Numerical Studies of High-Resolution iDQC MRS in Inhomogeneous Fields

Z. Chen[1,2], C. Cai[1], S. Cai[1], J. Zhong[3]

[1]Physics, Xiamen University, Xiamen, Fujian, China, People's Republic of, [2]Radiology, University of Rochester, Rochester, NY, United States, [3]Radiology, BME, Physics, University of Rochester, Rochester, NY, United States

Introduction

High-resolution MRS is a powerful tool for the study of molecular structures and dynamics, and *in vivo* metabolite distributions. However, many factors such as variations in environment may produce spurious field gradients that broaden resonance lines and hide fine spectral features. Intermolecular multiple quantum coherences (iMQCs) have triggered theoretical studies and resulted in exciting novel applications in NMR [1-3] and MRI [4,5] in recent years. In this abstract, a fast and efficient numerical algorithm is employed to simulate intermolecular double-quantum coherences (iDQCs) in MRS. The results show that iDQCs can significantly narrow the line-width under inhomogeneous fields while retaining all important information including chemical shifts, *J*-couplings, multiplet patterns, and relative signal intensities.

Methods

Although the quantum formalism gives a sense of how the pulse sequence will behave [1], efficient method can be developed based on the classical Bloch equation for numerical calculations [6]. The dynamic equation of the magnetization vector $\boldsymbol{M}^{(i)}(\boldsymbol{r},t)$ is

$$\frac{d\boldsymbol{M}^{(i)}(\boldsymbol{r},t)}{dt} = \gamma \boldsymbol{M}^{(i)}(\boldsymbol{r}) \times \left\{ \left[\frac{\omega_i}{\gamma}\hat{\boldsymbol{z}} + \boldsymbol{G}(\hat{\boldsymbol{s}},\boldsymbol{r})\boldsymbol{z} + \Delta\boldsymbol{B}(\boldsymbol{r}) + \boldsymbol{B}_r(\boldsymbol{r}) \right] + \sum_j \boldsymbol{B}_d^{(j)}(\boldsymbol{r}) \right\} - \frac{M_x^{(i)}(\boldsymbol{r})\hat{\boldsymbol{x}} - M_y^{(i)}(\boldsymbol{r})\hat{\boldsymbol{y}}}{T_2^{(i)}(\boldsymbol{r})} + \frac{M_0^{(i)}(\boldsymbol{r})\hat{\boldsymbol{z}} - \boldsymbol{M}_z^{(i)}(\boldsymbol{r})\hat{\boldsymbol{z}}}{T_1^{(i)}(\boldsymbol{r})}, \quad (1)$$

When a strong linear field is applied along a single direction $\boldsymbol{s}$, a Fourier analysis shows that the non-local dipolar field $\boldsymbol{B}_d(\boldsymbol{r})$ can be reduced into a local form, and a great time saving is achieved for numerical simulations. In this study Eq.1 was solved numerically with a fifth-order Cash-Karp Runge-Kutta method. *J*-coupling was introduced to the Bloch equation by the "effective chemical shift" method when the second $\pi/2$ pulse was selective [3].

Results

The pulse sequences shown in Fig.1 were used for a mixture of I and S spins. The second RF pulse is selective for I spin, while the first pulse and the pulse are non-selective. The simulated and experimental results were shown in Fig.2 and Fig.3. Fig2 is for a mixture of isopropanol (S) and imethyl-sulfoxide (DMSO, I), and Fig3 is for butanone (S) and C_6H_{12} (I). The line-width of the inhomogeneous field was about 100 Hz. The chemical shift of the solvent peak (I) was set to be zero for convenience. To obtain a projection spectrum similar with Fig.2b, rotations of ϕ angle around the centers of individual *J*-multiplets were performed. After this procedure, a projection along dipolar coupling direction maintains the frequency separation between the cross peaks while inhomogeneous broadening is suppressed.

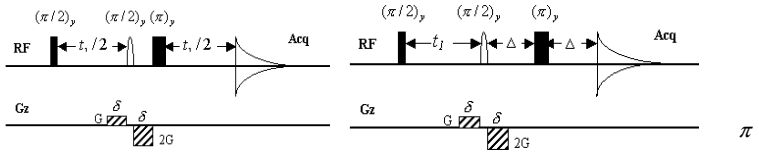

Fig.1(a) **Fig.1(b)**

Fig.1 Modified CRAZED sequences for iDQC.
Sequence (a) was used for Fig.2, sequence (b) was used for Fig.3

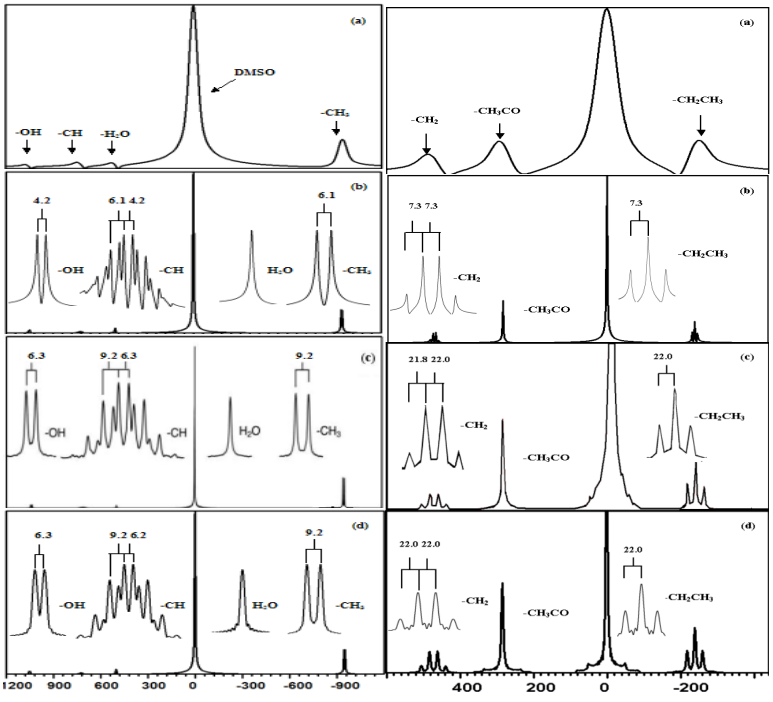

Fig.2 **Hz** **Fig.3** **Hz**

Fig.2 & Fig.3: (a) Conventional 1D ^{1}H spectrum. (b) Conventional 1D ^{1}H spectrum in the homogeneous field. (c) Accumulated projection of the 2D iDQC experimental spectrum. (d) Simulated accumulated projection of the 2D iDQC spectrum. (a), (c), and (d) are all in an inhomogeneous field with a line-width of 100Hz.

Discussion

Comparing Fig.2a~Fig.2d, one can see that the *J*-multiplets in Fig.2d are narrow and well resolved. The line-width reduced to about 3 Hz from 100 Hz. The simulation result coincides with the theoretical prediction and experimental result. It is worth noting that Fig.2c and Fig.2d result in a *J*-coupling constant 1.5 times that in Fig.2b. This change in scale factor was caused by the shearing procedure. The result of Fig.3 is similar to that inFig.2, but the scale factor becomes 3.0. The larger apparent *J*-coupling constant implies the easier resolving of *J*-multiplets. It is extremely useful when *J*-multiplets are complex and crowded.

In conclusion, the simulation method used here provides a convenient and reliable way for study of the complex spin systems under some antecedent limitation, thus give a guide to design better experimental parameters for improving the experimental results. The iDQC method has significant advantages over their iZQC counterpart [1], and it may be useful for *in vivo* high-resolution MRS studies in biomedicine research. Further work will be performed to demonstrate the limits of the field inhomogeneity and the size of the solute molecule which the method can overcome.

Acknowledgment

This work was partially supported by the NIH under Grants NS32024 and NS41048, and NNSF of China under Grants 10234070 and 10375049.

References

[1] Vathyam, S., et al., Science, 272, 92, 1996.
[2] Chen, Z., et al., J. Chem. Phys., 115, 10769, 2001.
[3] Chen, Z., et al., JACS, in press, 2003.
[4] Warren, W.S., et al., Science, 281, 247, 1998.
[5] Zhong J., et al., Magn. Reson. Med., 43, 335, 2000.
[6] Garrett-Roe, S., et al., J. Magn. Reson., 146, 1, 2000.