Dependence of rotating frame relaxation rates on frequency offset: spin-lock versus adiabatic rotation

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Introduction

Rotating frame relaxation rates ($R_{1\rho}$ and $R_{2\rho}$) measured during continuous-wave spin-lock pulse depend on the frequency offset ($\Delta\Omega$) between the pulse and the isochromat of interest [1]. This characteristic impairs a time-efficient utilization of this method for MRS applications *in vivo*, since data need to be acquired separately for each metabolite of interest. The present work investigates the frequency offset dependency of $R_{1\rho}$ and $R_{2\rho}$ during Hyperbolic Secant (HS) adiabatic full passage (AFP) pulses [2,3], comparing it to the case of continuous-wave irradiation. We specifically considered the relaxation channels of dipolar interactions in the weak field limit, and anisochronous exchange (*i.e.*, exchange between spins with different chemical shifts, $\delta\omega \neq 0$) in the fast exchange regime (FXR). Phantom measurements were performed to validate the theoretical predictions for adiabatic pulses.

Methods

Simulations. During adiabatic rotation relaxation rates were calculated as an average of instantaneous time-dependent contributions due to the different relaxation channels. The used relaxation functions were detailed in [3]. For anisochronous exchange, the population of the two exchanging sites was set to 0.5, and $\delta\omega = 0.85$ ppm. Simulations were carried out using Mathematica 5.3. *Phantom experiments* were performed on 4.7-T/40-cm magnet interfaced to Varian *INOVA* console. To investigate the dipolar relaxation channel, a 300 mM acetate solution in glycerol/water (0.9/0.1 by weight) was prepared, and the relaxation measurements of the methyl group of acetate at 2 ppm were conducted. To investigate the exchange relaxation channel, a water/ethanol sample was prepared at the molar ratio ~1:1:0.9. Adiabatic $R_{1\rho}$ or $R_{2\rho}$ measurements were obtained by placing a train of AFP pulses prior or after the excitation by adiabatic half passage pulse, respectively, as described previously [4,5]. Other parameters: $\omega_1^{max}/(2\pi)$ = 2.5 kHz, pulse time duration = 6 ms, as used for simulations.
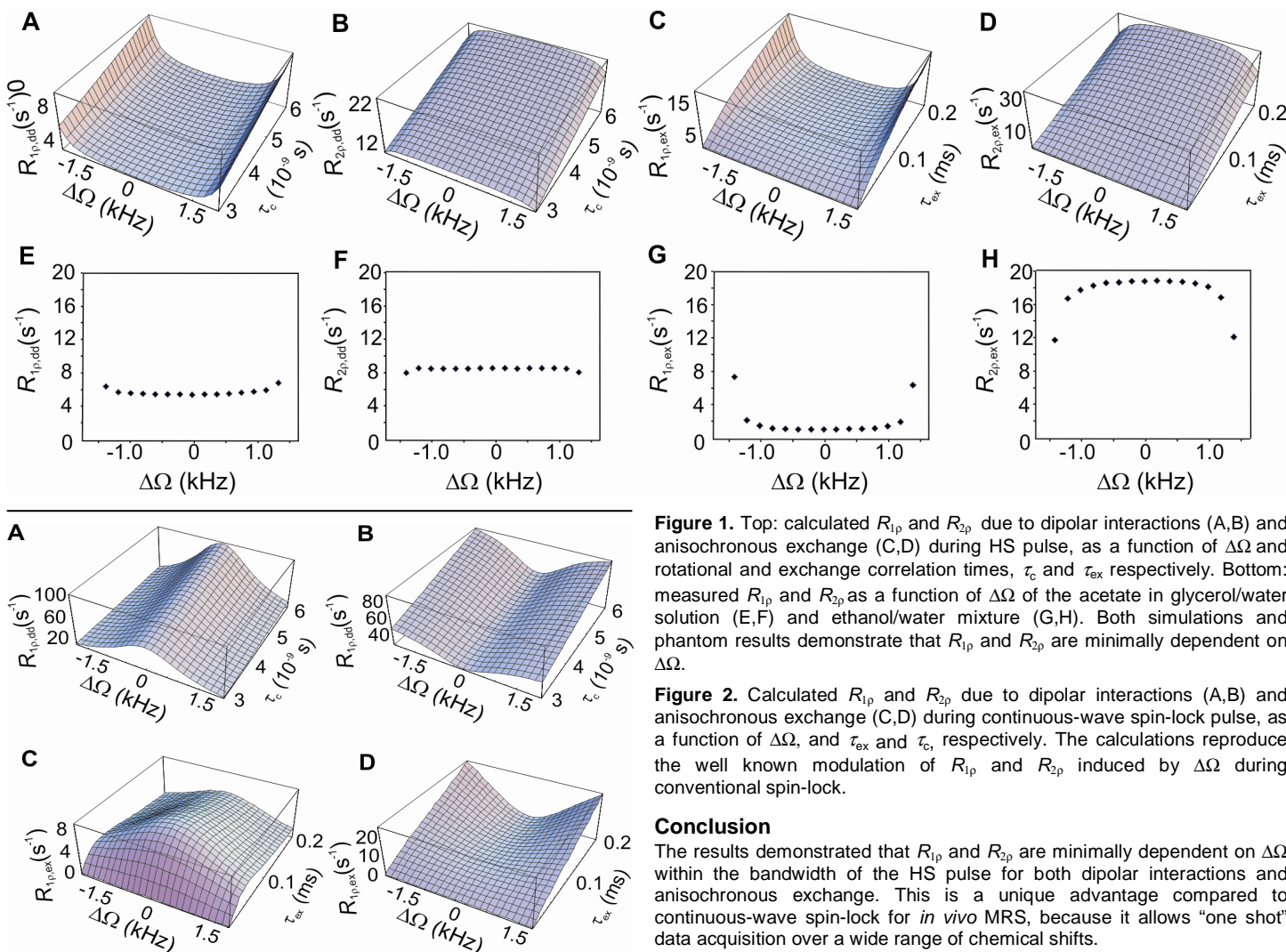
Results and discussion

Figure 1. Top: calculated $R_{1\rho}$ and $R_{2\rho}$ due to dipolar interactions (A,B) and anisochronous exchange (C,D) during HS pulse, as a function of $\Delta\Omega$ and rotational and exchange correlation times, τ_c and τ_{ex} respectively. Bottom: measured $R_{1\rho}$ and $R_{2\rho}$ as a function of $\Delta\Omega$ of the acetate in glycerol/water solution (E,F) and ethanol/water mixture (G,H). Both simulations and phantom results demonstrate that $R_{1\rho}$ and $R_{2\rho}$ are minimally dependent on $\Delta\Omega$.

Figure 2. Calculated $R_{1\rho}$ and $R_{2\rho}$ due to dipolar interactions (A,B) and anisochronous exchange (C,D) during continuous-wave spin-lock pulse, as a function of $\Delta\Omega$, and τ_{ex} and τ_c, respectively. The calculations reproduce the well known modulation of $R_{1\rho}$ and $R_{2\rho}$ induced by $\Delta\Omega$ during conventional spin-lock.

Conclusion

The results demonstrated that $R_{1\rho}$ and $R_{2\rho}$ are minimally dependent on $\Delta\Omega$ within the bandwidth of the HS pulse for both dipolar interactions and anisochronous exchange. This is a unique advantage compared to continuous-wave spin-lock for *in vivo* MRS, because it allows "one shot" data acquisition over a wide range of chemical shifts.

References: [1] Abergel and Palmer Concepts Magn Reson A 2003;19A(2):134. [2] Garwood and DelaBarre JMR 2001;153:155. [3] Michaeli et al. Curr Anal Chem 2008;4:8 [4] Michaeli et al. MRM 2005;53:823 [5] Michaeli et al. JMR 2006;181:138. **Acknowledgments**: BTRR - P41 RR008079, P30 NS057091, R01NS061866 and R21NS059813.