A Numerical Study for the Optimization of the Echo Time in GABA Spectral Editing Methods

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Introduction

γ-Aminobutyric acid (GABA) in brain can be measured by proton spectral editing. For the detection of the 3.01 ppm resonance, J-difference (JD) editing and double-quantum filtering (DQF) have been most productive. Both methods employ spectrally selective 180° r.f. pulses to manipulate the target coherences. The editing 180° pulse is commonly long (20 - 35 ms), however the approximation to the instantaneous 180° rotation for determining the optimal echo time has been prevailing, which leads to 1/4J (≅ 34 ms) for DQF and 1/2J (≅ 68 ms) for JD. The response of the spin system is rather complicated, depending on the type and the duration of the pulse. Optimization of the echo time for the selected 180° pulse at a given field strength is critical in detecting the small GABA signal. Here, we present a preliminary result of a simulation study, by the density-matrix formalism [1], for the optimization of the echo time to achieve the maximum available GABA signal in DQF and JD at various field strengths.

Methods

The spin system of GABA was modeled with $A_2M_2X_2$, where A, M and X spins resonate at 3.01, 1.89 and 2.28 ppm respectively, and J = 7.3 Hz. Time evolution of the density operator was performed, without T_2 effects, on $\rho = -A_y - M_y - X_y = -A_{1y} - A_{2y} - M_{1y} - M_{2y} - X_{1y} - X_{2y}$ at the beginning of the echo period. A normalized coefficient of the target coherence α, $\mathrm{Tr}\{\rho\alpha\}/\mathrm{Tr}\{\alpha^2\}$, was calculated with TE increment of 0.5 ms. The coherence outside the refocusing band of the 180° pulse was removed by a 2-step r.f. phase cycling. The simulation was programmed with Matlab (The MathWorks, Inc.).

Results and Discussion

The GABA DQF may target the coherences $2A_xM_z$ and $2M_xA_z$ following the first echo period, which are subsequently converted to DQ coherence for editing. The sum of the antiphase coherences, which is responsible for the GABA signal return, has to be maximized before the conversion. Fig. 1 depicts the target coherences versus TE, for a 2-ms long non-spectrally-selective 180° pulse (*e.g.*, slice-selective). Here, the r.f. pulse with shaped waveform was used to induce a 180° rotation at the three resonances uniformly. The maximum target coherence does not differ considerably at the three field strengths (B_0). However, the echo time that gives the maximum target coherence shifts towards 1/4J as B_0 increases; *i.e.*, 22, 25 and 29 ms at 1.5T, 3T and 7T, respectively. This shift is attributed to the decreasing strong-coupling effects with the increasing B_0. The theoretical maximum yield of this type of DQF, which is 37.5% with respect to the A_2-spin triplet, is achievable only when the optimal TE is used. The use of 1/4J at 1.5T, a typical field strength clinically accessible, will result in a substantial signal loss, which amounts to ~20% of the maximum available GABA signal, as shown in Fig. 1(a).

An improved version of GABA DQF is the preparation of the target antiphase coherences by a dual-banded 180° pulse, tuned to 3.01 and 1.89 ppm [2]. We address here that the theoretical editing efficiency of this method is 50%. Since only the A and M spins undergo 180° rotation, the J evolution associated with the X spins rewinds in the second half of the echo period, resulting in an equal amount of $2A_xM_z$ and $2M_xA_z$. This enhanced yield is attainable, also, only when an optimal TE is adopted. The echo time that corresponds to the maximum available signal increases with the duration T_p of the 180° pulse, Fig. 2. The maximum target coherence and the corresponding TE are (from left to right in Fig. 2) 0.92 at 36.8 ms, 0.96 at 42.8 ms, 0.94 at 49.4 ms, and 0.84 at 56.1 ms. The 21.7-ms long pulse gives the largest GABA signal among the four pulses, however the use of this pulse at 3T may involve the macromolecule (MM) contamination. The 35.6-ms long pulse has a high selectivity, yet the signal return is little. Fig. 3 presents the TE dependence of the target coherences at 1.5T, 3T and 7T, for dual-banded 180° pulses, all designed such that the refocusing ratio at the MM 1.72 ppm resonance is 0.08. The maximum target coherences are 0.54 (1.5T), 0.94 (3T) and 1.0 (7T) at TE of 70.1, 49.4 and 39.1ms, respectively. The signal return increases as B_0 increases. This is a benefit from the use of the shorter 180° pulse for the same selectivity.

A 26.5-ms long dual-resonance selective 180° pulse, which consists of a single-narrow-banded DANTE and a binomial r.f. pulse, is often used for the JD editing [3]. The target coherences are the in-phase A_y and the antiphase $4A_yM_{1z}M_{2z}$. Only the antiphase term changes with TE considerably. Fig. 4 shows that the $4A_yM_{1z}M_{2z}$ is maximized (0.81) at TE = 85 ms, while A_y decreases gradually with TE.

In summary, both the optimal TE and the maximum available yield of GABA editing depend on the duration of the 180° pulse and the residual strong-coupling effects. These can be resolved by enhancing B_0. At a high B_0 however, the requirement of greater r.f. power to maintain the same selectivity of the localization pulses for coupled spins is another issue to be discussed.

References

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3. A. C. Ognen *et. al.*, Epilesia **42** 543 (2001).

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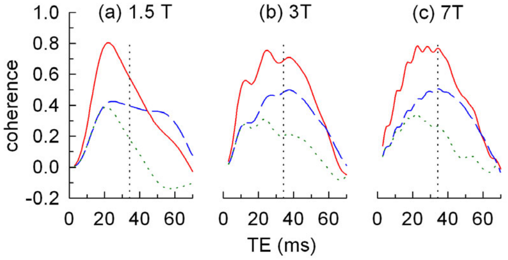

FIG 1. Echo time dependence of the normalized coefficient of the GABA antiphase coherences, $2A_xM_z$ (dashed), $2M_xA_z$ (dotted), and the sum of the coefficients (solid) for a 2-ms long non-spectrally-selective 180° pulse, at 1.5T, 3T, and 7T. The vertical dotted line indicates 1/4J (34.2ms).

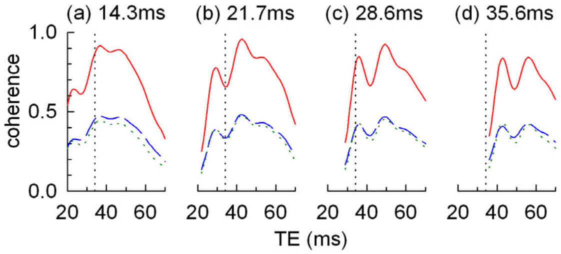

FIG 2. Similar plots to Fig. 1, for dual-banded 180° pulses with duration $T_p =$ 14.3, 21.7, 28.6 and 35.6 ms, at 3T. The r.f. pulses have a rectangular waveform that incorporates successive r.f. phase variations, governed by the frequency separation between 3.01 and 1.89 ppm.

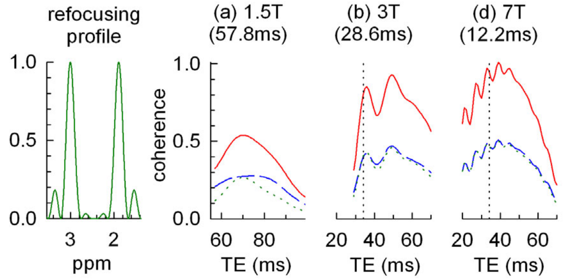

FIG 3. Similar plots to Fig. 2, for dual-banded 180° pulses with T_p = 57.8 ms (1.5T), 28.6 ms (3T), and 12.2 ms (7T). These 180° pulses were designed to have an identical refocusing profile, shown on the left.

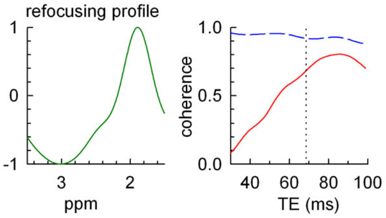

FIG 4. Echo time dependence of the coherences, $-A_y$ (dashed) and $4A_yM_{1z}M_{2z}$ (solid), for a 26.5-ms long dual-resonance selective 180° pulse (DANTE+binomial), at 2.1T. The vertical dotted line indicates 1/2J (= 68.5 ms).