Response of the AB spin system to STEAM coherence selection: novel avenues for spectral editing at very high B_0

V. Mlynarik[1], G. Gambarota[1], R. Gruetter[1]

[1]Laboratory of functional and metabolic imaging (LIFMET), Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland

Introduction

In the past few years, the signal dependence on the echo time (TE) and mixing time (TM) in the STEAM sequence has been investigated for a number of coupled spin systems, at field strengths of 1.5 – 3 T [1-5]. Nowadays, however, it is necessary to extend these analyses at higher field strengths. In fact, the magnetic field strength of the NMR spectrometers dedicated to in vivo studies is rapidly increasing: for studies in humans, a number of high field (>3 T) MR scanners have been operational already for some time and, for animal research, 9.4 T systems are increasingly becoming ubiquitous. With increasing B_0, the spectra of coupled spin systems become more sensitive to small changes in the timing parameters (TE and TM) of STEAM sequences. The aim of the present study was to evaluate the effects of higher B_0 on the AB spin system and to elucidate the novel coherence behaviour unique to these high B_0.

Methods

Density matrix simulations were developed to investigate the spectral features of the signal shape of the AB coupled spin system under STEAM coherence generation. Citrate was chosen as a model of the AB spin system. We investigated the AB spin system since analytical formulae are available for the signal intensity of this spin system under STEAM excitation [2]. The values of J coupling and chemical shift difference were measured in a citrate phantom at 9.4 T ($J = 15.3$ Hz, $\delta = 40.7$ Hz). The signal intensity as a function of TE (from 0-100 ms) and TM (from 0-50 ms) was evaluated at 1.5 T, 3 T and 9.4 T. MR spectra of a phantom containing citrate and creatine were acquired using an actively-shielded 9.4T/31cm magnet (Varian/Magnex) with 12 cm i.d. high-performance gradients (400 mT/m in 130 µs). The creatine singlet at 3 ppm served as reference for phase correction.

Results

At 1.5 T, the simulations for the STEAM signal intensity of citrate were in excellent agreement with the analytical and experimental results of previous studies [1-3] (not shown). Figure 1 shows the simulated signal modulations, at constant TE, as a function of TM. At low fields, only minor changes in the signal intensity of the coupled spin system were observed at constant TE. As the field strength increases, the oscillations were increasingly evident and resulted in a complete inversion of the spectral multiplet. Simulated and experimental spectra - acquired at the same TE (TE = 66 ms) with two different TM delays (23 and 35 ms) show the modulation of the spectral shape of the AB spin system (Fig. 2).

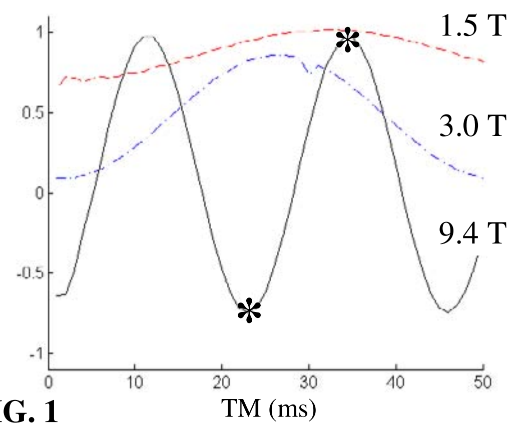

FIG. 1

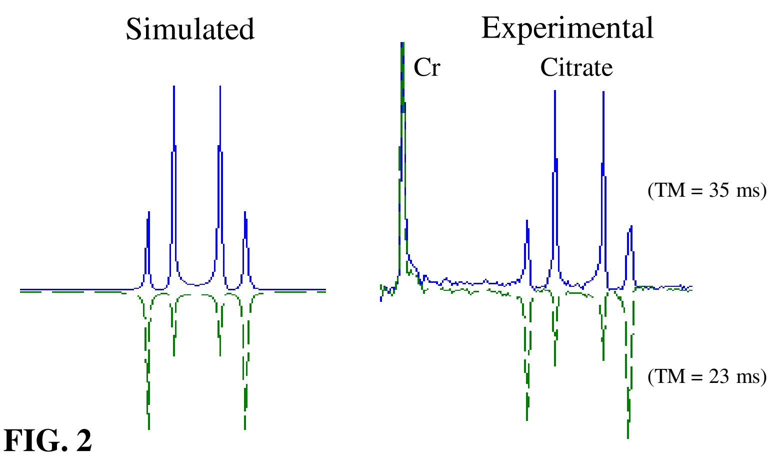

FIG. 2

Figure 1. The simulated signal modulation for the AB spin system of citrate under STEAM excitation, plotted as a function of TM, at constant TE, for different values of the field strength. For each field strength, the TE which provided the maximum signal modulation was chosen (1.5 T, TE = 60 ms, 3.0 T, TE = 60 ms, 9.4 T, TE = 66 ms). The asterisks indicate the signal amplitude of the TM oscillations at 9.4 T, at the values of TM = 23 and 35 ms. The scale of the signal intensity is normalized to value of signal at (TE = TM = 1 ms). **Figure 2.** Simulated (**left**) and experimental (**right**) spectral shape of the AB protons of citrate at a fixed TE = 66 ms and TM = 35, 23 ms (upright spectrum and inverted spectrum, respectively), acquired at 9.4 T. In the experimental spectrum, note the singlet of creatine.

Discussion

The density matrix simulation of the response of the AB spin system to STEAM coherence selection was in excellent agreement with experimental data (Fig. 2) and with the response predicted by analytical solutions provided in previous studies [1-3], thus validating the approach to numerically simulate spin system behaviour. Although most attention has been paid to the TE signal dependence, these previous studies [1-5] have also analyzed the modulations in the signal intensity of coupled spin systems, when TE is kept constant and the TM is varied (TM oscillations). The TM oscillations are influenced by zero-quantum coherences, which are characterized by the transition frequency $\nu = (\delta^2 + J^2)^{1/2}$. As the field strength increases, both the frequency and amplitude of the TM oscillations increase. While the physical mechanism underlying the TM oscillation is the same at low and high field strength, at high field strength, however, the higher sensitivity of coupled spin systems to changes in timing parameters brings out spectral features – such as spectral lineshape inversion with TM – which are not present at low fields.

Simulations of coupled spin systems at higher field strengths are necessary not only for optimization of sequence timings but also for design of new spectral editing approaches which might be based either on multiple quantum coherence or difference spectroscopy editing. Specifically, the TM oscillations could be exploited for new spectral editing methods, such as, for example, spectral editing of resonances of coupled spin systems which lie underneath singlets, since the lineshape of singlets is independent of TM.

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