Fully-refocused SPatio-temporal ENcoding (SPEN) MRSI using Fourier-Encoding Polychromatic Spectral Pulses

Zhiyong Zhang[1,2] and Lucio Frydman[1]

[1]*Chemical Physics Department, Weizmann Institute of Science, Rehovot, Israel,* [2]*Department of Electronic Science, Xiamen University, Xiamen, Fujian, China*

Target audience: MRI/MRSI sequence programmers, researchers interested in brain metabolic mapping and water-fat separation imaging.

Purpose: To develop a fast and robust MRSI sequence to map chemical shift images using Fourier encoding of the resonances and single-scan fully refocused spatiotemporal encoding of the images.

Introduction:

SPatiotemporal ENcoding (SPEN) [1] provides an alternative to EPI with similar acquisition durations, resolution and sensitivity parameters. Particularly robust are fully-refocused SPEN experiments [2], providing a voxel-by-voxel refocusing of all frequency shifts in the sample along the PE domain. While this removes all shift information, we have recently shown how polychromatic (PC) pulses targeting a priori resonances, can be used to phase modulate and eventually separate peaks from different sites [3]. In this study, this Fourier Encoding based on PC 180° pulses is combined with fully-refocused SPEN experiments, to provide a PC-SPEN MRSI sequence that is both efficient and robust for the rapid acquisition of spectroscopic images.

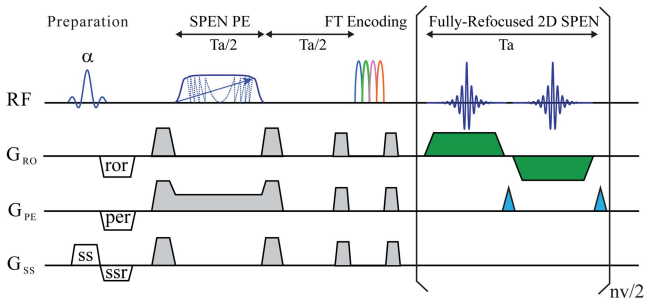

Fig. 1 Fully-refocused polychromatic SPEN (PC-SPEN) MRSI sequence. The shaped pulse with an arrow represents a 180° adiabatic sweep pulse imparting the SPEN; the multi-color shaped represents a Fourier-encoding 180° polychromatic pulse imparting different phases on different resonances and allowing the separation of N site 2D images in N scans [3].

Methods:

An example of PC-SPEN MRSI is shown in Fig. 1. The PC 180° pulse following the adiabatic sweep 180° pulse and timed as indicated, provides full refocusing [2] while addressing N resonances of interest according to $PC_m = \sum_{n=1}^{N} P_{180}^{n}(\Omega_n) e^{i\pi mn/N}$, where $0 \le n \le N\text{-}1$, m is a scan index among $M \ge N$, and $P_{180}^{n}(\Omega_n)$ is a selective 180° pulse centered at the frequency of the n-th resonance, Ω_n. This manipulation behaves as Fourier encoding, imparting a phase modulation $e^{i2\pi mn/N}$ into n-th chemical shift component in m-th scan. After Fourier transforming these scans' signals, all chemical shifts – as well as their images – are separated. Moreover, this PC pulse restores to equilibrium all spins that were not targeted by the initial slice-selective excitation, enabling multi-slice spectroscopic imaging. Notice that, for the different decoded image components there will a position shift along SPEN's low-bandwidth dimension, which can be corrected using the corresponding chemical shift information. All the SPEN images are processed with a referenceless super-resolution (SR) reconstruction algorithm [4].

Results & discussion:

A phantom made up of three components (Cho, NAA, Lac methyl resonances at 3.16, 1.93 and 1.27 ppm; N = 3.) was test. Its PC-SPEN results are shown in Fig. 2a-f for an overdetermined number of M = 6 scans. These phase modulated SPEN images were used in a Fourier transform, yielding the chemical shift separated imaging in Figs. 2g-i). Figure 3 shows PC-SPEN's performance to separate fat and water in the inferior abdomen region of a mouse. Multi-can spin echo images involving fat suppression and water suppression highlight the water- (Fig. 3a) and fat-rich (Fig. 3b) regions, respectively. Using Fourier encoding with M = 4 scans, comparable water- and fat-tissue images (Fig. 3c and d) are separated by the PC-SPEN MRSI sequence. A slight signal decay at the edges of Fig. 3d arises from imperfections in the adiabatic sweep inversion pulse near the edges of the FOV along SPEN dimension.

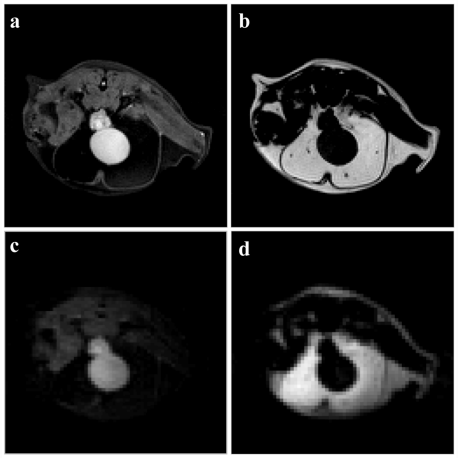

Fig. 3 *In vivo* fat/water separation capabilities of the PC-SPEN MRSI method, as applied to abdominal mouse investigations. (a, b) Multi-scan spin echo references involving fat (a) and water suppression (b). (c, d) Water- and fat- tissue images separated by PC-SPEN MRSI sequence. Parameters: FOV = 45 × 45 mm^2; matrix size = 64 × 64; slice thickness = 2 mm; Ta = 24.6 ms; PC pulse duration = 5 ms; Total scan time for multi-scan spin echo is 11 min, while the PC-SPEN MRSI required only 20 sec.

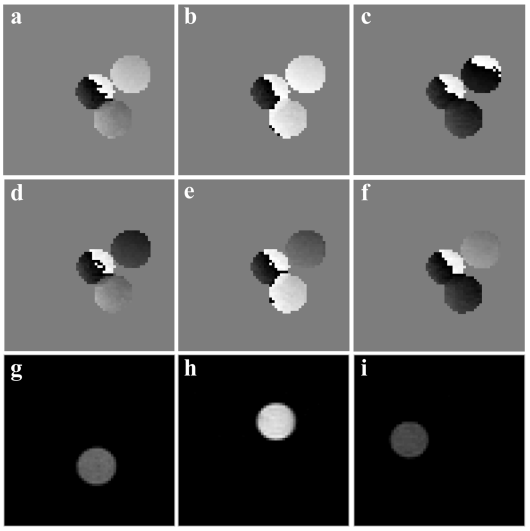

Fig. 2 Phantom test for the PC-SPEN MRSI sequence performed on three tubes containing separate choline (Cho, 50 mM), N-Acetyl-L-Aspartic acid (NAA, 250 mM) and sodium lactate (Lac, 125 mM) solutions, immersed in a water tube. (a-f) Six phased SPEN images, modulated by the 20 ms PC pulses imparting the spectral Fourier encoding. (g-i) Separated chemical shift component images decoded from (a-f). Scan parameters: FOV = 20 × 20 mm^2; matrix size = 64 × 64; slice thickness = 4 mm; Ta = 24.6 ms. Total scan time = ~24 min with an average of 128 for SNR sake.

Conclusion:

PC-SPEN MRSI provides a robust technique to map multiple chemical shift images with high time efficiency.

Acknowledgements:

This work was funded by Israel Science Foundation grant 795/13, by ERC advanced Grant #246754, and by the generosity of the Perlman Family Foundation. ZZ is also thankful for financial support from the China Scholarship Council (201306310056).

References: [1] A. Tal, L. Frydman, Prog. Nucl. Magn. Reson. Spectrosc., 57(2010): 241-292. [2] R. Schmidt, and L. Frydman, Magn. Reson. Med., 71(2014):711-722. [3] Z.Y. Zhang, P. Smith and L. Frydman, J. Chem. Phys. In press. [4] A. Seginer, R. Schmidt, A. Leftin, et al., Magn. Reson. Med., DOI: 10.1002/mrm.25084