Highly efficient square wave distant dipolar field and its applications for in vivo MRI

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Introduction

Intermolecular multiple-quantum coherences (iMQCs) originated from distant dipolar field (DDF) possess numerous interesting properties [1]. They have been developed for many important applications in NMR spectroscopy [2] and MR imaging [3]. However, a more general utilization of iMQCs is hindered by the poor signal-to-noise ratio inherent to current methodologies. Recently, Branca and co-workers suggested to use square wave DDF to enhance the iMQC signal intensity. A variant of CRAZED (Cosy Revamped with Asymmetric Z-gradient Echo Detection) sequence was proposed, which was called Z-modulation Enhanced to Binary for self-Refocused Acquisition (ZEBRA) sequence [4]. In this abstract, a composite adiabatic inversion pulse was utilized to replace the series of adiabatic inversion pulses in the ZEBRA sequence, and the technique was applied to in vivo MR imaging.

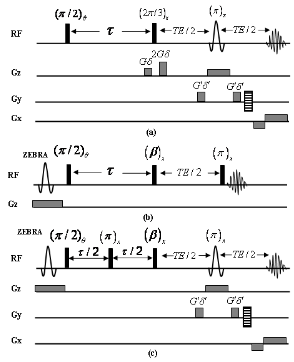

Fig. 1 Pulse sequences used to detect iDQC signal. (a) Original CRAZED imaging sequence, (b) ZEBRA spectroscopic sequence, and (c) ZEBRA imaging sequence.

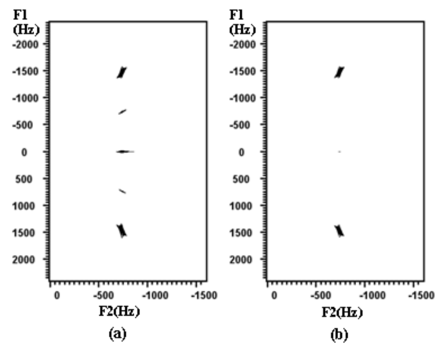

Fig. 2 2D iMQC spectra of a lemon sample from the ZEBRA sequence without phase cycling (a) and with a four-step phase cycling (b).

Experiments and results

The experiments were performed at 298 K on a 7T MRI system with horizontal-bore Magnex magnet, equipped with 10 cm bore imaging gradients at 40 G/cm. Fig. 2 shows the 2D spectra of a whole lemon sample to illustrate the effects of the ZEBRA sequence, which is shown in Fig. 1(b). To distinguish the signals from different iMQC orders in the 2D spectra, the ^{1}H frequency offset was set to 740 Hz. The MR images of the lemon sample are shown in Fig. 3. The experimental parameters were: 7 cm field of view, 64 × 64 matrix, TR = 6 s, and 2 mm slice thickness. Fig. 3(a,b) were obtained with the ZEBRA sequence proposed by Branca and co-workers [4]. Fig. 3(c,d) were obtained with the modified ZEBRA sequence shown in Fig. 1(c). Fig. 3(e,f) were obtained with the CRAZED sequence shown in Fig. 1(a). The echo time (TE) was optimized for maximal signal intensity: 240 ms for the ZEBRA sequence and 300 ms for the CRAZED sequence. The profiles were obtained from the accumulated projections of all voxels onto the horizontal axis.

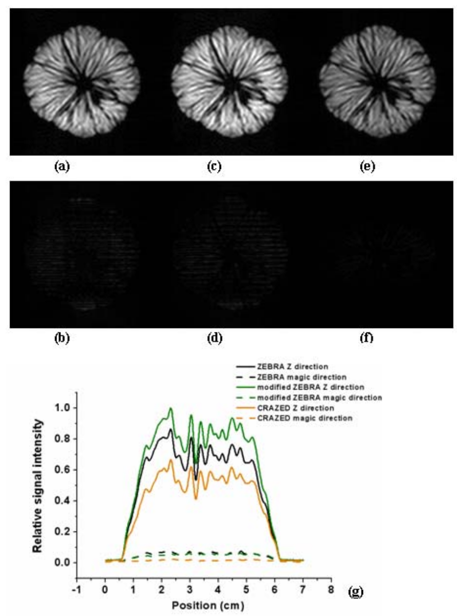

Fig. 3 MR images of a whole lemon from the ZEBRA and CRAZED sequences. (a) Image from the ZEBRA sequence proposed by Branca et al. with the DDF along the Z direction; (b) the same as (a) but with the DDF along the magic angle direction; (c) Image from the modified ZEBRA sequence proposed in this work with the DDF along the Z direction; (d) the same as (c) but with the DDF along the magic angle direction; (e) image from the CRAZED sequence with the CSGs along the Z direction; (f) the same as (e) but with the CSGs along the magic angle direction; and (g) the profile curves corresponding to (a~f).

Discussion

All the intermolecular double-quantum coherence (iDQC), intermolecular single-quantum coherence (iSQC) and intermolecular zero-quantum coherence (iZQC) signals appear when no phase cycling is applied (Fig. 2(a)). The intensity of iDQC signal is strongest because the ZEBRA sequence has been optimized for the iDQC signal. When a four-step phase cycling with the phases of the first RF pulse (x, -x, y, -y) and the receiver (x, x, -x, -x) is applied, only iDQC signals remain (Fig. 2(b)). These results indicate that the ZEBRA sequence combined with the four-step phase cycling scheme can provide pure iDQC signal with +2 and -2 coherence orders.

The same lemon sample was used to study the effectiveness of the ZEBRA sequence in MR imaging. As illustrated in Fig. 3, the ZEBRA sequence results in better images in comparison to the CRAZED sequence (Fig. 3(a,c) versus Fig. 3(e)). The signal intensity from the original ZEBRA sequence is about 1.3 times of that from the CRAZED sequence (Fig. 3(e)), while it is about 1.5 times for the modified ZEBRA sequence shown in Fig. 1(c). The smaller gain (1.5) for the modified ZEBRA sequence compared to the theoretical prediction (1.78) may be mainly due to the incomplete rectangular exciting profile of the adiabatic inversion pulse, which leads to non-ideal square wave DDF. The smaller gain (1.3) of the original ZEBRA sequence compared to the modified one (1.5) implies the adverse effect of greater diffusion attenuation during the action of the series of slice selective off-resonance inversion pulses used in the original ZEBRA sequence.

Acknowledgment

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References

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