Ultra high-resolution absorption intermolecular multiple-quantum NMR spectroscopy without strong coupling artifacts under inhomogeneous fields

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Introduction

Intermolecular multi-quantum coherence (iMQC) is capable of improving NMR spectral resolution[1]. However, the usefulness of conventional 2D iMQC high-resolution methods is considerably reduced by two main drawbacks. Firstly, none of the existing 2D iMQC spectra has double-absorption mode hitherto. The phase-modulated signal introduces unfavorable line broadening and phase-twisted peak shape[2]. Secondly, strong scalar couplings lead to additional cross-peaks usually known as "strong coupling artifacts"[3]. To solve the above problems, and to shorten the long scan time of 2D spectra and suppress strong solvent signals as well, a pulse sequence which combines iDQF-HOMOGENIZED[4] with constant-time (CT) scheme[5], dubbed as CT-iDH is designed.

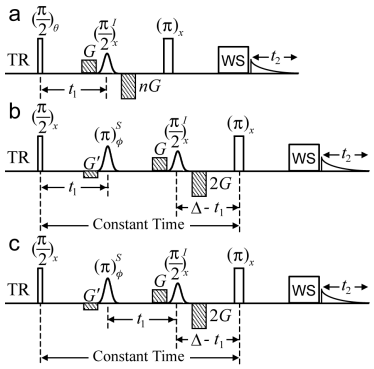

Fig. 1 Pulse sequence: (a) original iZQC (n = 0) or iDQC (n = 2), (b) CT-iDH-iZQC, and (c) CT-iDH-iDQC

Methods

To obtain absorption spectra, our idea is to record two equally weighted signals with mirror image pathways[2]: one is from CT-iDH-iZQC (Fig. 1b), and the other is from CT-iDH-iDQC (Fig. 1c). Although either spectrum has undesirable phase-twisted lineshape, these two signals can be combined via data processing to form a complete echo in both dimensions of time domain, thus yielding a 2D amplitude-modulated spectrum in frequency domain.

For strong coupled systems, the hard π pulse leads to coherence transfer between t_1 and t_2, and produces cross-peaks[3]. However, the CT-iDH sequence is designed with a constant t_1 evolution time when the solute precessions under frequency offsets and J-couplings remain invariant, because no other RF pulse is exerted on the solute spins. Therefore, the frequency offsets and J-couplings of solutes will not cause t_1-modulation.The cross-peaks have the same t_2-precessions as axial peaks and will exactly overlap each other. Consequently, no extra strong coupling artifacts will appear in the CT-iDH spectra.

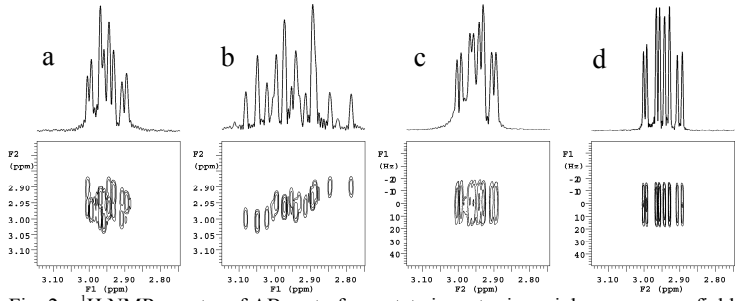

Fig. 2 ^{1}H NMR spectra of AB part of aspartate in water in an inhomogeneous field with a linewidth of 40 Hz: (a) original iZQC spectrum, (b) original iDQC spectrum, (c) CT-iDH-iZQC spectrum, and (d) CT-iDH absorption spectrum.

All experiments were performed on an 11.74 T Varian NMR System, using a 5 mm indirect detection probe at 298 K. The parameters were G' = 0.07 T/m with a duration of 1.2 ms, G = 0.16 T/m with a duration of 1.2 ms, G_1 = 0.14 T/m with a duration of 1.0 ms, and G_2 = 0.24 T/m with a duration of 1.0 ms, respectively. An 8-step phase cycling was applied for the CT-iDH sequences: ϕ = (x, y, -x, -y, x, y, -x, -y), φ = (x, x, x, x, -x, -x, -x, -x) and receiver = (x, -x, x, -x, x, -x, x, -x). The phase cycling for the first RF pulse of the original iZQC/iDQC sequences is: θ = (x, y, -x, -y, x, y, -x, -y). The repetition time (TR) and the echo time (TE) were TR/TE = 2000/200 ms. 500×25 points were acquired with spectral widths of 5000 Hz × 120 Hz in F_2×F_1 dimensions in circa 16 min.

Results and discussions

In Fig. 2, the protons in aspartate form a typical ABX spin system. The strong coupling effect in either original iZQC or iDQC spectra (Fig. 2a~b) may lead to misinterpretation or incorrect quantification of metabolites. However, there is no observable strong coupling artifacts in the 2D CT-iDH spectrum (Fig. 2c~d). Furthermore, since the dispersion parts are eliminated, the resolution of the CT-absorption spectrum (Fig. 2d) is improved by two times.

In Fig. 3, though the spectral resolution of the CT-iDH-iZQC spectrum (Fig. 3b) remains the same as the iZQC spectrum (Fig. 3a), the strongly-coupled multiplets of citrate (AB spin system) in Fig. 3a are distorted in the resonance intensities. In the CT-iDH-absorption spectrum (Fig. 3c), not only the correct multiplet intensity pattern is preserved, but also the spectral linewidth is reduced by half.

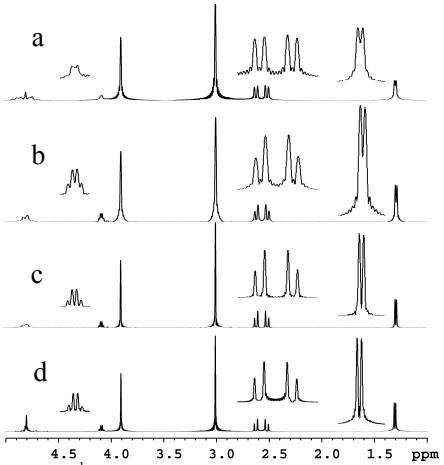

Fig. 3 ^{1}H NMR spectra of the sample of water solution of creatine, lactate and citrate. (a) original iZQC projection spectrum, (b) CT-iDH-iZQC projection spectrum, and (c) CT-absorption projection spectrum. (a)~(c) are all acquired under an inhomogeneous field with a linewidth of 40 Hz. (d) 1D conventional spin-echo spectrum in a homogeneous field. From (a) to (d), the linewidths of creatine singlets at about 3 ppm are 6.4 Hz, 7.2 Hz, 3.8 Hz and 3.2 Hz, respectively.

Acknowledgments

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Reference

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

2. States D. J., et al., ***J. Magn. Reson.***, 48, 286-292, 1982.

3. Thrippleton. M. J., et al., ***J. Magn. Reson***., 174, 97-109, 2005.

4. Chen X., et al., ***Phys. Chem. Chem. Phys.*** 9, 6231-6240, 2007.

5. Nagayama K., et al., ***J. Magn. Reson***., 40, 321-334, 1980.