Optimized outer volume suppression for slice selective MRSI

A. Henning[1], M. Schär[1,2], R. F. Schulte[1], K. P. Pruessmann[1], P. Boesiger[1]

[1]Institute for Biomedical Engineering, University and ETH Zurich, Zurich, Kanton Zurich, Switzerland, [2]John Hopkins University, Baltimore, MD, United States

Introduction

In spite of significantly improved saturation pulses [1,2] sufficient outer volume (OVS) and especially fat suppression in MRSI could only be achieved in combination with PRESS localization [3]. PRESS causes immense chemical shift displacement at higher field strength. Therefore metabolite ratios in spectra at outer regions of the FOV are not reliable. Over-prescribed PRESS MRSI, in which the non-overlapping areas of the excited volumes are saturated by OVS bands, was only shown in combination with single suppression bands [3]. Slice selective MRSI, which guarantees correct metabolite ratios, has been unfavorable due to high lipid content in the spectra. In this work the flip angles of multiple, overlapping suppression bands were optimized considering crossing and progressing T1 relaxation during the OVS scheme. Therefore sufficient, T1 and B1 insensitive outer volume suppression in combination with over-prescribed PRESS MRSI and even slice selective MRSI could be achieved. The optimization was performed for higher-order phase pulses (HOPP), which combine a high selectivity with - in comparison to VSS [1,3] or QPP [2,4,5] - an even larger bandwidth and hence a negligible chemical shift displacement.

Materials and Methods

The flip angle optimization was based on Bloch equations. In a first step a simplified model, neglecting bandwidth and profile of the HOPP pulses and the performance of spoiling gradients, has been chosen to calculate the optimal flip angles for each saturation band. For a single suppression band of the total duration τ, consisting of a RF-pulse with the flip angle φ, a slice selective and a spoiling gradient and a delay, the residual longitudinal magnetization M_R can be calculated from $M_R = M_I e^{-\tau/T_1}\cos\varphi + M_O(1-e^{-\tau/T_1})$. M_O is the equilibrium magnetization; M_I is the magnetization at the beginning of the sequence and depends on T_R. For n crossing suppression bands with the duration's τ_1 - τ_n the residual magnetization M_R can than be derived as: $M_R = M_I e^{-(\tau_1+....\tau_n)/T_1}\cos\varphi_1...\cos\varphi_n + M_0[\ (1-e^{-\tau_n/T_1}) + ... + (1-e^{-\tau_1/T_1})e^{-\tau_2/T_1\cos\varphi_2}...e^{-\tau_n/T_1\cos\varphi_n}\ ]$. The optimized flip angles based on the simplified model have been verified considering the properties of HOPP-pulses and spoiling gradients by Bloch integration using the Runge-Kutta method. Finally the optimized OVS scheme was applied in Brain MRSI. All MRI and MRSI experiments were performed on a Philips 3T scanner (Philips Medical Systems, Best, The Netherlands). The HOPP pulses were applied prior to either PRESS MRSI or slice selective MRSI. Pulse duration and flip angle of each suppression band were separately adjustable. Two cycles of suppression bands with optimized flip angles for simultaneous suppression of subcutaneous fat and CSF were applied.

Results and Discussion

For two and more suppression cycles not only a single optimal flip angle but a range of optimal flip angles for each T1 exists (Figure 1a). Due to progressing T1 relaxation the optimal range depends on the time delay between saturation band and the start of the MRSI sequence (Figure 1b). The optimal regions for different T1 values overlap (Figure 1c). Therefore for each saturation band a T1 independent flip angle adjustment can be achieved, which enables simultaneous water and fat suppression. The simulated suppression profile in Figure 1d indicates that a 2-cycle OVS scheme based on multiple HOPP saturation bands allows a highly-selective and consistent fat suppression. Figure 2 verifies the flip angle optimization and shows consistently good fat suppression around the skull in slice selective MRSI and complete fat suppression using over-prescribed PRESS MRSI. Best results could be achieved using the smallest possible number of saturation bands to suit the anatomy and the shortest possible HOPP-pulses (2ms). The enlarged spectra in the 3rd row of Fig. 2 show, that while PRESS MRSI (d) data have distorted metabolite ratios, it is possible to achieve entirely fat free spectra with the correct metabolite ratios in voxel directly adjacent to the skull combining the described flip angle optimized OVS scheme and slice selective MRSI (b).

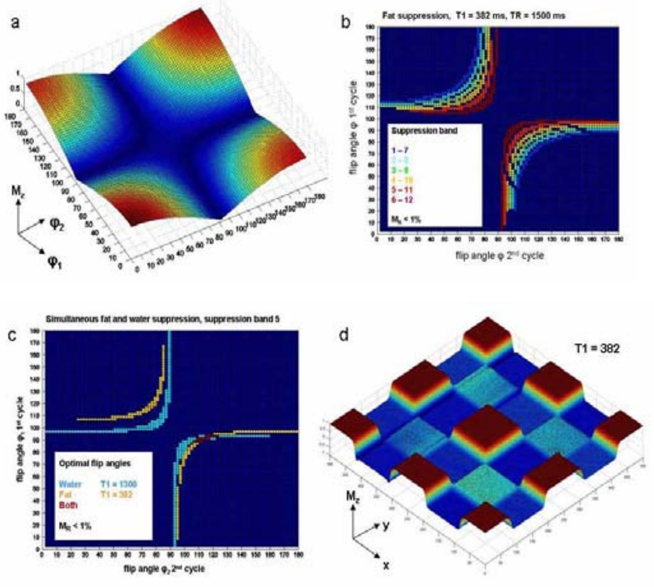

Figure 1 *Flip angle optimization for fat suppression, multiple saturation bands, 2 suppression cycle* ***a)*** *residual magnetization vs. flip angle φ_1 and φ_2; first saturation band* ***b****) optimal flip angle range vs. position of the saturation band in the OVS sequence* ***c)*** *simultaneous suppression of fat (T_1 = 382 ms) and water (T_1 = 1300 ms)* ***d)*** *simulation of HOPP suppression profiles using 4 crossing saturation bands optimized for fat saturation*

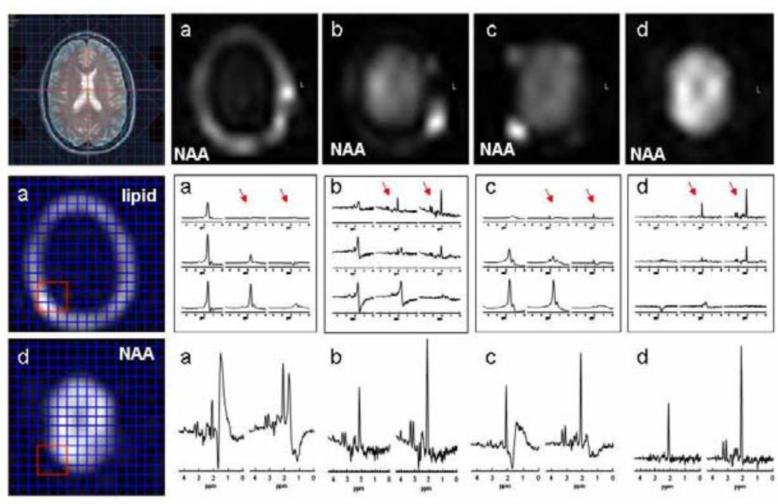

Figure 2 *Verification of flip angle optimization for 8 saturation bands for fat suppression in brain MRSI* ***a)*** *slice selective MRSI w/o OVS* ***b)*** *slice selective MRSI with 8 HOPP-based saturation bands, 2 suppression cycles* ***c)*** *PRESS MRSI w/o OVS* ***d)*** *PRESS MRSI with 8 HOPP-based saturation bands, 2 suppression cycles; metabolite images and spectra are scaled to the individual maximum; consistently good fat suppression around the skull in slice selective MRSI and complete fat suppression using over-prescribed PRESS MRSI*

References

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