Effectively Decoupled Spiral CSI with Frequency-Selective Lipid Suppression at 3 T

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Introduction

Fast Constant Time (CT)-PRESS based spiral chemical shift imaging (CSI) [1,2] has been introduced as an alternative to short TE CSI. By using effective homonuclear decoupling [3] it allows the detection of coupled resonances such as glutamate (Glu) and *myo*-inositol (mI) with improved signal separation and high signal-to-noise ratio (SNR). The PRESS pre-localization is advantageous for lipid suppression when pre-selecting a volume entirely within the brain. But it also increases the minimum evolution time (t_c, echo time at the central CS encoding step), which can be used to optimize the SNR of a particular coupled resonance. Using a PRESS module also potentially increases the signal loss due to transverse relaxation. Therefore, the aim of this work was to implement a fast effectively decoupled CSI sequence without PRESS pre-localization in order to reduce the minimum t_c. A frequency-selective inversion pulse was used to suppress lipid signals from the scalp.

Methods

All measurements were performed on a GE 3 T MR scanner equipped with self-shielded gradients (40 mT/m, 150 mT/m/ms). A quadrature bird-cage coil was used for both RF excitation and signal reception.

The implemented sequence consists of six parts: (a) a frequency-selective inversion pulse (b) two CHESS pulses for water suppression, (c) an outer volume suppression (OVS) module, (d) a slice(*z*)-selective excitation pulse, (e) a slice-selective(*x*) refocusing pulse (167°) for CS encoding in f_1, and (f) a spiral readout gradient for combined spatial(*xy*)-spectral(f_2) encoding. The inversion pulse (20 ms) was designed with a pass band of 500 Hz and a transition band of only 50 Hz [4]. The pulse was applied with a frequency offset of -285 Hz relative to the singlet resonance of N-acetyl-aspartate (NAA) at 2 ppm. The CS encoding pulse was shifted in increments of 6.4 ms in 17 steps leading to a spectral width SW_1 of only 78.125 Hz. Therefore, the 2D spectra are severely aliased in f_1. But as the signals occur close to the spectral diagonal, the aliasing does not lead to signal overlap. By eliminating the *y*-selective refocusing pulse and using the *x*-selective pulse for CS encoding t_c could be reduced from 151 ms to 125 ms. The spatial-spectral encoding was performed with 12 spatial interleaves for an oversized FOV of 48×48 cm^2 with a 32×32 matrix (2×1.5×1.5 cm^3 nominal voxel size) and SW_2 of 1050 Hz. Due to hardware restrictions the number of data points acquired continuously at the readout bandwidth of 250 kHz was 7168. Therefore, each readout consisted of 10 blocks of 7168 points to increase the nominal spectral resolution in f_2. The readout was repeated with the start of data acquisition shifted by 1.3 ms to fill the resulting gaps in the acquisition. The spiral CSI module was shifted together with the CS encoding pulse in order to increase the SNR. With a TR = 2s T_{meas} was 13:44 min. If the experiment is not limited by SNR, a variation of the spiral design (24×24 cm^2, 16×16 matrix) can be used leading to a T_{meas} of 4:40 min.

The data post-processing comprised gridding, apodization in the spectral dimensions (multiplication with sine-bell functions and zero-filling), and FFT. A t_1-dependent linear phase correction was performed along f_2 to correct for the differences of the start of data acquisition. After unwrapping the 2D spectra in f_1 diagonal spectra were calculated by integrating the signal along f_2 within a ±13 Hz interval around the spectral diagonal.

Results and Discussion

The sequence was tested on a spherical GE MRS phantom filled with a solution of various brain metabolites at physiological concentration levels. The 2D contour plot from a single voxel of the phantom (Fig. 1, bottom) demonstrates the effect of the effective decoupling scheme as the line splitting due to J-coupling is suppressed in f_1. Therefore, all the signals appear as single lines in the corresponding diagonal spectrum (Fig. 1, top). With a TI of 470 ms the lactate resonance at 1.3 ppm is completely suppressed while other resonances are unaffected. For the in vivo application of the method a 20×107×142 mm^3 volume (axial slice orientation) was selected by OVS just above the ventricles of a healthy volunteer as shown in Fig. 2a. The TI was 190 ms. Both spectra from voxels containing predominantly gray matter (Fig. 2b) and subcutaneous fat (Fig. 2c), respectively, demonstrate that the spectral region downfield of 2 ppm is not affected by the inversion pulse. The suppression factor for the lipids is about 7. Figure 2b also shows the good separation of the Glu C4 resonance due to effective decoupling.

Conclusion

The presented data show the feasibility of effectively decoupled fast spiral based CSI. This implementation allows the reduction of the minimum t_c of the sequence. An inversion pulse with a sharp transition band of 50 Hz was used to suppress lipid signals from the scalp. By using effective decoupling this work demonstrates that compounds such as Glu and mI can be reliably measured without water or lipid baseline artifacts which typically hamper short TE CSI. Further improvement in lipid and water suppression can be achieved by using a spatial-spectrally selective refocusing pulse which pass band does not include these resonances. Changing the selectivity of the refocusing pulse to *z* permits a multi-slice variant of this method.

References

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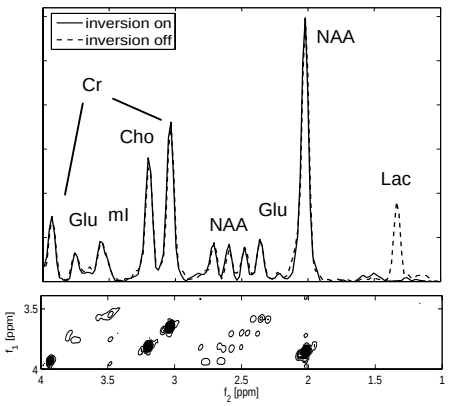

Fig. 1: 2D contour plot and diagonal spectrum (with (solid), without (dashed) inversion)) from a single voxel from a phantom filled with a solution containing physiological concentrations of several brain metabolites.

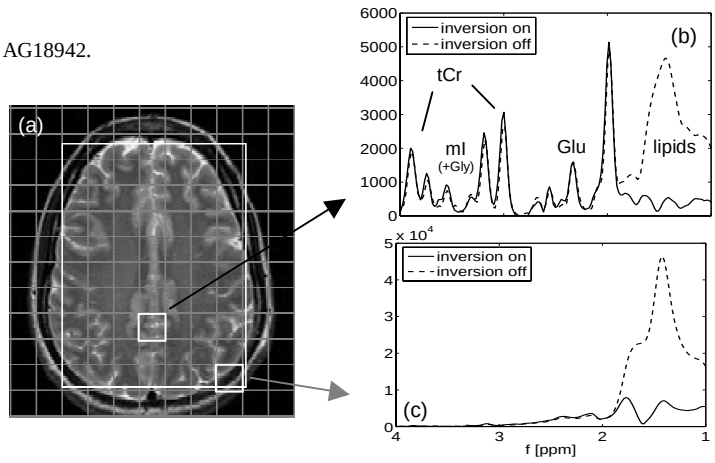

Fig. 2: Effectively decoupled spectra from voxels from a healthy volunteer containing predominantly gray matter (b) and subcutaneous fat (c), respectively. The location of the voxels is indicated in the water MRI (a). Also shown is the volume as defined by OVS and the *x*-selective refocusing pulse. For each voxel the spectra acquired with inversion (solid) and without inversion (dashed) are shown.