Short Echo Time Proton Spectroscopy of the Human Brain at 3 Tesla Using an Optimized PRESS Sequence without Water Suppression

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Introduction: Since 1998 several techniques have been developed for in vivo proton NMR spectroscopy (^{1}H MRS) without water suppression (WS) to detect metabolites and water simultaneously. The latter is utilized as a reference signal for data processing (lineshape, frequency and/or phase corrections) and absolute quantification [1-8]. As gradient induced sideband signals of the predominant water signal are the major obstacle for ^{1}H MRS without WS, high quality measurements with very short echo times (TE) are a great technical challenge. Therefore, this study aimed at three aspects: (i) the modification of a PRESS sequence to allow TE values as short as possible, (ii) the assessment of different variants of recently proposed two-scan techniques [7,8] which use chemical shift (cs) selective inversion of metabolite signals, and (iii) the comparison and quantification of ^{1}H MR spectra of the human brain acquired with and without WS.

Method: The used pulse sequence is depicted in Fig.1. In two experiments, one or two cs selective adiabatic 180° pulses, which invert the metabolite signals upfield and/or downfield with respect to the unaffected water signal, are applied prior to an optimized PRESS sequence. In variant #1 described in [7], one experiment is performed without inversion (signal S_A), the other with inversion (signal S_B). To detect metabolites from both the upfield and downfield region, two inversion pulses are applied consecutively. Otherwise only one pulse inverts the frequency region of interest. By combining the two time domain (TD) signals S_A and S_B, water and metabolite signals are separated 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 imperfections of the inversion and ensures an efficient elimination of the water signal and corresponding gradient induced artifacts. Absolute metabolite quantification is achieved by $c_{met}=(s_{met}/s_{wat}) \cdot (2/(1+F_B) \cdot c_{wat,iv} \cdot (2/n_{met})$, s_{met} and s_{wat} being the signal intensity of metabolites and water, $c_{wat,iv}$ the water concentration in the tissue, and n_{met} the number of spins contributing to s_{met}. The formula is modified easily, if complete model functions are used in the fitting procedure instead of individual resonance lines. In variant #2 described in [8], the downfield region is inverted in one experiment and the upfield region in the other. Since the unintended reduction of the water signal is similar in both experiments, a correction factor may often be dispensable. Thus, without using a correction factor, water and gradient induced artifacts are effectively suppressed in the TD signal S_A-S_B and the corresponding spectrum $FT(S_A-S_B)$, while metabolite signals are detected both upfield and (with 180° phase difference) downfield.

In the PRESS sequence, short TE values were achieved by use of an asymmetric 90° pulse and spoiler gradients of variable duration and strength. A 16-step phase cycle suppressed unwanted coherences in case of insufficient spoiler gradients. Alternatively and for comparison, WS by presaturation was used.

Experimental: Experiments were performed on a 3T Magnetom Allegra head scanner (Siemens, Germany) equipped with standard gradients (max. 40 mT/m and 400 mT/m/ms, used ramp time 0.250 ms) and a standard CP Birdcage RF head coil used for transmission and signal reception. The PRESS sequence allows *in vivo* measurements of the human brain with TE>=12 ms. The sequence parameters were: 22 ms inversion pulses as described in [7]; 90°: 1.4 ms asymmetric pulse derived from a Hamming filtered sinc-pulse; refocusing 180°: mao4-pulses, ~4ms in vivo; spoiler gradients: 0.5-2.0 ms, 18-31 mT/m. Phantom measurements were conducted on a sphere filled with a solution of 10 mM acetate and 10 mM lactate. In vivo measurements were performed on healthy volunteers with: voxel size: 15^3 mm^3; TE=12-14 ms, TR= 3 s; 32 accumulations per scan; 4 dummies; spectral width: 1200 Hz, 2K data points. The results were compared to PRESS spectra acquired with WS and 64 accumulations. The extracted water signal was used for automatic eddy current, frequency and constant phase correction. Neither a linear phase correction nor a baseline correction was applied to the FT spectrum. Quantification was performed using the AMARES module of the MRUI program (version 2.2) [9].

Results and Discussion: The efficient suppression of water and accompanying gradient induced artifacts was assessed in phantom measurements. A typical *in vivo* spectrum measured without WS on a healthy volunteer (left parietal lobe, mainly white matter) is depicted in Fig.2 with the assignment of the major peaks. Comparable spectrum quality was obtained for different volunteers as well as in measurements performed with WS. A comparison between the two variants for MRS without WS proposed in [7] and [8] yielded similar results for the upfield cs region which is of main interest for most applications. However, using variant #1 the detection of downfield signals was inferior to the results reported in [8] for rat brain studies at 9.4T. The main advantage of variant #2 is that the inversion of both cs regions is performed immediately prior to the RF excitation. Thus T_1 effects and magnetization transfer between protons of metabolites (e.g. NH) and water are minimized. The disadvantage is that the exact information on the water signal intensity is lost and thus the simultaneously detected water signal is less valuable for absolute quantification than in variant #1. The need for a correction factor in variant #1 is not a real drawback because its calculation is straightforward and the caused SNR loss is negligible [7]. A comparison between spectra acquired without WS with measurements performed with WS or with results reported in [10], which were obtained at 3T or 4T with WS and TE~10 ms, proves that ^{1}H MRS without WS is indeed promising because any loss of spectrum quality is avoided. After the automatic separation of metabolite and water signals, quantification is possible by using one of the available quantification methods as demonstrated in Fig.3 which shows an analysis of another *in vivo* data set by AMARES. The extracted TD signal $(S_A+F_B \cdot S_B)$ and $(S_A-F_B \cdot S_B)$ were fitted separately and the results used for absolute quantification.

Conclusion: An improved PRESS sequence with very short TE≥12 ms was implemented on a 3T head scanner. It allows the simultaneous and quantitative detection of metabolites and water with at least comparable spectrum quality as with WS. However, it is advantageous to avoid WS and to use water for corrections and absolute quantification. Dependent on the metabolites of interest, the necessity of absolute quantification and considering specific advantages and drawbacks, one of the two variants for cs selective inversion of metabolite signals can be chosen. Even shorter TE values may be obtained by following the approaches described in [11,12].

References: [1] Hurd RE et al., MRM 40, 343(1998). [2] Kreis R et al., Proc. ISMRM, 1998, p.24. [3] van der Veen JW et al., Radiology, 217, 296(2000). [4] Serrai H et al., JMR 149, 45(2001) and JMR 154, 53-59(2002). [5] Clayton DB et al. JMR 153, 203(2001) and Concepts in Magn. Reson. 13, 260(2001). [6] Dong Z et al., MRM 51, 602(2004). [7] Dreher W et al., MRM 54, 190(2005) and ISMRM 2006, p.3066. [8] de Graaf RA et al., Proc. ISMRM, 2006, p.3063. [9] Vanhamme L et al., JMR 129, 35(1997). [10] Zhang K, Ernst T., MRM 52, 898(2004). [11] Geppert C et al., MAGMA 16, 144(2003). [12] Mlynarik V et al., MRM 56, 965(2006).

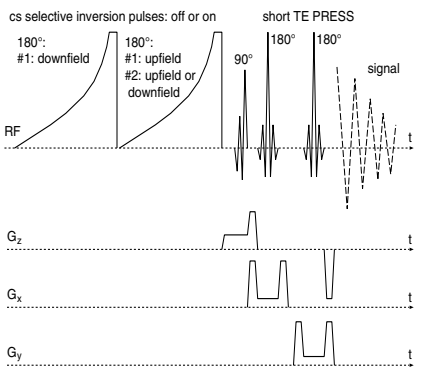

Fig.1: Optimized short TE PRESS sequence (TE≥12 ms) without WS implemented on a 3T head scanner.

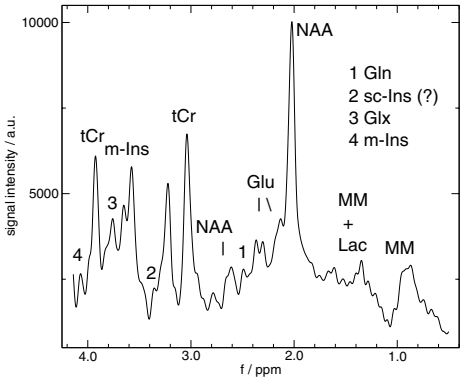

Fig.2: In vivo PRESS spectrum (TE=14 ms) without WS measured on a healthy volunteer.

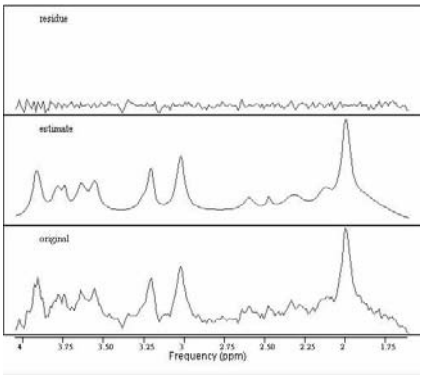

Fig.3: Results of signal fitting by AMARES (from top: residue, fitted, measured spectrum)