Improved detection of homonuclear coupled spins with constant-time PRESS and broadband refocusing pulses

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Introduction

Constant-time point-resolved spectroscopy (CT-PRESS) [1] is a single voxel technique that simplifies the spectral pattern and permits the detection of J-coupled resonances with high signal-to-noise ratio by using effective homonuclear decoupling [2]. The technique relies on non-selective refocusing, i.e., effective homonuclear decoupling is only achieved if the RF pulses refocus all the resonances in a J-coupled spin system. However, this cannot be achieved throughout the volume of the selected voxel due to the chemical-shift displacement error (CSDE) caused by the limited bandwidth of the slice-selective RF pulses, leading to signal loss for coupled resonances. In this study a broadband slice-selective 180° refocusing pulse (S-BURBOP [3]) was designed and implemented into CT-PRESS. It was evaluated and compared to a conventional Shinnar-Le Roux (SLR) pulse on a phantom and in vivo on healthy volunteers.

Methods

The S-BURBOP pulse was designed using numerical optimization based on optimal control theory [3]. The robust pulse reached broadband 180° universal rotation within a range of ±20% B_1 errors. Typically the bandwidth of refocusing pulses is increased by reducing the flip angle and scaling the pulse to the maximum available B_1 field [4]. We therefore compared the S-BURBOP pulse to the default SLR pulse with 167° and 180° flip angles (Table 1). In theory the 167° flip angle leads to a 5% signal reduction compared to 180° pulses.

CT-PRESS consists of a PRESS module in which the last refocusing pulse is shifted in subsequent acquisitions to encode chemical-shift information in the second time dimension (t_1). The time interval between excitation and data acquisition is kept constant throughout the experiment. Therefore the evolution of J-coupling is the same for each chemical-shift encoding step and the line splitting is suppressed in the frequency dimension f_1 corresponding to t_1. Following a CHESS water suppression module, CT-PRESS was applied with 65 time shifts of $\Delta t_1/2$ = 1.6 ms (TR=2s; 25mm cubic voxel). The average echo time (t_e) of 139 ms was optimized for the detection of Glutamate (Glu) [5].

Experiments were performed on a 3T GE Signa system with a quadrature birdcage coil on a spherical phantom and on three healthy volunteers (approved by the institutional review board). 1D spectra were extracted by integrating over an interval of 0.20ppm around the diagonal of the 2D spectrum in magnitude mode.

Results

CT-PRESS measurements were performed with the default SLR refocusing pulse of the GE PRESS sequence and repeated with both refocusing pulses replaced by the S-BURBOP pulse (Table 1). The spectra were normalized to the maximum peak of the methyl resonance of Creatine (Cr) at 3.03ppm. Independent of the refocusing pulse, the spectra showed the same signals from Cr (3.91ppm), Choline (Cho), and N-Acetyl Aspartate (NAA 2.01ppm) as illustrated in Fig. 1 and Table 2. For the examined SLR pulses the signals of coupled resonances were similar. The signals from Glx (Glu+Gln 3.76ppm), Glu (2.35ppm), and Lactate (Lac 1.31ppm) were significantly larger with S-BURBOP compared to SLR. In two out of the three volunteers, the S-BURBOP pulse led to the detection of the small Glutamine (Gln) C3 resonance at 2.11ppm, which was below the detection threshold when using the SLR pulse.

Discussion and Conclusions

CT-PRESS significantly simplified the spectra due to effective homonuclear decoupling. Compared to the SLR pulse the broader bandwidth of the S-BURBOP pulse reduced the chemical-shift displacement, which increased the signal of J-coupled resonances with large chemical-shift differences such as Glu, Gln, and Lac. The spectrum of volunteer C measured with S-BURBOP showed some signal at <1.5ppm. It was probably due to excitation of lipid signal from the scalp far from the PRESS voxel and could be avoided with outer-volume suppression pulses. The larger bandwidth comes at the cost of larger pulse energy (Table 1) and therefore the application of S-BURBOP may be limited to measuring with long repetition times. S-BURBOP pulses are insensitive to ±20% B_1 errors and are consequently robust against experimental imperfections.

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References: [1] Dreher W, Leibfritz D, MRI 1999; [2] Bax A, Freeman R, JMR 1981; [3] Janich MA, et al, JMR 2011; [4] Raidy T, et al, ISMRM 1995 p.1020; [5] Mayer D, Spielman DM, MRM 2005.

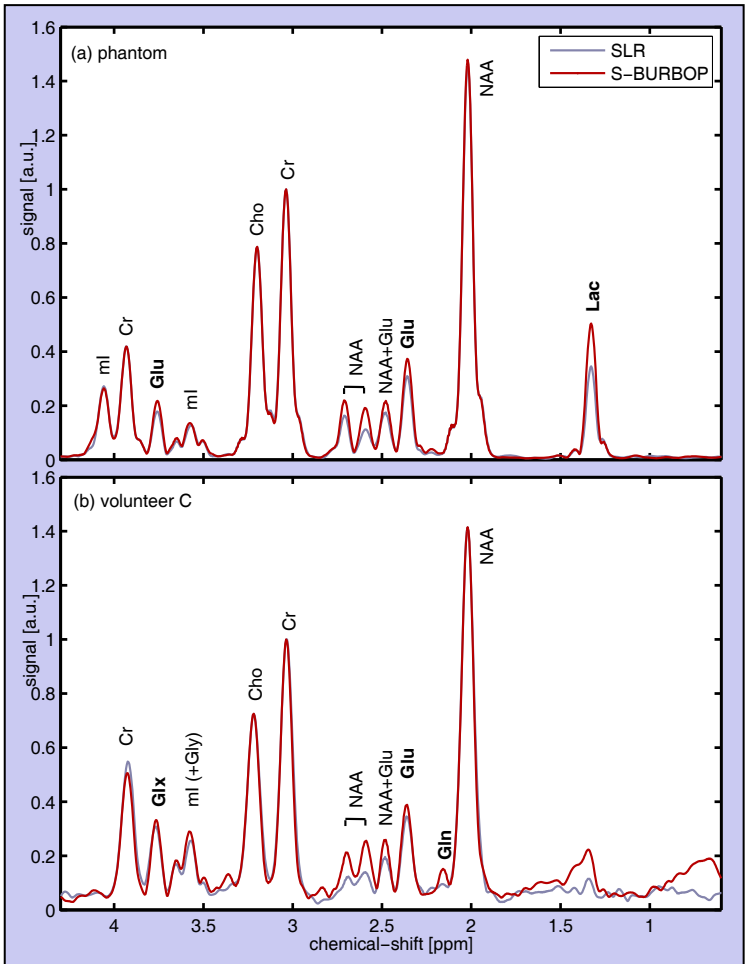

Fig. 1: (a) CT-PRESS spectra from a spherical phantom filled with various brain metabolites at physiological concentration levels acquired with the default SLR pulses (1899Hz bandwidth, blue) and the S-BURBOP refocusing pulses (3749Hz bandwidth, red). (b) CT-PRESS spectra from the occipital lobe with predominantly gray matter of a representative subject using the same pulses as in (a).

pulse	duration [ms]	bandwidth [Hz]	$B_{1,max}$ [µT]	flip angle [deg]	energy (relative)
SLR	5.2	1385	21	167	0.7
SLR	4.1	1761	29	180	1.4
SLR	3.8	1899	29	167	1.0
S-BURBOP	5.2	3749	29	180	8.4

Table 1: RF pulses applied in the CT-PRESS sequence.

(a) phantom	Cr	Glu	Cho	Glu	NAA	Lac
SLR	0.42	0.18	0.79	0.31	1.46	0.35
S-BURBOP	0.42	0.22	0.79	0.37	1.48	0.50

(b) in vivo	Cr	Glx	Cho	Glu	NAA	Lac
SLR	0.52±0.03	0.28±0.03	0.67±0.05	0.32±0.03	1.49±0.10	n/a
S-BURBOP	0.52±0.05	0.33±0.01	0.71±0.02	0.43±0.04	1.58±0.14	n/a
p-value	0.46	**0.03**	0.12	**<0.01**	0.13	n/a

Table 2: Max. spectral peak amplitudes of methylene Cr (3.91ppm), Glx (3.76ppm), Cho (3.19ppm), Glu C4 (2.35ppm), NAA (2.01ppm), and Lac (1.31ppm) divided by max. peak amplitude of methyl Cr (3.03ppm). The pulses from Table 1 were used on (a) phantom and (b) in vivo on three healthy volunteers. The p-values give the results of a t-test on same means of the peak amplitudes measured with SLR and S-BURBOP. Compared to SLR, the signals from Glx, Glu and Lac were significantly higher with S-BURBOP indicating that the larger bandwidth improved effective homonuclear decoupling by reducing the CSDE.