Enhanced contrast in CEST MRI via intermolecular double quantum coherences

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Introduction

Tremendous potential of chemical exchange saturation transfer (CEST) agents has been demonstrated in recent years as an emerging class of magnetic resonance imaging contrast media [1]. To achieve high CEST efficiency, however, a RF saturation pulse of long duration is usually required, especially when the concentration of the exchangeable solute protons is low. The long duration saturation pulse may potentially cause overheat or even burns for in vivo applications. In our recent study of the CEST effect with intermolecular double quantum coherence (iDQC) [2], we note that an enhanced CEST contrast can be obtained with iDQC signals, even lower saturation energy was used.

Methods

The iDQC based CEST signals were obtained with a modified CRAZED sequence [3] followed by a standard spin-echo (SE) imaging sequence to form images (Fig. 1). A common $I \rightleftharpoons S$ two-site exchange model with I for lager pool and S for small pool was investigated in this study. Taking account CEST effect, a theoretical analysis for pool I was obtained using the depicted sequence

$$M_{iDQC}^{I} \propto \frac{1}{4}[M_0^I - \frac{k_{SI} M_0^S \sigma}{r_I}(1-e^{-r_I t_{sat}})]^2 \sin^2\alpha \sin\beta(1-\cos\beta) \quad (1)$$

The theoretical analysis from conventional SQC can be expressed by [1]

$$M_{SQC}^{I} \propto [M_0^I - \frac{k_{SI} M_0^S \sigma}{r_I}(1-e^{-r_I t_{sat}})] , \quad (2)$$

where k_{SI} is the exchange rate, σ is the saturation efficiency factor, t_{sat} is saturation duration, and $r_I = 1/T_1^I + k_{IS}$.

Comparing Eq. (1) with Eq. (2), a quadratic rather than a linear dependence on k_{SI} etc is seen with iDQC signals.

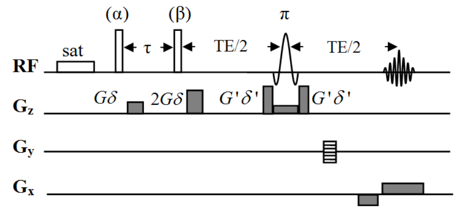

Fig. 1 The pulse sequence for iDQC CEST MRI experiments.

Results and Discussion

All measurements were carried out on a 500 MHz Varian spectrometer equipped with a 5 mm ID probe, which has a self-shielded x, y, z gradient coil. A phantom is made of two co-axial tubes. The inner tube was filled with 1% (w/v) agar gel and 0.1 mol glucose, and the outer one was filled with 1% agar gel alone. G = 0.1 T/m and the duration δ = 2 ms were used. A pair of spoil gradients were used with a strength of $G' = 0.2$ T/m and a duration of 1 ms. The field of view (FOV) = 5 mm × 5 mm, matrix size = 64 × 64, slice thickness = 4 mm. A four-step phase-cycling scheme of the α pulse (x, –x, y, –y) and receiver (x, x, -x, -x) was employed to suppress the residual conventional SQC signals. Four trains of Gaussian pulses, with total saturation durations of 0.5 s, 1 s, 2 s, and 4 s, respectively, were used to obtain the saturation transfer effects.

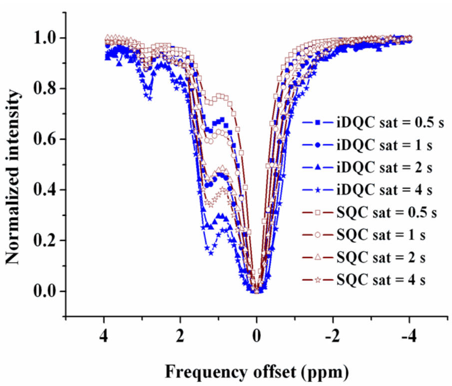

Fig. 2 z-spectra of conventional SQC and iDQC CEST experiments.

Fig 2 shows the z-spectra of iDQC CEST experiments and conventional SQC CEST experiments, with the chemical transfers at about 1.3 ppm investigated. The efficiency of the CEST from iDQC signal is clearly higher than that from the conventional SQC signal. Images from iDQC CEST MRI method and conventional SQC CEST MRI method are shown in Fig. 3. Comparing these two kinds images, it is obvious that an enhanced contrast is obtained by the iDQC method. For example, the signal difference generated by applying 2 s saturation duration with iDQC method is larger than that generated by applying 4 s saturation duration with conventional SQC method. It indicates that iDQC method allows a lower saturation power and shorter saturation time to obtain similar contrast as the conventional SQC method. Therefore, it may reduce the potential RF damages in clinic applications and be more suitable for studying the CEST effect in low concentration exchangeable solute proton systems.

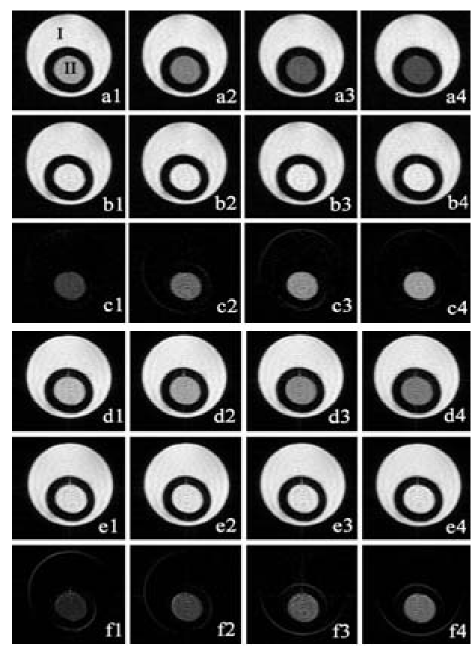

Fig. 3 iDQC CEST images (a1-c4) and corresponding conventional SQC CEST images (d1-f4). From left to right the four images correspond to the total saturation time of 0.5 s, 1 s, 2 s, and 4 s, respectively. a1-a4 and d1-d4 are the images when CEST effect is "on" with saturation irradiation at 1.3 ppm away from water resonance; b1-b4 and e1-e4 are the images when CEST effect is "off " with saturation irradiation at -1.3 ppm away from water resonance; c1-c4 and f1-f4 are the corresponding difference images of these "on" and "off " images.

Acknowledgments

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References

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