High-Resolution MR Spectroscopy in Inhomogeneous and Unstable Fields via Intermolecular Zero-Quantum Coherences

X. Chen[1], M. Lin[1], T. Lin[1], Z. Chen[1], and J. Zhong[2]

[1]Department of Physics, Xiamen University, Xiamen, Fujian, China, People's Republic of, [2]Department of Imaging Sciences, University of Rochester, Xiamen, NY, United States

Introduction

Intermolecular zero-quantum coherences (iZQCs) are not susceptible to magnetic field inhomogeneities over distances much larger than the dipolar correlation distance, and can be used to achieve high-resolution spectra in inhomogeneous fields[1]. However, due to its intrinsic low SNR, iMQC spectroscopy requires more scanning time than its 1D counterparts. As a result, motions in *in vivo* studies will cause strong t_1 noises in the 2D spectra of iMQCs and thus restrict previous attempt of high-resolution[2]. IZQCs have been utilized to achieve high-resolution NMR in unstable fields of a 25 T electromagnet[3]. In current work, the detailed mechanism to achieve high-resolution spectroscopy in unstable fields via iZQCs is presented and a modified iZQC pulse sequence, the iDQF-HOMOGENIZED[4] with stroboscopic acquisition (dubbed as SB-iDH), is designed to suppress inhomogeneous broadenings and motion artifacts in MRS.

Methods

The desired evolution of a typical iZQC sequence can be given as:

Fig.1. The SB-iDH pulse sequence.

$$I_z S_z \xrightarrow{\frac{\pi}{2}I_x,\frac{\pi}{2}S_x} \frac{1}{4}I^- S^+(t_1) \xrightarrow{\frac{\pi}{2}I_x} \frac{1}{4}I_z S^+ \xrightarrow{\pi I_x, \pi S_x, D_{IS}I_z S_z t_2} \frac{1}{4}S^-(t_2) \qquad (1)$$

where I spin (corresponding to solvent) and S spins (corresponding to solutes) are spin-1/2 systems. The iZQCs are not sensitive to static field inhomogeneity:

$$M_S \sim e^{i\omega_{ZQC}t_1} e^{i\omega_{SQC}t_2} = e^{i[-\omega_I - \Delta\omega(\mathbf{z}) + \omega_S + \Delta\omega(\mathbf{z})]t_1} e^{i[\omega_S + \Delta\omega(\mathbf{z})]t_2} = e^{i(-\omega_I + \omega_S)t_1} e^{i[\omega_S + \Delta\omega(\mathbf{z})]t_2} \qquad (2)$$

where $\Delta\omega(\mathbf{z})$ denotes the angular frequency deviation at the position $\mathbf{z}$. However, it is more complicated in the case of unstable fields. The magnetic field varies from scan to scan as t_1 increases:

$$M_S \sim e^{i\omega_{ZQC}t_1} e^{i\omega_{SQC}t_2} = e^{i[-\omega_I - \Delta\omega(\mathbf{z},t_1) + \omega_S + \Delta\omega(\mathbf{z},t_1)]t_1} e^{i[\omega_S + \Delta\omega(\mathbf{z},t_1,t_2)]t_2} = e^{i(-\omega_I + \omega_S)t_1} e^{i[\omega_S + \Delta\omega(\mathbf{z},t_1,t_2)]t_2}. \qquad (3)$$

Although the unstable factor is eliminated in the iZQC term, the t_1 dependence of $\Delta\omega$ in the t_2 acquisition will lead to strong t_1 noises. From Eq. (3) it can be seen that the elimination of the chemical shift term in the t_2 period can suppress the influence of t_1-dependent $\Delta\omega$ without affecting the spectral information in the F1 axis. A CPMG scheme with stroboscopic acquisition is utilized for this attempt: one-point acquisitions take place at spin echo maxima between CPMG trains. As a result, chemical shift is refocused in the F2 dimension. The intermolecular double-quantum filter (iDQF) scheme[4] is also utilized for solvent suppression.

Experiment was performed on a Varian Unity+ 500 MHz NMR spectrometer. To simulate the inhomogeneous and unstable field environment, the shimming coils are deliberately detuned to produce a field inhomogeneity of 60 Hz, and background field gradients randomly vary from scan to scan in the range of $-0.01\,\text{Gauss}\cdot\text{cm}^{-1} \sim 0.01\,\text{Gauss}\cdot\text{cm}^{-1}$. A solution of methyl ethyl ketone (MEK) dissolved in cyclohexane is used. The parameters of coherence selection gradients (CSGs) are $G' = 4\,\text{Gauss}\cdot\text{cm}^{-1} \times 0.5\,\text{ms}$, $G = 10\,\text{Gauss}\cdot\text{cm}^{-1} \times 0.5\,\text{ms}$. 100×512 points were acquired with spectral widths of 100×1500 Hz. A 2-step phase cycling was used: the phases for the 2nd RF pulse and the receiver were (x, y) and $(x, -x)$, respectively.

Results

The results are presented in Fig. 2. It can be seen that high-resolution spectral information such as chemical shifts and *J*-coupling multiplets can be obtained in the SB-iDH spectrum. For comparison, an experiment with the same sequence and parameters but without stroboscopic acquisition was performed. Strong t_1 noises can be observed in the 2D spectrum and severe artifacts in the projection conceal the "real" resonances. *In vivo* studies utilizing the SB-iDH sequence are under work.

Fig. 2. ^{1}H NMR spectra of MEK in cyclohexane. (a) Conventional 1D spectrum in a homogeneous field, (b) the iZQC spectrum without stroboscopic acquisition in an inhomogeneous and unstable field, and (c) the iZQC spectrum obtained by the SB-iDH sequence in the same field condition as (b).

Acknowledgments

Reference

1. Vathyam S., et al., *Science* 272, 92, 1996.

2. Galiana G., et al., *J. Am. Chem. Soc.* 127, 17574, 2005.

3. Lin Y. Y., *Phys. Rev. Lett.* 85, 3732, 2000.

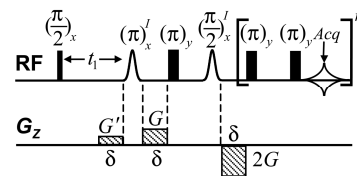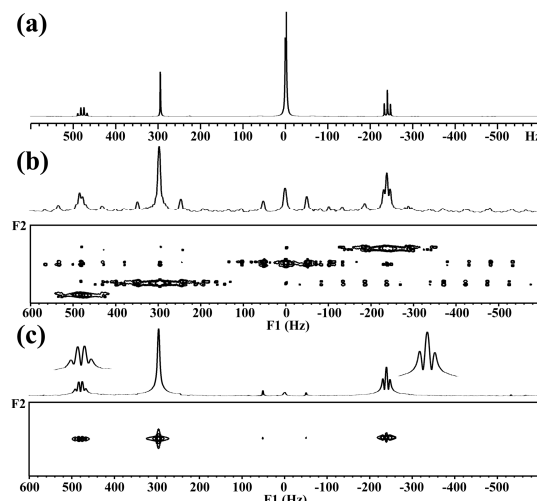4. Chen X., et al., *Phys. Chem. Chem. Phys.* DOI: 10.1039/b709154k, 2007.