SAR-reduced spectroscopic FAST imaging with variable flip angles

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Introduction

A method to reduce the specific absorption rate (SAR) of the SSFP (Steady State Free Precession) based fast spectroscopic imaging (SI) technique spFAST [1] is presented. For spFAST the FID-like signal S_1 is acquired while the echo-like signal S_2 is suppressed. An optimal flip angle α_{opt} which depends on the relaxation times T_1 and T_2 and on the repetition time TR is used to maximize the signal-to-noise ratio (SNR) [2]. A better spectral resolution and a higher SNR can be achieved with increasing field strength. However, the specific absorption rate (SAR) limits the applicability of SSFP based SI methods for higher B_0 fields. In the present study we show that variable flip angle schemes with a maximum flip angle lower than α_{opt} allows a considerable SAR reduction with only minor SNR loss. Furthermore, the oscillating signal intensities can be exploited for k-space weighting in one spatial phase encoding direction thus reducing the sidebands of the spatial pointspread function (PSF).

Methods

We chose a flip angle series with 32 modulated flip angles and a repetition time of TR = 72ms. The flip angle series were calculated using typical apodization functions: a) $\alpha_N = \alpha_0 + [\alpha_d(1 - |k/16|)]$ (sawtooth-like), b) $\alpha_N = \alpha_0 + [\alpha_d\ e^{-4(k/16)^2}]$ (gaussian), c) $\alpha_N = \alpha_0 + [\alpha_d\ |\cos(k\,\pi/32)|]$ (cosine) and d) $\alpha_N = \alpha_0 + [\alpha_d\ [0.54 + 0.46\cos(k\,\pi/16)]]$ (Hamming window) with k =-15.5,…, 15.5, $\alpha_d = \alpha_{max} - \alpha_0$ and the maximal and minimal flip angles α_{max} and α_0. Eight sets of relaxation times were chosen: i) T_1=1500ms, T_2=70ms, ii) T_1=1250ms, T_2=1250ms, iii) T_1=2000ms, T_2=300ms, iv) T_1=900ms, T_2=350ms, v) T_1=1500ms, T_2=250ms, vi) T_1=915ms, T_2=402ms, vii) T_1=1530ms, T_2=595ms, and viii) T_1=1787ms, T_2=309ms, the latter three sets being derived from phantom measurements.

Simulations were performed with SPINEVOLUTION (version 3.4, [3]) and data were evaluated with self written Python scripts. The relative SAR was calculated with the quadratic relation: $SAR = \sum_{i=1}^{32}(\alpha_i/90)^2$ [4], while the PSF was computed by Fourier transforming (FT) the signal. The SNR was determined as $SNR = \sum_{i=1}^{N_{PE}} S_i/\sqrt{N_{PE}}$, with N_{PE}=32 for the constant flip angles. For the oscillating flip angles the N_{PE} (between 20 and 32) was determined that maximizes the SNR. For 2D measurements N_{PE} equals the number of phase encoding steps in one spatial dimension.

Experiments were performed on a 7T/20cm animal scanner (Bruker-Biospin, Germany) with standard gradients BGA-12S (12cm inner diameter, maximum strength 400mT/m, slew rate 4000mT/m/ms). A linear resonator of 72mm inner diameter was used for RF transmission and reception. For simultaneous slice selection, RF excitation and water suppression $1\,\tau\,1\,\tau\,\bar{8}\,\tau\,8\,\tau\,\bar{1}\,\tau\,\bar{1}$ spectral spatial pulses with excitation minima at multiples of $1/\tau$ were used. Additionally, a 10ms gaussian 90° pulse was applied before the excitation pulses. The echo-like signal S_2 was destroyed by crusher gradients. For 2D measurements a matrix size of 32x32 voxels (1.5x1.5x5mm^3 each), a repetition time of 75ms, 2 dummy cycles (with 32 flip angles each) were used. The total acquisition time was 2'04''. For phantom measurements tubes with 2.8cm diameter filled with $CuSO_4$ doped agarose were used. The pure phantom, that was used for simulation verification, had relaxation times of T_1=1787ms and T_2=309ms. To one phantom creatine (50mmol/l) was added. The creatine in the agarose gel had relaxation times of T_1=915ms and T_2=402ms for the CH_2 resonance and T_1=1590ms and T_2=595ms for the CH_3 resonance.

Results and Discussion

All simulations showed an oscillating signal behavior for the FID-like signal with regard to the pulse number for all excitation schemes and relaxation times. The simulated effects could be verified in the experiments. For T_1=1500ms and T_2=250ms, which are typical for brain metabolites at 7T, the constant flip angle α_{opt} is 30°. Using the oscillating flip angle schemes described above, good results were obtained for all relaxation times using gaussian flip angle series with $\alpha_d = 20°$ and I) $\alpha_0 = 6°$ or II) $\alpha_0 = 8°$ allowing an SAR reduction to 30% or 37% respectively (with respect to 100% for $\alpha = 30°$). The SNR-loss depends on the relaxation times and is for example 24% or 16% respectively for the relaxation times v) (see Methods). For the relaxation times i) the SNR-loss is only 10% or respectively 7% for $\alpha_{opt} = 20°$ and an SAR-reduction to 67% or 83% (with respect to 100% for 20°).The corresponding PSF show reduced sidebands by a minimal line broadening of the FWHM. Figure 1 shows simulated signals and the associated PSF. Measured metabolic images of creatine and maps of spectra are depicted in fig. 2 and demonstrate the lower sidebands of the PSF (in the vertical phase encoding direction in which the signal oscillations occurred) for the series with $\alpha_0 = 6°$ compared to an image acquired with $\alpha = 30°$.

Conclusion

The proposed sequence offers an excellent alternative for the standard spFAST method with constant flip angle. The SAR can be reduced considerably by varying the flip angles. This improves the potential of in vivo applications, particularly for higher field strength. Moreover, the sidebands of the PSF can be suppressed in one phase encoding direction which provides better spatial localization.

References

[1] Dreher W. et al., MRM 50: 453-460 (2003).
[2] Scheffler K., Concepts in Magnetic Resonance 11: 291-304 (1999).
[3] Vesthort V. & Griffin R., JMR 178: 248-282 (2006).
[4] Collins C. N., Li S. & Smith M. B., MRM 40: 847-856 (1998).

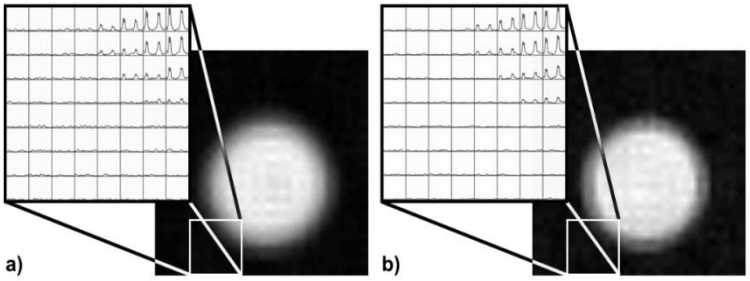

Fig. 2: Metabolic images and maps of spectra of the agarose phantom doped with creatine for a: constant flip angle = 30° and b: excitation with the gaussian variable flip angle series I).

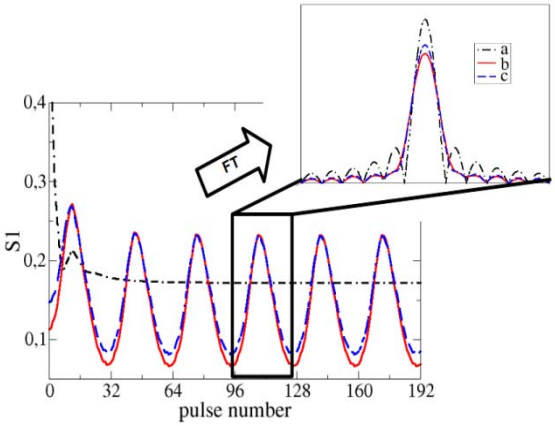

Fig. 1: Simulated signal intensities in dependence on the pulse number and associated PSF for T_1=1500ms and T_2=250ms, a: const. flip angle = 30°, b+c: variable gaussian flip angle series I) and II).