Fast 3D ^{1}H Spectroscopic Imaging of the Human Brain at 3 Tesla using "spectroscopic Missing Pulse – SSFP" with 3D Spatial Selection

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Introduction

Over the past years several methods for fast 3D ^{1}H MR spectroscopic imaging (MRSI) derived from corresponding fast MRI methods have been proposed to map the distribution of human brain metabolites. Besides echo planar MRSI and spiral MRSI [1-4], various pulse sequences based on the condition of steady state free precession (SSFP) have attracted wide interest because of their high SNR_t and their short minimum measurement time [5]. In recent works, two fast SSFP based MRSI sequences, spectroscopic CE-FAST [6] and spectroscopic Missing-Pulse SSFP (spMP-SSFP) [7] were applied to the human brain at 3T. One drawback of these implementations is that spatial selectivity is only possible in one spatial dimension leading to problems with local shimming and signal leakage of lipid signals from the scalp. This work presents improvements of the spMP-SSFP sequence which allow fast 3D ^{1}H MRSI of the human brain with full 3D spatial selectivity in about 6 minutes. In addition, as a separate water and fat suppression is not needed and phase correction of the spectra is avoided due to the acquisition of complete spin echoes, this spMP-SSFP sequence is very robust and requires only minimal user interaction.

Methods

The spMP-SSFP pulse sequence is presented schematically in Fig.1. Spectral-spatial composite pulses [8] (1-τ-1-τ-8-τ-8-τ-1-τ-1; spectral minima appear at 1/τ) with τ = 1960 µs are used for simultaneous slice and chemical shift selective RF excitation and water/lipid suppression. As proposed in the corresponding MP-SSFP MRI sequence [9] the 2nd composite pulse excites an orthogonal slice with respect to the slice of the 1st composite pulse. Thus only intersecting spins from both slices are refocused at the time of the missing pulse, while spins experiencing only one composite pulse are inherently dephased. Spatial selection in the 3rd dimension is achieved with two 2 ms slice selective 90° saturation pulses and surrounding crusher gradients carried out within the first T period which is similar to the MEGA and BASING techniques [10,11]. The spoiler gradients located after the 1st composite pulse and before and after the acquired echo eliminate unwanted coherences (cf. Fig.1). The flip angles are adjusted to $\alpha_1 = 48°$ and $\alpha_2 = -48°$ for maximum SNR_t. A VOI of 90*110*58 (x*y*z) mm³ is chosen to excite six transversal slices of the brain while the FOV has a size of 140³ mm³. With 16³ nominal phase encoding steps the nominal voxel size is 0.7 cm³. Using 3-fold Hanning filtered k-space weighting improves the SNR_t and reduces the number of phase encoding steps to 1913, but increases the real voxel size to 2.8 cm³. An acquisition window of $T_{acq} = 102.4$ ms results in a time T = 62 ms, a repetition time TR = 3T = 186 ms and a total measurement time of $T_{meas} = 6:08$ min including 64 dummy cycles to establish the steady state. The spMP-SSFP sequence was implemented on a 3T Allegra head scanner (Siemens, Germany) and experiments were performed on healthy male volunteers with the standard circularly polarized head coil. Postprocessing of the spectra included apodization in k_x, k_y, k_z with a 50% Hamming filter and in k_ω with a TRAF [12] function (T_2*=80 ms), zerofilling from 256 to 2048 data points, FFT, magnitude calculation, frequency correction and peak integration for the metabolic images.

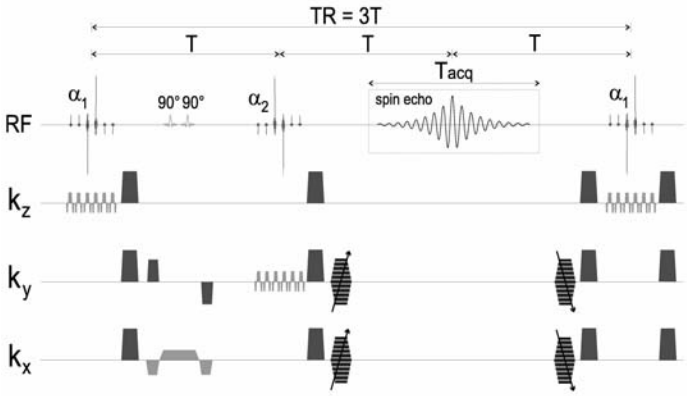

***Fig.1**: Scheme of the spectroscopic Missing Pulse SSFP sequence*

Results

Fig.2 shows a magnitude spectrum of a voxel marked in the spectral map on the right and proves the excellent water suppression and the high SNR_t. Lipid contamination from voxels in the extracranial fat tissue is strongly reduced which is verified in the spectral map with a spectral range of 4.5 to 0.5 ppm obtained from slice no. 3. The sizes and locations of the FOV (dotted line) and the VOI (solid line) are marked in the six MRI images in Fig.3. The corresponding metabolic images of NAA, tCr and tCho demonstrate the high spatial resolution and reflect the anatomical structures very well, in particular NAA and tCr.

Discussion/Conclusion

An improved spectroscopic MP-SSFP sequence was implemented as a robust and efficient method for fast 3D ^{1}H MRSI. It combines the high SNR_t and the short minimum measurement time of spectroscopic SSFP sequences with the possibility of 3D spatial selection. Therefore, reduced FOVs can be realized allowing smaller voxel sizes in a reasonable time. Furthermore, only minimal user interaction is required as no separate water/lipid suppression and phase correction are needed. The use of additional saturation pulses in the first T period will allow to excite not only rectangular but arbitrary-shaped VOIs. However, the number of saturation pulses will be limited by the higher SAR values.

References

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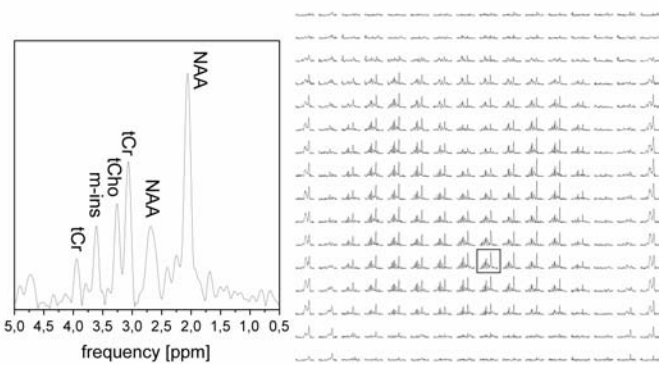

***Fig.2**: Magnitude spectrum from the voxel marked in the spectral map, spectral map from slice number 3 (4.5 – 0.5 ppm)*

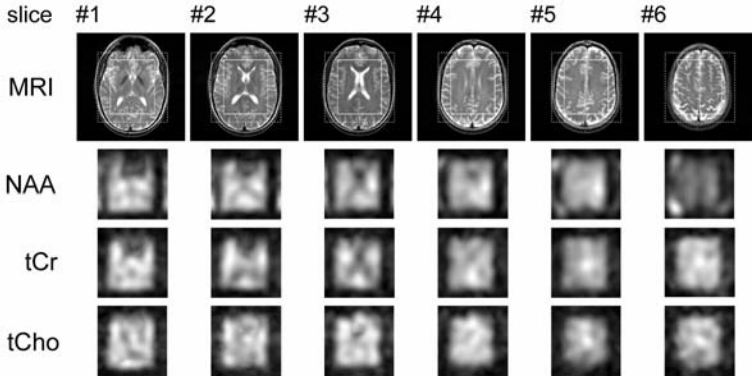

***Fig.3**: Metabolic images (NAA, tCr and tCho) of the excited six slices and corresponding MRI images; FOV (dotted line) and VOI (solid line) marked in MRI images*