Localized two-dimensional correlated spectroscopy based on Hadamard encoding technique

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Introduction

In vivo localized magnetic resonance spectroscopy (MRS) is widely used for noninvasive analysis of tissue metabolites. Localized in vivo two-dimensional (2D) MRS was introduced to greatly overcome the low spectral resolution of one-dimensional (1D) MRS through spreading resonances on a 2D plane. A few 2D pulse sequences have been developed to obtain high-resolution in vivo human brain spectra [1,2]. However, conventional 2D spectroscopy always requires long scan time due to the long magnetization recovery time between the repeated excitations with different indirect dimension evolution times. Here, a new pulse sequence based on Hadamard encoding technique [3] was devised to speed up the acquisition of 2D correlation spectroscopy (COSY).

Methods

For Hadamard encoding technique [3], the center frequencies of M interested signal-loading areas are collected through a conventional single-pulse 1D spectrum. These M center frequencies are encoded according to an N order Hadamard matrix (N ≥ M) to generate the soft polychromatic excitation pulse which can excite M frequency sites simultaneously. After N scans with soft polychromatic pulses, the N composite free induction decay signals from the M frequency sites are decoded with the same Hadamard matrix. Then, a 2D COSY spectrum can be constructed utilizing the COSY symmetry.

The new pulse sequence is shown in Fig. 1. The first selective soft pulse is a polychromatic excitation pulse capable of exciting M interested signal-loading areas. The time τ is constant, which is in contrast to the variational indirect evolution time in conventional COSY sequence.

All experiments were performed on an 11.74 T Varian NMR System (Varian, Palo Alto, CA) with 54 mm narrow bore, using a 5-mm indirect detection probe at 298 K. A phantom built of two concentric glass cylinders was used to demonstrate the feasibility of this new sequence. The inner 1-mm-diameter tube is filled with lactate (Lac) solution and the outer 5-mm-diameter tube with γ-aminobutyric acid (GABA) solution. Three voxels of 0.3×0.3×16, 0.5×0.5×16, and 2.0×2.0×16 mm^3, were prescribed to cover only inner tube, only outer tube, and both inner and outer tubes, respectively. An eight-order Hadamard matrix was utilized and the repetition time is 5 s. The total experimental time including 4 dummy scans is about 1 min for each 2D COSY spectrum. The raw data were saved and processed using home-made software. All 2D spectra are displayed in magnitude mode.

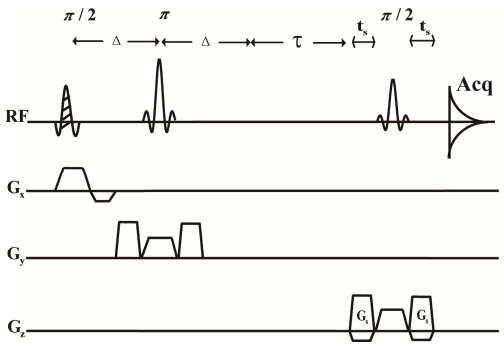

Figure 1. 2D localized COSY sequence based on Hadamard encoding technique.

Results and discussion

The experimental results of the two-compartment phantom obtained with the scheme in Figure 1 are presented in Figure 2. The axial gradient echo image in Figure 2a shows the sample geometry. The voxels of Figure 2b, c and d were located in the inner tube, outer tube, and both inner and outer tube, respectively. The spectra of Figure 2b, c and d show the signals solely from Lac, GABA, and from both GABA and Lac, respectively. These spectra are clean without contamination from other substances. These results confirm the correctness of the volume localization of the new scheme and show that the new scheme has the ability to detect the signals from a specific voxel. It should be noted that the new sequence suffers from chemical shift displacement as the point-resolved spectroscopy (PRESS) sequence. The result in Figure 2 also suggests that the new scheme is a time-efficient way to acquire localized 2D COSY spectra. For conventional localized COSY sequence [1], it always requires tens of minutes to obtain a 2D spectrum if a repetition time of 5 s is also used. For the sample here, the time efficiency is improved by dozens of times for the new scheme. However, if a complicated sample with a large number of interested signal-loading areas is investigated, the order of corresponding Hadamard matrix will increase and thus the improvement of time efficiency will decrease.

In summary, a fast acquisition sequence was designed to obtain 2D localized COSY spectra. It may promote the wider application of the 2D localized COSY in in vivo study.

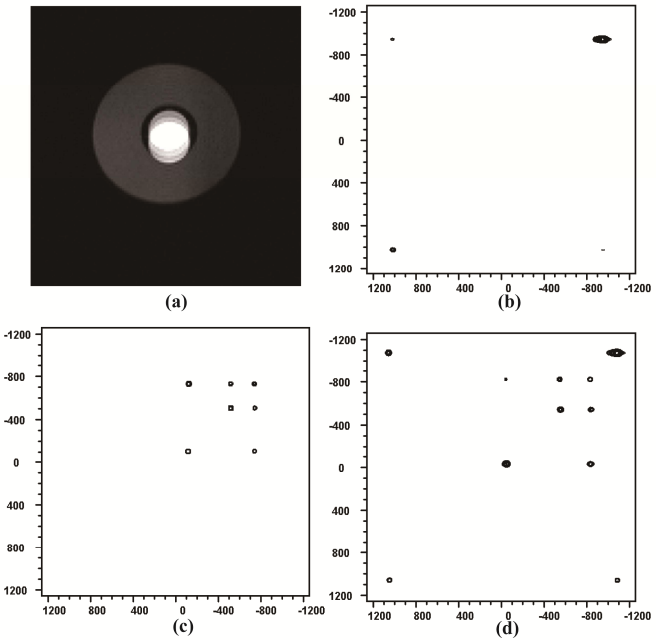

Figure 2. (a) Axial gradient echo image of a phantom made of two concentric tubes containing Lac and GABA solutions. (b~d) 2D localized COSY spectra from the voxel (inner tube) only containing Lac (b), the voxel (outer tube) only containing GABA (c), and the voxel containing both Lac and GABA (d).

Acknowledgments

This work was partially supported by the NNSF of China under Grants 11105114, 11174239 and 21175099, and the Fundamental Research Funds for the Central Universities under Grant 2010121010.

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