A Robust Suite of Fast and Ultrafast Methods for In Vivo Spectroscopic Imaging of pre-Targeted Peaks

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Introduction

Magnetic resonance spectroscopic imaging (MRSI) plays numerous roles in contemporary research. In particular, faithful maps of individual metabolites may be obtained by MRSI, and be used to elucidate the relationships between the brain's metabolism to its structure and function, or to diagnose the status of healthy and malignant tissues. However, traditional chemical shift imaging (CSI) may suffer from protracted acquisitions due to the high (4D) dimensionality nature of these experiments. **In this study three new fast and robust MRSI methods are presented, designed under the assumption that the MRSI scan will only address pre-determined, user-selected frequencies.** The three methods are: SPatiotemporal ENcoded Spectroscopic Imaging (**SPENSI**), PolyChromatic SPatiotemporal Encoding (**PC-SPEN**) and Spectroscopically Encoded Chemical Shift Imaging (**SECSI**).

Methods

SPENSI

SPENSI relies on an "ultrafast" encoding [1] (using swept adiabatic π pulses) to encode the targeted spectral frequencies. Subsequently gradient "blips" in the acquisition block select a chemical shift frequency that is then imaged at each line. The block is embedded in a phase encoding CPMG-based echo train for the 2nd dimension. This is a single-shot 2D spatial /1D spectral method.

PC-SPEN

An *N*-component PolyChromatic (PC) π-pulse following a chirp π-pulse provides fully refocused SPEN imaging for all encoded frequencies [2,3]. The phases of the *N* PC pulses are Fourier modulated in *N* scans to allow separate 2D spatial images for all resonances by the Fourier transformation. This requires at least N scans.

SECSI

Multiband selective pulses target only resonances of interest [4], with possible relaxation enhancement if protons exchange with the non-excited water. Imaging is achieved by a 1D LASER block, followed by a GRASE-like acquisition. Spectra are resolved by a matrix inversion for *N* refocused readout gradients at τ intervals. A full 2D spatial / 1D spectral acquisition in a single-shot is achieved by an echo train carrying out the phase encoding

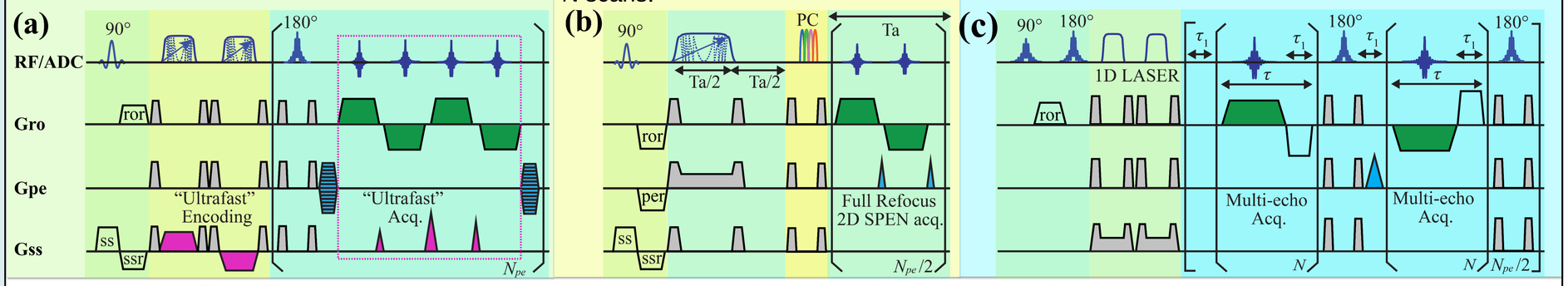

Fig. 1 Three spectroscopic imaging sequences. (a) SPENSI; (b) PC-SPEN; (c) SECSI. See text for specific details.

Results

A comparison of the methods is illustrated in Fig. 2, on a test phantom, while in vivo water/fat(/silicon) separation is shown for each in Figs. 3-5. (See captions for details)

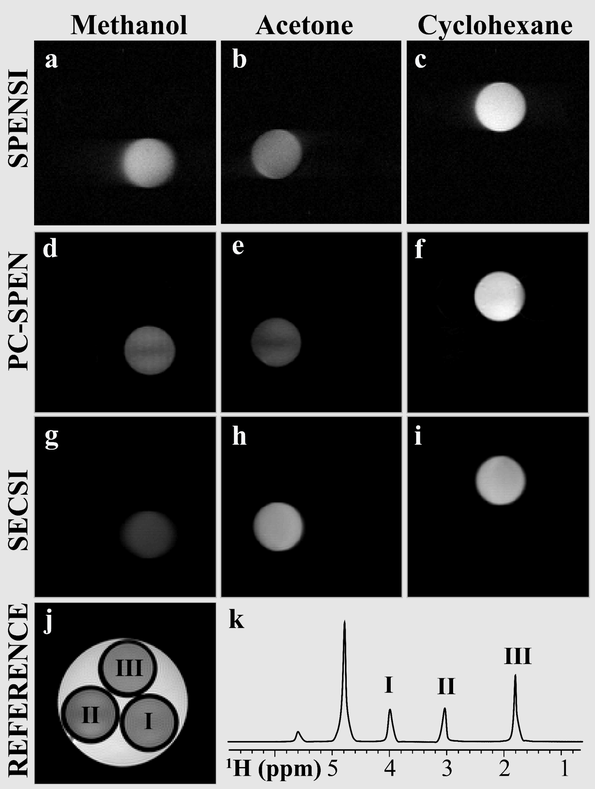

Fig. 2 Three-chemical imaging of a phantom made of Methanol, Acetone, and Cyclohexane tubes inside a water tube; see spectrum and reference at bottom. SPENSI and SECSI are single-shot acquisitions while PC-SPEN is a three shot acquisition with phase modulation addressed by PC pulses.

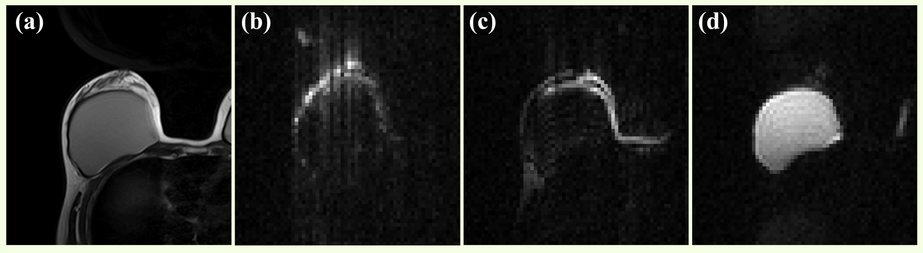

Fig. 3 3T healthy volunteer breast imaging using a "single shot" **SPENSI** sequence. (a) turbo-SE reference image. (b) Connective tissue, (c) fat, and (d) a silicone implant. FOV = 24 × 24 cm^2, slice thickness =10 mm, image size = 64×64.

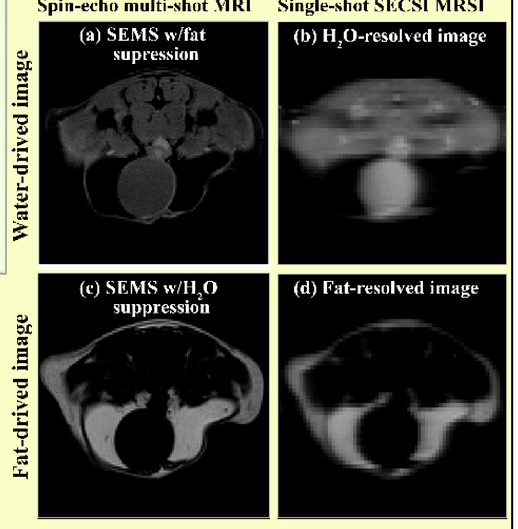

Fig. 4 *In vivo* fat/water separation using the **SECSI** sequence, applied to abdominal mouse imaging at 7T. (a, c) Multiscan spin echo references involving fat suppression (a) and water suppression (c). (b, d) Water- (b) and fat-tissue (d) images separated by a single-scan SECSI acquisition. Common imaging parameters: FOV =32 × 32 mm^2, slice thickness = 2 mm. The reference image matrix size was 128×128; due to the short T_2s the SECSI image size was 64×64, which explains the lower resolution. Total SECSI acquisition time (including a reference navigator scan): 4 sec.

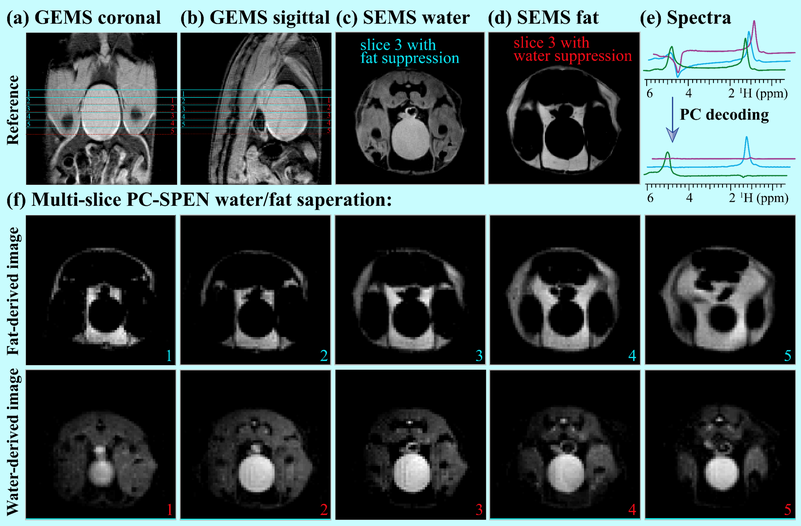

Fig. 5 *In vivo* fat/water separation using the **PC-SPEN** methodology, applied to abdominal mouse imaging at 7T. (a, b) Scout images for the 5-slice selection, the water-derived slices are marked in red lines while the fat-derived slices are marked in green lines. (c, d) The 3rd multiscan spin echo references involving fat suppression (c) and water suppression (d). (e) The spectra acquired using the sequence with slice selection pulse followed by PC pulses in three scans and well-separated spectra after applying a Fourier transform (PC decoding) on the encoded spectra. (f) The water/fat separation using PC-SPEN sequence, applied to the 5 slices. Common parameters of these images: FOV =40 × 40 mm^2; slice thickness = 2 mm; bandwidth of chirped pulse =10.9 kHz; PC pulse duration = 5 ms . The total scan time for PC-SPEN is 15 sec using 3 scans with PC phase modulation. The edges' decay along SPEN dimension in PC-SPEN images is due to the chirp encoding profile has rising and falling edges.

Conclusion: The new methods provide new options of acquiring MRSI information in a faster, more efficient manner.

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