Ultrafast high-resolution NMR spectroscopy through indirect zero-quantum coherence detection in inhomogeneous fields

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Target audience

The target audience of present study is the researchers who are interested in NMR study on intact biological tissues or in vivo metabolites in organisms.

Purpose

High-resolution NMR is an important tool for molecular structure analysis. In some cases, however, high-resolution NMR spectra are virtually impossible to obtain by conventional NMR methods because of external field inhomogeneity or internal heterogeneity of sample. Therefore, there is a great deal of interest recently in exploring high-resolution NMR techniques in inhomogeneous fields. Recently, we proposed a scheme via spatially encoded intermolecular zero-quantum coherence (iZQC) to obtain high-resolution NMR spectra in inhomogeneous fields with two scans.[1] However, the low sensitivity of iZQCs limits its application, especially in *in vivo* cases. In this study, we present another approach for high-resolution NMR spectra in inhomogeneous fields via intramolecular zero-quantum coherence (ZQC) technique.

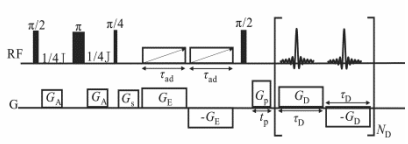

FIG. 1 pulse sequence for ultrafast high-resolution NMR spectra through intramolecular zero-quantum coherence.

Methods

The pulse sequence is shown in Fig. 1. Instead of using the conventional preparation module $(90°)_x$-TE/2-180°-TE/2-$(90°)_x$, we use the module $(90°)_x$-TE/2-180°-TE/2-$(45°)_{y,-y}$ because it can eliminate all the resonances from uncoupled spin systems (TE ≈ 1/2J in this study). Note that the utilization of 45° RF pulse flip angle leads to 50% signal loss.[2] The gradient G_s in Fig. 1 serves to select the desired coherence transfer pathway, and G_E and G_D are encoding and decoding gradients, respectively. The WURST adiabatic pulse has a duration of τ_{ad}. The gradient G_p prior to acquisition is adjustable to set the middle of chemical shift range in the middle of detection period τ_D.

All experiments were performed on a 500 MHz NMR spectrometer with indirect detection probe. The sample was ethyl 3-bromopropionate ($BrCH_2CH_2COOCH_2CH_3$). The ZQC spatial encoding experiments were performed with same parameter setting in homogeneous and inhomogeneous fields. The inhomogeneous field was created by deshimming the X1, Y1 and Z1 coils. A two-step phase cycling scheme was used: the phase for the 45° RF pulse was (y, -y) and the phase for the receiver was (x, -x). The experimental time for a two-dimensional (2D) spectrum was 21 s.

Results and discussion

The experimental results are given in Fig. 2. In homogeneous field, the average line-width of the conventional one-dimensional (1D) high-resolution ^{1}H NMR spectrum is 3 Hz (Fig. 2a). In the projection of 2D ZQC spectrum along the F1 dimension, the peak position is determined by the frequency difference of the *J*-coupled spins involved in the ZQC transfer (Fig. 2b, d and f). The average line-width of the peaks measured from the projection spectrum is approximately 51 Hz in homogeneous field (Fig. 2b). This indicates that our method cannot reach the resolution of conventional ^{1}H spectrum in homogeneous field. In the two inhomogeneous fields (Fig. 2c and f), the line-width of the projection spectrum is reduced from 1000 Hz to 56 Hz (Fig. 2d) and 2000 Hz to 66 Hz (Fig. 2f). These results illustrate that by tracking the differences of the precession frequencies of two spins, high-resolution spectral information can be obtained in inhomogeneous fields.[3] The resolution can be further improved by reducing the sweep rate *R* of adiabatic pulse. In our experiments, *R* was set to 2000 kHz/s to provide a compromise between sensitivity and resolution.

It is important to differentiate the detection of ZQCs and the detection of iZQCs. While both techniques achieve high resolution along the indirect dimension, their principle and applicability are different. The ZQC method is strictly limited to scalar-coupled spin systems, while the iZQC method relies on long range dipolar interactions between solvent and solute.[2]

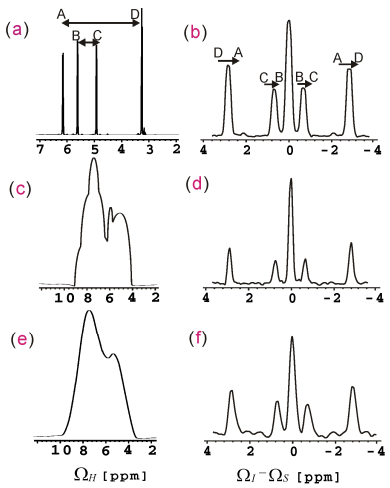

FIG. 2. (a, c, e) Conventional ^{1}H NMR spectrum acquired in (a) a well shimmed magnetic field, (c) an inhomogeneous field with a line-width of 1000 Hz, and (e) an inhomogeneous field with a line-width of 2000 Hz; (b, d, f) projection of the 2D ZQC spectrum acquired in the same field as for (a, c, e) respectively.

Conclusion

Spatially encoded ZQC technique is proposed to ultrafast achieve high-resolution NMR spectral information under inhomogeneous fields. For the first time, the gradient-driven decoding technique was employed to selectively acquire ZQC signals. Experimental observations demonstrate the feasibility of the new method. This work may provide a new way for in vivo study of metabolites in organisms.

Acknowledgement

This work was partially supported by the NNSF of China under Grants 11105114 and 11275161.

References

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