Fast 3D Proton Spectroscopic Imaging of the Human Brain at 3 Tesla By Combining Spectroscopic Missing Pulse SSFP and Echo Planar Spectroscopic Imaging

W. Dreher[1], P. Erhard[1], and D. Leibfritz[1]
[1]Dept. Chemistry, University of Bremen, Bremen, Germany

Introduction: The fast spectroscopic imaging method "spectroscopic missing pulse SSFP" (spMP-SSFP) is one of the candidates for fast 3D proton spectroscopic imaging of the human brain with minimum user interaction [1,2]. However, the minimum total measurement time T_{min} is rather long for large spatial 3D matrices, as k-space sampling is only accelerated by using short TR values, typically 150-200 ms. Additionally, if only one accumulation is acquired for a short total measurement time, it is not possible to use phase cycling to suppress artifact signals or to apply k-space weighted averaging to increase the SNR_t and improve the spatial response function [3]. In the present study, this disadvantage is eliminated by sampling the echo-like signal in the presence of an oscillating read gradient, i.e. by combining spMP-SSFP with the principle of echo planar spectroscopic imaging (EPSI) [4-6].

Method: The scheme of the pulse sequence is depicted in Fig.1. RF excitation and refocusing as well as spatial preselection in two directions are achieved by two spectral-spatial pulses. In between these, 4-6 outer volume suppression (OVS) RF pulses are applied to suppress residual lipid signal from the scalp. Centered at the time of the missing pulse, continuous data acquisition is performed in the presence of a symmetrically oscillating read gradient in slice direction. Spatial localization in the two other (in-plane) directions is achieved by phase encoding gradients applied prior to and rewound after each acquisition window. Data acquisition is preceded by 64 dummy cycles to establish the steady state.

Experimental: All experiments were performed on a 3T Magnetom Allegra head scanner (Siemens, Germany) equipped with standard B_0 gradients (max. 40 mT/m and 400 mT/m/ms, used ramp time 200 µs) and a standard CP Birdcage RF head coil used for RF transmission and reception. The sequence parameters were: TR=189 ms, two 1-τ-1-τ-8-τ-8-τ-1-τ-1 spectral-spatial pulses [7] (τ=2ms, 300 µs sinc3-pulses) used for exciting and refocusing metabolite signals while suppressing water and lipid signals; maximum total flip angle for phantom measurements (α_1=40°, $\alpha_{2=}$-40°) and for in vivo measurements (α_1=50°, $\alpha_{2=}$-65°); FOV: 220mmx220mmx112mm; VOI: 220mmx120mmx56 mm; four 30mm OVS slices; spatial matrix size: 32x32x16; circularly reduced k-space sampling (in-plane) with two accumulations (T_{meas}=4:40 minutes) and additional k-space Hamming weighted averaging with four accumulation in the center of k-space (T_{meas}=4:19 minutes); continuous acquisition of 2K complex data points within 100 ms; symmetrically oscillating read gradient in slice direction with a period of 2 ms (yielding a spectral width of 500 Hz) and a gradient ramp time of 200 µs. The measured signals were interpreted as high field signals with respect to the (suppressed) water signal.

Measurements were performed on a spherical phantom (diameter: 180 mm, filled with an aqueous 50 mM solution of creatine (Cr), acetate (Ac) and myo-inositol (m-Ins) with in inserted tube (diameter: 15 mm, filled with water) as well as on healthy volunteers. SI measurements were performed after three-plane scout imaging and interleaved TSE imaging with 16 slices (5 mm thickness, 2 mm gap) used for positioning (FOV, VOI, OVS slices). Data were processed using programs written in IDL (ITT, USA). First, two data sets acquired under either positive or negative read gradient were extracted. After apodization with a cosine function, FFT in k_{slice}-direction and correction for chemical shift artifacts, the resulting 2x16 2D data sets were processed by apodization (Hamming function (α=0.54) in the spatial directions, cosine or exponential function in the time domain), followed by a 2D FFT and magnitude calculation. Finally, the two SI data sets were added for each slice. Metabolic images were calculated by peak area integration.

Results and Discussion: The implemented pulse sequence reduced the minimum total measurement time T_{min} by a factor of 16. Compared to the implementation described in [1], this acceleration was used to enlarge the FOV and spatial matrix size and to exploit the potential of k-space weighted averaging. Despite the larger number of phase encoding steps in the in-plane directions, the nominal voxel size was reduced to 0.33 cm^3 (from 0.5 cm^3)and the total measurement time reduced to 4:18 minutes (from 6:09 minutes).

Fig.2 shows results of a phantom measurement. The 16 metabolic images calculated from the myo-inositol signal at 3.56 ppm demonstrate the quality of the spatial resolution, both in the slice ("EPI") and in the in-plane (phase encoding) directions. The same spatial prelocalization as used in the measurements on volunteers was applied in slice (56 mm in z) and in one phase encoding (120 mm in y) direction. Fig.3 shows data measured on the brain of a volunteer. Fig.3a displays a typical spectrum from one SI voxel. The main signals are assigned to N-acetyl aspartate (NAA), total creatine (tCr), choline containing compounds (tCho) and m-Ins. Fig.3b,c show the TSE MR image and the NAA image for one slice containing the ventricles. The NAA image, which was calculated in all 32x32 voxel without masking, delineates the ventricles and shows some remaining problems with lipid signals. The array of 14x14 spectra (Fig.3d) illustrates the homogenous spectrum quality obtained. A high SNR is achieved despite the small voxel size, the short T_{meas} and the inherent SNR losses (~12% in the current implementation) caused by using oscillating gradients, i.e. non-constant velocity of travelling through k-space. The high SNR is, at least in part, due to the fact that the short T_{min} of the new methods allowed k-space weighted averaging. In the future, further SNR improvements can be obtained by optimized ramp sampling and by using state-of-the-art array coils for signal reception.

Conclusion: The combination of the principles of two fast SI methods, spMP-SSFP and EPSI, reduces T_{min} considerably, allowing either a higher temporal resolution, a larger spatial matrix size and/or k-space weighted averaging, while maintaining all advantages of spMP-SSFP. The inherent SNR_t loss caused by using oscillating read gradients can be compensated by applying k-space weighted averaging. A further T_{min} reduction could be achieved by parallel SI [8,9]. However, if T_{min} is already short enough, array coils can be used exclusively for signal reception to maximize the SNR.

References: [1] C. Schuster et al., MRM 57,82(2007). [2] C. Schuster et al., MRM 60,1243(2008). [3] J.W. Hugg et al., MRM 36,469(1996). [4] P.Mansfield, MRM 1,370(1984). [5] P. Webb et al., MRM 12,306(1989). [6] S. Posse et al., Radiology 192,733(1994). [7] Z. Starcuk et al., JMR 66,391(1986). [8] U. Dydak et al., MRM 46,713(2001). [9] S.Y. Tsai MRM 59,989(2008).

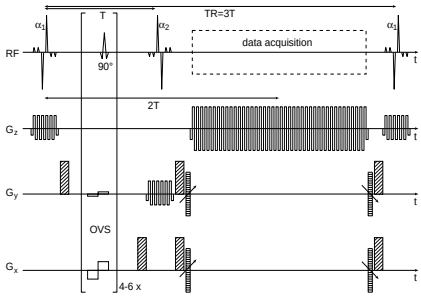

Fig.1: Scheme of the spMP-SSFP sequence with oscillating read gradient during data acquisition.

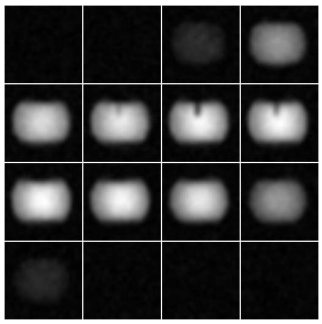

Fig.2: metabolic images of m-Ins measured on a spherical phantom for all 16 7-mm-slices.

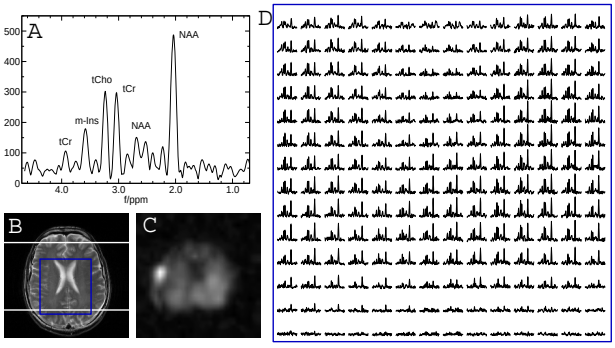

Fig.3: Results on a volunteer: (a) single SI spectrum, (b) TSE water image and (C) corresponding NAA image of one slice, (D) map of spectra (4.3-1.0 ppm).