{-\tau/T_{2,DQC}}e^{-t_2/T_2}.$$

where J_2 is the second order Bessel function; $\tau_d=(\gamma\mu_0 M_0)^{-1}$ is the dipolar field time constant; γ is the gyromagnetic ratio; μ_0 is the magnetic permeability constant; and M_0 is the equilibrium magnetization per unit volume. Therefore, the acquired signal is a function of $T_{1\rho,DQC}$ as well as T_{SL}. The separated distant spins of two individual molecules are simultaneously locked in a parallel configuration by the locking field and each component will decay at a relaxation time constant [2]. Their substantial distance makes the correlative couplings effectively insignificant compared with the locking field. For two like spins with same relaxation time constant (namely $T_{1\rho,j}=T_{1\rho,k}=T_{1\rho,SQC}$), the following relationship holds: $T_{1\rho,DQC}=T_{1\rho,SQC}/2$, where $T_{1\rho,SQC}$ is the conventional rotating-frame single-quantum coherence (SQC) spin-lattice relaxation time.

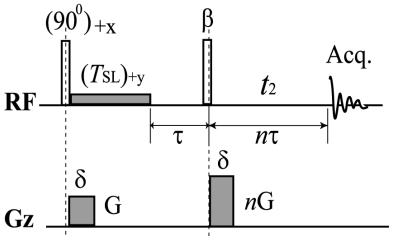

Fig.1 Pulse sequence for investigating the behavior of $T_{1\rho,DQC}$ relaxation.

Experiments were performed on a Varian Unity$^+$ 500 NMR spectrometer equipped with self-shielded z-gradient coils. A phase cycle scheme, in which $(x, -x, y, -y)$ for the first 90° RF pulse with the receiver phase $(x, x, -x, -x)$, is necessary to suppress the conventional SQCs. The duration of 90° pulse was 6.5 μs and a minimum delay τ was used to eliminate the influence of traverse relaxation. Data were measured in samples of fresh pork muscle and cartilage, by the variation of duration T_{SL} with different spin-lock powers, and related times were calculated by fitting the intensities of each peak to the mono-exponential relaxation curves.

Results and Discussion

$T_{1\rho,DQC}$ fitting curves based on the mono-exponential relationship are plotted as a function of T_{SL} ranging from 2 ms to 56 ms in Fig.2. With the increase of locking powers, the signal decay is less pronounced. The measured relaxation values with varied locking powers listed in Table 1. It shows that $T_{1\rho,DQC}$ is approximately half of the conventional SQC $T_{1\rho,SQC}$ as predicted. $T_{1\rho,DQC}$ of muscle is increased by 45% from 0.52 kHz to 3.14 kHz and it shows the characteristic of "relaxation dispersion".

In such an experiment, the dephasing of spins is reduced during the locking pulse and the signal is less sensitive to diffusion loss. $T_{1\rho,DQC}$ is suitable for probing slow-motion macromolecules when the B_1 field matches with the correlation time of certain biological tissues [1]. The imaging contrast between different tissues can be optimized by adjusting the locking duration T_{SL} on a suitable locking field. Recently, we developed $T_{1\rho,DQC}$-weighted imaging technique on a 7.05 T Varian Unity Inova microimaging spectrometer. The results show that this technique provides a novel imaging contrast [4].

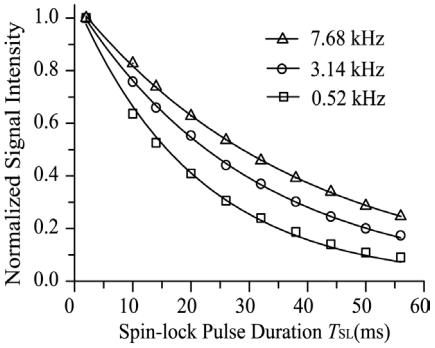

Fig.2 $T_{1\rho,DQC}$ decay curves as a function of spin-lock pulse duration for a pork muscle collected on different spin-locking powers.

Acknowledgment

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Table 1 Relaxation measurements of muscle and cartilage of pork sample

Spin-lock power (kHz)	Pork muscle T_1=(2.37±0.09)s; T_2=(30.0±0.1)ms		Pork cartilage T_1=(1.56±0.05)s; T_2=(33.7±0.2)ms	
	$T_{1\rho,DQC}$ (ms)	$T_{1\rho,SQC}$ (ms)	$T_{1\rho,DQC}$ (ms)	$T_{1\rho,SQC}$ (ms)
0.52	20.8±0.6	45.7±0.4	29.6±1.1	59.7±1.7
1.84	27.7±0.3	58.7±0.5	42.2±1.0	81.7±0.3
3.14	30.1±0.2	64.4±0.5	45.2±1.2	87.9±0.5
5.37	35.0±0.3	71.0±0.5	46.1±1.2	95.0±0.6
7.68	38.4±0.3	80.0±0.7	53.1±2.3	105.3±1.1

References

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