Comparison of SSFP based and classical Proton Spectroscopic Imaging Sequences

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Introduction

Various pulse sequences based on the formation of a steady state (SSFP) signal have been proposed for proton SI and demonstrated to the rat brain in vivo [1]. In this work the signal-to-noise ratio per unit measurement time (SNR_t) of the echo-like SSFP variant (spectroscopic CE-FAST) is experimentally compared to a classical spin-echo SI experiment [2,3] that sets the gold standard in terms of sensitivity [4]. Although FID-like SSFP based proton SI measurements exhibit a higher SNR_t than their echo-like variants spectroscopic CE-FAST is preferably used because of excellent water suppression and reproducibility.

Methods

Pulse sequences: Various pulse sequences for SSFP based proton SI with 2D or 3D spatial resolution have been implemented on a 4.7T NMR imaging system [1]. These sequences measure the FID-like signal S_1, the echo-like signal S_2 or both signals in separate but adjacent acquisition windows. RF excitation is performed with slice selective or chemical shift selective RF pulses. In this abstract a 3D chemical shift selective SSFP based measurement using the echo-like signal S_2 (sequence shown in Figure 1) is compared to a classical 2D spin-echo SI measurement. Parameters of the SSFP measurement are as follows: flip angle α=40°, FOV 32x32x32mm^3, 16x16x16 phase encoding steps in x,y and z, TR=72ms, spectral width 10kHz, 128 dummy cycles, one accumulation, total measurement time T_{meas}=5:02min. In the classical SI measurement parameters are set for a fair comparison: FOV 32x32mm^2, 2mm slice, 16x16 phase encoding steps in x and y, TE=144 ms, spectral width 4006 Hz, one accumulation. TR is adjusted to 1152 ms in order to get the same total measurement time as in the SSFP experiment.

Experimental setup: Experiments are carried out on a 4.7T/40cm Bruker Biospec System (Bruker, Ettlingen, Germany) equipped with an actively shielded gradient set capable of switching 170mT/m in 450µs. RF transmission is accomplished with a saddle-type resonator and a surface coil is used for signal reception. In vivo measurements are performed on healthy female Wistar rats anesthetized with 0.8% halothane in a 7:3 N_2O/O_2 mixture and placed prone in a stereotactic animal holder. The B_0 field homogeneity is optimized for the classical 2D spin-echo SI experiment with its slice being the central slice of the SSFP measurement.

Data analysis: Measured data are processed using the interactive data language IDL (Research Systems, Inc., Boulder, USA). 4D data sets (k_ω-k_x-k_y-k_z) of a steady-state measurement are preprocessed by sine-bell apodization (0,π) and Fourier transformation (FT) along k_z with N_z=16. Thereafter, the 3D data sets (k_ω-k_x-k_y) are apodized with a Hamming function (α_H=0.66) along k_x and k_y and a cosine function (0,π/2) in the SSFP measurements. The same standard apodization procedure for echo-like signals is applied to the time domain signals of the classical SI measurement.

Results and Discussion

Figure 2 shows the results of a measurement on the rat brain in vivo. The signal intensity is reduced in the lower part of the brain is due to the sensitivity profile of the surface coil used for signal reception. The localization of the array of spectra in Figure 2b (classical SI) and 2c (SSFP) corresponds to the grid overlaid on the anatomical image (cf. Figure 2a). The magnitude spectra shown in 2d (classical SI) and 2e (SSFP) originate from the marked voxel. The separation of the tCr (3.03ppm) and choline (3.21ppm) signals of the SSFP measurement can be improved by optimized apodization functions. Due to the fact that the full echo (acq. time 127.9ms) is acquired in the classical SI experiment in contrast to a half echo in the SSFP measurement (acq. time 51.2ms) the classical SI spectra feature a higher spectral resolution.

The SNR_t (i.e. the SNR divided by the square root of the total measurement time) is calculated taking the NAA signal at 2.01 ppm of the given magnitude spectra as the reference signal. The noise is determined from the signal free region with frequencies between 7.0ppm and 6.0ppm. The SNR_t of the echo-like SSFP sequence is about 56% of the classical SI. Here the different point spread functions (PSF) due to the apodization in k_z are already taken into account (factor 1.5). This result is verified by phase-graph calculations carried out earlier [1]. In addition, it has been shown by these calculations that SSFP based measurements detecting the FID-like signal S_1 exhibit a higher SNR_t than classical SI experiments, however FID-like SSFP based proton SI and classical SI experiments have not been compared in vivo yet. Since in the SSFP measurements the B_0 field homogeneity should be optimized over the complete 3D volume (this would have resulted in lower sensitivity for the classical 2D spin-echo experiment), a slight increase in SNR_t for SSFP is feasible. Moreover the SNR_t can be further increased by using shorter repetition times as has been shown by simulations [1].

Conclusion

It has been shown that sequences for SSFP based proton SI yield a comparable SNR_t to classical SI measurements. Although the spectral resolution is limited by the repetition time of the experiment (especially at low B_0), high 3D spatially or temporally resolved applications benefit from the short minimum total measurement time of SSFP sequences.

References

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Figure 1

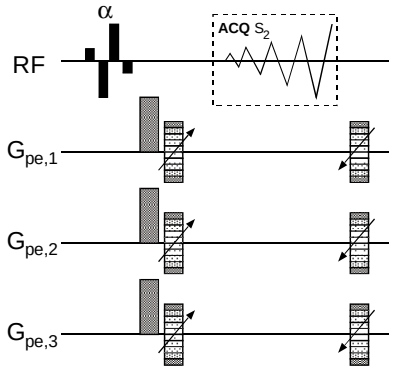

Figure 1: Schematic drawing of spectroscopic CE-FAST pulse sequence

Figure 2

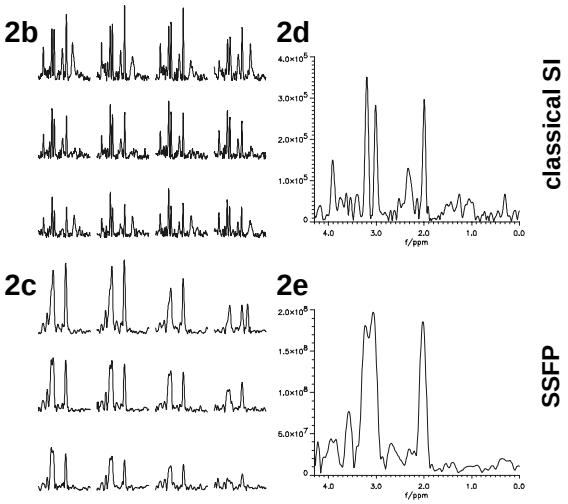

Figure 2:In vivo measurement, central slice. (a) Anatomical FLASH image, (b,c) array of spectra (classical SI, SSFP), (d,e) magnitude spectra of central voxel (classical SI, SSFP)