Short TE PRESS Proton NMR Spectroscopy without Water Suppression. Application to the Human Brain at 3 Tesla

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Introduction: Several techniques have been proposed to avoid water suppression (WS) and to allow the simultaneous detection of metabolites and water in localized proton NMR spectroscopy (^{1}H MRS) in vivo [1-7]. The main purpose is to use the separated water signal as a reference signal for data processing (lineshape, frequency, phase correction) and for absolute quantification. Furthermore, time consuming adjustments for water suppression are avoided. However, gradient induced sidebands of the water signal are still the major technical challenge for ^{1}H MRS without WS. In a recently proposed two-step method [7] the simultaneously detected water and metabolite signals can be separated by adding or subtracting two time domain (TD) data sets measured either without or with additional chemical shift selective inversion of metabolite signals prior to a standard localization technique such as PRESS or STEAM. In the present study, this method was modified and implemented on a 3T head scanner using an optimized short TE PRESS sequence. The sequence was tested on phantoms and applied to healthy volunteers.

Method: The pulse sequence used to detect water and metabolite signals simultaneously [7] is depicted in Fig.1. Prior to a PRESS sequence, two chemical shift selective adiabatic pulses, which invert the metabolite signals upfield and downfield with respect to the unaffected water signal, are either switched off (A) or switched on (B) in two consecutive experiments. By combining the two TD signals S_A and S_B, water and metabolite signals are obtained by $(S_A+F_B \cdot S_B)$ and $(S_A-F_B \cdot S_B)$, respectively, where the correction factor F_B accounts for experimental imperfections of the inversion pulses. In the difference spectrum, the gradient induced sideband signals are reduced because they are proportional to the amplitude and coherent to the phase of the water signal. The water signal was used to correct for B_0 shifts and to perform eddy current and automatic constant phase correction. The parameter for the linear phase correction was derived from phantom measurements.

Experimental: All experiments were performed on a 3T Allegra head scanner (Siemens, Germany) equipped with standard gradients (max. 40 mT/m; 400 mT/m/ms slew rate, used ramp time 200 µs). The standard circularly polarized Birdcage RF head coil was used for RF transmission and signal reception. The PRESS sequence provided by the manufacturer was modified to reduce the minimum TE to 13-17 ms (dependent on the minimum RF pulse lengths). The sequence parameters were: inversion pulses: 20-22 ms, Hwang-pulses ($HS_{1/2}$, R=31.415, $0.9 \cdot T_p$; tanh/tan, R=100; $0.1 \cdot T_p$; empirically optimized frequency offsets) [8]); 90°: 1.8 ms, Hamming filtered sinc-pulse; refocusing 180°: 2.6-4.2 ms, mao4-pulses [9]; 1ms spoiler gradients. To minimize the delay between inversion and RF excitation, spoiler gradients between and after the inversion pulses were omitted. Phantom measurements were conducted on a sphere (17 cm i.d.) containing a solution of 50 mM acetate (Ace), 50 mM creatine (Cr) and 50 mM myo-inositol (Ins). In vivo measurements were performed on healthy volunteers. The main parameters were: voxel size: 15^3 mm^3; TE=13 ms (phantom) or 17 ms (in vivo); TR= 3 s; 32 accumulations per scan; 4 dummies; spectral width: 1200 Hz, 2K data points. The results were compared to PRESS spectra (64 accumulations) acquired with WS [10]. The extracted water signal was used for eddy current correction and automatic constant phase correction. Apodization was performed using a product of a cosine-window $(0,\pi/2)$ and a decaying exponential. The parameter for linear phase correction was determined in phantom experiments and then applied to in vivo data. Neither a baseline correction nor other correction schemes were applied to the FT spectrum.

Results: Fig.2 depicts a phantom spectrum ($FT(S_A-S_B \cdot F_B)$, F_B=1.02) with the expected resonances of Ace, Cr and Ins. The flat baseline and absence of artifact signals indicates the excellent water suppression and the corresponding suppression of gradient induced sideband signals below the noise level. The necessity to suppress gradient induced artifacts was observed in the FT spectrum of $S_A+S_B \cdot F_B$. In in vivo data, the amplitude of the largest artifact signals, which appear at a distance of about +/- 1.6 ppm from water, was twice the intensity of the CH_3 signal of NAA at 2.01 ppm. A typical in vivo spectrum measured within 3:12 minutes on the healthy human brain in the left parietal lobe (mainly white matter) is shown in Fig.3 (F_B=1.15). The linewidth of the NAA signal was about 4-5 Hz without linebroadening, and 6-7 Hz with apodization. Comparable spectrum quality was obtained in other measurements on the same or other volunteers. In the difference spectra, water extraction was always sufficient to observe the CH_2 signal of tCr, in most cases also the [2]CH Ins signal. While the extracted water signal was used for B_0, eddy current and constant phase correction, absolute quantification of metabolites using water as an internal reference is possible, but was not performed yet.

Discussion: Using the standard hardware (gradients, RF coil) of a 3T head scanner, the TE of PRESS measurements can be reduced to 13-17 ms. A further reduction of TE could be achieved by using improved hardware (to realize shorter pulses durations) and/or asymmetric RF pulses [11,12]. Optimized inversion pulses of 20-22 ms duration allow the efficient separation of water and metabolite signals in short TE PRESS without WS, in spite of T_1 and T_2 relaxation effects. The large dynamic range of the TD data caused by the simultaneous detection of water and metabolite signals does not diminish the spectrum quality (lineshape, linewidth, SNR) as shown by comparing spectra acquired without and with WS. The separated water signal can be used for (i) eddy current correction leading to improved lineshape, (ii) for precise automatic B_0 and constant phase correction and (iii) as a reference signals for absolute quantification (as shown in [7]). Data processing is straightforward and does not require additional user interaction. Finally, the preprocessed TD data or the FT spectra can be quantitatively analyzed by any quantification method.

Conclusion: Short TE PRESS ^{1}H spectra can be acquired without WS on the human brain at 3T without a loss of spectrum quality. As only adiabatic inversion pulses are used, the method is robust against B_1 inhomogeneities and additional adjustments are not required.

References: [1] Hurd RE et al., MRM 40, 343-347(1998). [2] Kreis R, Boesch C, Proc. ISMRM, 1998, p.24. [3] van der Veen JW et al., Radiology, 217, 296-300(2000). [4] Serrai H et al., JMR 149, 45-51(2001) and JMR 154, 53-59(2002). [5] Clayton DB et al. JMR 153, 203-209(2001) and Concepts in Magn. Reson. 13, 260-275(2001). [6] Dong Z et al., MRM 51, 602-606(2004). [7] Dreher W., Leibfritz D., MRM 54, 190-195(2005). [8] Hwang T-L et al., JMR 138, 173-177(1999). [9] Mao J et al., JMR 79, 1-10(1988). [10] Ogg RJ et al. JMR B 104, 1-10(1994). [11] Zhang K, Ernst T., MRM 52, 898-901(2004). [12] Geppert C et al., MAGMA 16, 144-148(2003).

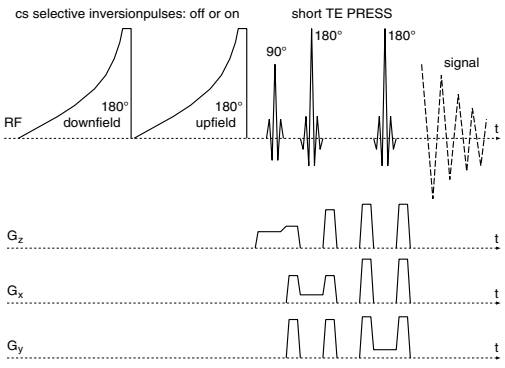

Fig.1: Pulse sequence for short TE PRESS without WS implemented on a 3T head scanner.

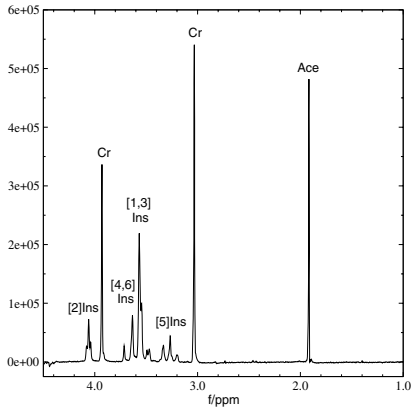

Fig.2: Phantom PRESS spectrum (TE=13 ms) without WS measured on a solution of Ace, Cr and Ins.

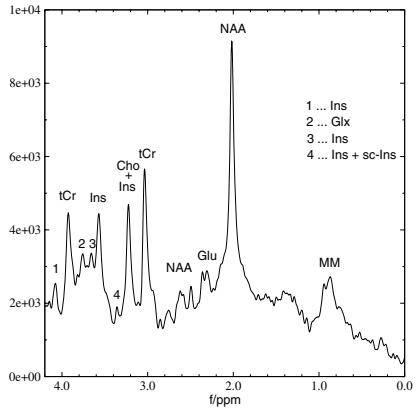

Fig.3: In vivo PRESS spectrum (TE=17 ms) measured without WS on the human brain.