Removal of Artifacts Arising from Stimulated Echoes in Proton Two-Dimensional Double-Quantum Magnetic Resonance Spectroscopy

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Introduction

Double quantum filtered (DQF) spectroscopy based on PRESS localization[1] is a valuable technique for detecting low-level metabolites including GABA[2] and glutathione[3] in brain studies. Recently, Pictet et al. reported that two-shot stimulated echoes (STE) are generated in PRESS-based DQF spectroscopy by the double quantum mixing and read pulses, giving rise to spurious signals near the water resonance frequency[4]. In that study phase cycling was used to remove the stimulated echo artifacts. These STE artifacts are also present in PRESS-based two-dimensional double quantum (2DDQ) spectroscopy[5]. However, a short phase cycling scheme may not work here because the stimulated echoes will not be in a steady state after each t1 increment, and it is not practical to use extended phase cycling schemes due to the constraint on data acquisition times. In this investigation, we present how using a spoiling pulse can be effective in removing the undesirable stimulated echo signals.

Materials and Methods

Studies were carried out on a Philips 1.5 T Gyroscan Intera whole body clinical scanner. A 2DDQ spectroscopy patch was generated by modification of a DQF pulse sequence[3]. Similar to a previous implementation[5], the 2D data set was acquired in 4 separate data acquisitions, each having 32 t1 data points and an increment of 2 ms. The combined data set has 128 evenly spaced t1 points from 0 to 63.5 ms. The t2 (single quantum) time domain was acquired with 1 kHz bandwidth and one of 256, 512 or 1024 sampling points. MREST pulses were used in all 6 directions outside the region of interest. The study was done with the setup optimized for the detection of the GABA C4 protons[6], with TE = 68 ms, TR=1500 to 2000 ms, and a binomial selective pulse for converting the double quantum to anti-phase single quantum signal. The STE spoiling consisted of a 90-degree hard RF pulse (1 ms length) immediately followed by a gradient pulse (15 ms length, gradient strength 15 mT/m, the angle between the gradient and the B_0 field was the magic angle). This block of RF and gradient pulses was executed after the signal acquisition to destroy the z-component of the magnetization, which stores the spin order giving rise to the two-shot stimulated echoes. The STE spoiling block was positioned at a fixed time point in each sub-cycle of the pulse sequence, such that the spin magnetizations at the beginning of each sub-cycle were constant and the data acquisition for the longest t1 was not interfered. Data processing was done offline on a Dell 340 Precision workstation using internally developed software written in IDL. The two dimensional time domain data were zero-filled to an array size of 1024*128 (SQ: 1024; DQ: 128). Apodization by gaussian functions was done for both the t2 and t1 dimensions with half-widths of 300 (SQ) and 150 (DQ) ms, respectively.

The solution phantom was constructed with a one-liter spherical glass vial with a cylindrical neck. The solution contained 50 mM of GABA and 70 mM of lactate dissolved in distilled water. Sodium azide was added as a preservative. The region of interest was a 5x5x5 cm^3 volume near the center of the bottle. Single quantum spectra, 1D DQF spectra (two step phase cycling, NSA=32) and 2DDQ spectra (two step phase cycling, NSA = 2) with and without STE spoiling were acquired. Spectra from control subjects were acquired with ROIs ranging from 6x6x6 to 7x8x8 cm^3, NSA = 6. Spectra acquired with (n=3) and without (n=8) STE spoiling were compared.

Results

Using two-step phase cycling, the 1D DQF phantom spectra do not contain prominent spurious signals but a clear peak arises from the two-shot stimulated echoes (Fig a, upper trace). However, when the STE spoiling pulse is applied, the residual water signal in the DQF spectrum is reduced close to the noise level (Fig a, lower trace). In contrast, the 2D phantom spectra without STE spoiling do exhibit prominent interference signals with single quantum frequencies near that of water at 4.8 ppm (Fig b). The interference peaks are completely absent with STE spoiling (Fig c). Likewise, *in vivo* human brain spectra without STE spoiling show various degrees of spurious signals near the water peak. Fig d demonstrates a case with prominent interference related to the two-shot STE. Once again, STE spoiling consistently and significantly reduces the size of the spurious signals near the water peak, and provides a reproducible spectral pattern in the region previously susceptible to interference (Fig e).

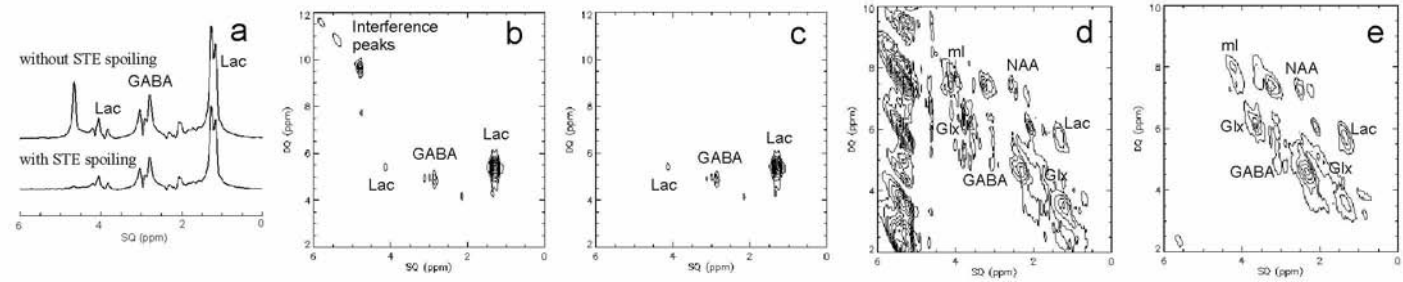

Figure. See text for explanations.

Discussion and Conclusions

The artifacts related to the stimulated echo mainly affect signals with single quantum frequency greater than 3.5 ppm. Therefore, this is not a concern for the quantification of GABA and some other metabolites. However, for the study of galactitol (SQ at 3.6-4.0 ppm), double bond lipids (SQ at 5.5 ppm), and other metabolites this is an important concern. The spoiling of the z-magnetization effectively removed the artifacts. However, STE spoiling does have the undesirable effect of decreasing the signal-to-noise ratio. This effect can be reduced if a shorter sampling time interval is used.

Acknowledgements: The authors are grateful to Dr. Andreas Trabesinger for providing DQF and 2D spectroscopy software, and for insightful discussion.

References : 1. Jouvensal L et al, MRM 1996:36:487-90; 2. Keltner JR et al, MRM 1997: 37:366-71; 3. Trabesinger AH et al, MRM 1999: 42:283-9; 4. Pictet J et al, MAGMA 2004: 17:74-9; 5. Wang ZJ et al, MRM 2003: 49:615-9; 6. Wilman A et al, JMR(B) 1995:109:169-74.