Fast SSFP Based Spectroscopic Imaging Optimized For Lactate Using Partial Refocusing Of Signal Modulations caused by J-coupling

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Introduction

Several new sequences based on the condition of steady state free precession (SSFP) have been proposed recently for ^{31}P [1] and ^{1}H [2] spectroscopic imaging (SI). A modification of the spectroscopic CE-FAST sequence [2] is described which allows very fast 3D SI with increased sensitivity for lactate (Lac) making use of partial signal refocussing of coupled signals. The effect is shown in phantom and in vivo/ex vivo experiments on rat brain.

Methods

The proposed pulse sequence is depicted in Fig.1. A chemical shift (cs) selective composite pulse is used for signal excitation/refocussing that was optimized regarding a flat frequency profile for flip angles of 40° to maximize the signal intensity for singlet signals at typical values of TR, T1, T2. Signal distortion for large offset frequencies is avoided by detecting only the echo-like signal S2 (as in the imaging sequence CE-FAST [3]) and suppressing the FID-like signal S1 by spoiler gradients. Spatial resolution is achieved by phase encoding gradients. The train of six rectangular pulses (1-τ-1-τ-8.0-τ-8.0-τ-1-τ-1, minima appear at 1/τ) originally used for simultaneous water and fat suppression with τ=1.25 ms [4] can be adjusted by varying τ according to the desired spectral range as shown in Fig. 2. The calculated pulse profiles are shown in red τ=2.4 ms and black: τ=0.8 ms). The postitions of the methyl signals of Lac and N-acetyl aspartate (NAA) signals are marked by black bars. If τ is shortened to 0.8 ms it is possible to achieve an elevated CH_3 signal of lactate at 1.33 ppm because the coupled resonance at 4.11 ppm (CH(C-2)) is not or only partially refocused by the composite pulse. A similar mechanism has been described for the case of double-spin-echo spectroscopy [5].

The sequence was implemented on a 4.7 T/40 cm Bruker Biospec system with actively shielded gradients (170mT/m in 450µs). The FOV was 48x48x48 mm³ (in vivo: 32³ mm³) with a matrix of 16x16x16. 512 complex data points were sampled with 10 kHz. With a TR of 65ms a total measurement time of 4 min 20s is achieved. Phantom experiments were performed using a spherical sample (40 mm i.d.) filled with an aqueous solution of 50 mM NAA and 50 mM Lac. A saddle-type resonator was used for RF transmission and detection. For in vivo experiments, healthy female Wistar rats (250-300g) were anaesthetized with 0.8-1.5% halothane in 7:3 N_2O:O_2. A surface coil of 18mm (i.d.) was used for signal detection. SI data showing lactate were acquired 1h post mortem. Postprocessing included apodization in k_ω, k_x, k_y, k_z, zero filling, 3D FFT and magnitude calculation.

Results

Fig. 3 illustrates the effect of partial refocusing of the methyl signal of Lac in the phantom measurement. The sequence parameters were the same for both cases except for the different inter-pulse delay τ (red: 2.4 ms, black 0.8 ms) corresponding to the calculated pulse profiles shown in Fig.2. The magnitude spectra originate from the same voxel and were identically postprocessed. While the NAA singlets show nearly identical intensity, an approximately two-fold increase of the lactate resonance at 1.33 ppm is observed. In addition, water suppression is improved because of the broader minimum of the modified composite pulse. A magnitude spectrum from ex vivo rat brain (1h post mortem) is given in Fig. 4 showing a 2x2x2 mm³ (nominal size) voxel of the 16x16x16 matrix. The major metabolites (Cho, tCr, NAA) from the excited/refocussed spectral interval can be identified as well as the large peak of lactate.

Discussion

When comparing the calculated pulse profiles and the phantom spectra for different τ it can be seen that the (partial) refocussing of the Lac signal gains a considerable signal increase at 1.33 ppm. The independence of the singlet signal of NAA of τ indicates that this increase of the Lac signal is not due to the pulse profile at the resonance frequencies of both methyl signals, but originates from the negligible or only partial excitation/refocussing of the coupled Lac resonance at 4.11 ppm. Additionally, there is hardly any TR dependence of the SSFP signal of Lac if the J modulation of the Lac signal is (partially) refocussed. Lipid signals overlapping with the lactate signal are a problem when applying this sequence on animal brains, particularly in voxels close to the skull. Note that the limited spectral resolution, an inherent disadvantage of SSFP based SI, is only of minor importance for the fast detection of Lac because of the rather large cs difference to the predominant neighboring NAA signal at 2.01 ppm.

References

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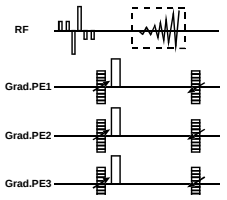

Fig. 1

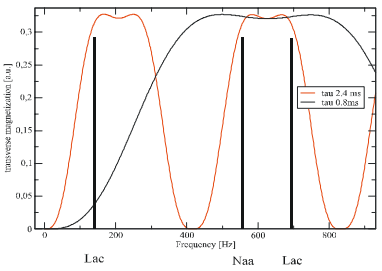

Fig.2

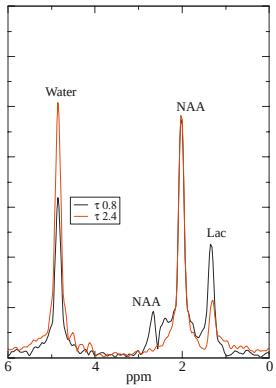

Fig 3

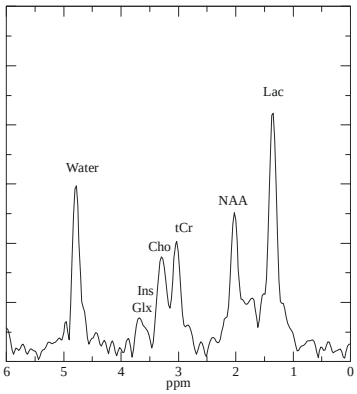

Fig.4

Fig 1: spectroscopic CE-FAST sequence with composite pulse excitation
Fig 2: calculated pulse profiles for τ=0.8 and τ=2.4
Fig 3: NAA/Lac phantom spectra for τ=2.4 ms (red) and τ=0.8ms (black)
Fig 4: post mortem (1h) rat brain magnitude spectrum acquired with τ=0.8ms