Optimisation of asymmetric adiabatic pulses for single voxel metabolite cycled ^{1}H-MRS in the human brain at 9.4 Tesla

Ioannis Angelos Giapitzakis[1], Tingting Shao[1], Nikolai Avdievich[1], Roland Kreis[2], and Anke Henning[1,3]

[1]*Dept. of High-Field Magnetic Resonance, Max Planck Institute for Biological Cybernetics, Tübingen, Baden-Württemberg, Germany,* [2]*Departments of Radiology and Clinical Research, University of Bern, Bern, Switzerland,* [3]*Institute for Biomedical Engineering, University and ETH Zürich, Zürich, Switzerland*

INTRODUCTION: Metabolite cycling is a method in which the metabolites up-field or down-field of the water peak are alternately inverted [1] using asymmetric adiabatic pulses [2] leaving the water peak essentially unaffected. Thus, the subtraction of two consecutive acquisitions leads to a spectrum without the water peak, while their sum leads to a pure water spectrum. The advantages of this technique compared to water suppression techniques are that the water signal can be used for frequency and phase alignment prior averaging [3, 4], to measure chemical exchange between metabolites and water [5] and for eddy current correction [6] without scan time prolongation. **The purpose of this research** was to optimize the characteristics of the asymmetric adiabatic inversion pulse to implement metabolite cycling at 9.4 Tesla for human brain application.

METHODS: Details and basic shape of the asymmetric adiabatic pulse are described in [2]. It features a steep transition bandwidth (TBW) on the water side of a broad inversion band (Inversion Bandwidth (Inv. BW): frequency range in which $M_z \leq -0.95M_o$). Inv. BW and TBW depend mainly on 3 factors: 1) the duration of the adiabatic pulse, 2) the frequency sweep range and 3) the B_1^+ field amplitude. Bloch simulations were used to find optimal parameter sets, where the excitation profile was studied as a function of the three influencing factors for the following parameter range: duration of the pulse from 20 to 40ms, frequency factor from 1 to 4 and B_1^+ field values from 15 to 25μT. The frequency factor is simply a number which multiplies the basic frequency sweep range (from -11.36 to 0.12 kHz). The simulations were performed using self-written scripts in MATLAB (The Mathworks, Natick, USA) to solve the Bloch equations. For the verification of the simulations, experiments were done on a spherical spectroscopy phantom filled with an aqueous solution of acetate and lactate, with the inversion pulse as pre-pulse in an imaging experiment (data not shown) and as a metabolite cycling pulse in the mixing time of a spectroscopy STEAM experiment (TE/TM/TR: 10/50/2000ms, voxel size: 2x2x2cm^3, 128 averages, $B_1^+{}_{(min)}$: 22μT, pulse duration: 23ms, freq. factor: 2, |frequency offset|: 325 Hz, 8 channel TxRx array head coil). Finally, *in vivo* spectroscopy measurements (TE/TM/TR: 15/50/3580ms, voxel size: 2x2x2cm^3, 128 averages, $B_1^+{}_{(min)}$: 15μT, pulse duration: 33.6ms, freq. factor: 4, |frequency offset|: 360 Hz) were performed on a healthy volunteer using a 16 channel dual row transmit coil array in combination with an inserted close-fitting 31 channel receive array [7]. All experiments were carried out on a 9.4T Magnetom SIEMENS scanner.

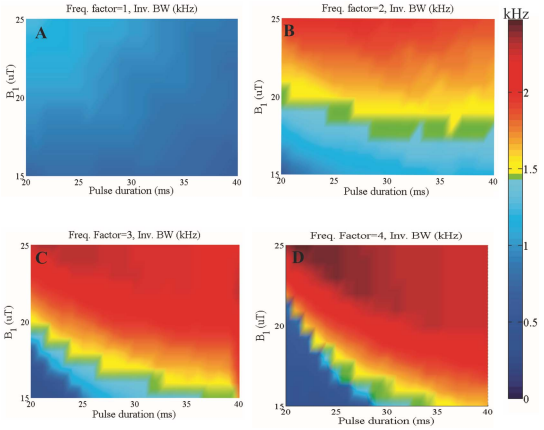

Fig. 1: *Inversion bandwidth from simulations (no relaxation) as a function of frequency factors, time duration and B_1 values. The green area indicates the zone of a minimum BW of 1.4 kHz desired for 9.4T brain MRS.*

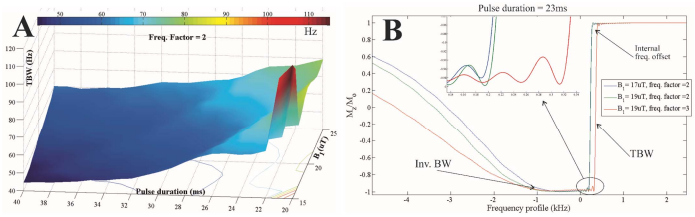

Fig. 2: ***A)*** *TBW simulated for different B_1^+ values and pulse durations, with a frequency factor of 2.* ***B)*** *Longitudinal magnetization profile simulated for different B_1^+ values and frequency factors for a pulse duration of 23ms.*

RESULTS: The simulated results show that the bandwidth of the previously described pulse [1] is not sufficient to cover the desired frequency range of 3.5ppm at 9.4Tesla (1400Hz, figure 1-A) using a reasonable pulse duration and given the low B_1^+ fields at ultra high field. In addition, the findings verified the formerly selected values for metabolite cycling at 3T and 7T [4, 8]. The general trend is that the Inv. BW increases when the pulse duration, frequency sweep range or B_1^+ field increases (figure 1). Nevertheless, the pattern is different for the TBW (figure 2-A). There is a trade off between the frequency sweep range and the minimal B_1^+ field arising from the adiabatic condition. As a consequence, a higher frequency sweep range (freq. factor) demands a higher B_1^+ field in order to achieve a sufficient Inv. BW. The simulations demonstrate that there are several combinations of these three factors that fullfil the criterion of the 1400Hz. Some optimum values with regards to pulse duration, B_1^+ field, TBW and Inv. BW are shown in Table 1. Moreover, the absolute value of the internal frequency offset of the frequency profile is also determined by these three factors (figure 2-B). Furthermore, for a given B_1^+ field the exciation profile presents more ripples as the frequency factor increases. As a result, a lower freq. factor is preferable. In addition, the outcomes from the spectroscopy trials (figure 3) indicate that metabolite cycled STEAM can be achieved at 9.4T for phantoms and human brain.

CONCLUSIONS: This abstract shows that **metabolite cycled ^{1}H-MRS is feasible at 9.4T in the human brain** after optimization of the inversion pulse. In addition, the experiments demonstrate that RF coils with high transmit efficiency are preferable for optimal inversion pulse performance.

Table 1

B_1 (μT)	Pulse duration (ms)	Freq. factor	Tran. BW (Hz)	$\lvert Internal\ freq.offset \rvert$ (Hz)	SAR (normalized units)
17	**28**	**3**	**55**	**223**	**1**
18	**26**	**3**	**59**	**241**	**1.04**
19	**24**	**2**	**65**	**262**	**1.07**
20	**23**	**2**	**68**	**273**	**1.14**
21	**23**	**2**	**68**	**271**	**1.25**
22	**22**	**2**	**71**	**284**	**1.32**

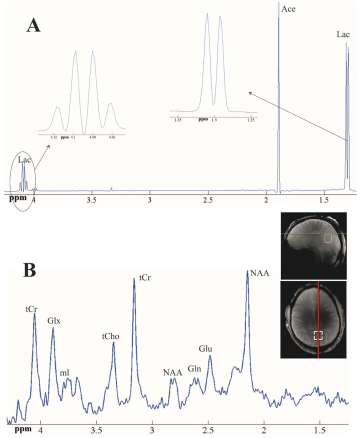

Fig. 3: *Metabolite cycled STEAM MRS at 9.4T.* ***A)*** *Phantom measurements. The methine quartet of lactate at 4.09 is well observable.* ***B)*** *Initial in vivo spectrum measured on a healthy volunteer again proving the potential to cover the whole upfield range even at 9.4T*

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Co-sponsored by the European Social Fund and national funds (NSRF 2007-2013) through the Greek State Scholarships Foundation (IKY) and also supported by the Swiss National Fund (320030_135743).