A New Method for Localized Proton NMR Spectroscopy with Increased Signal-to-Noise Ratio if T_2^* Is Much Smaller Than T_2

W. Dreher[1], D. Leibfritz[1]

[1]FB 2 (Chemie), Universität Bremen, D-28334 Bremen, Germany

Introduction: The use of localized in vivo MRS largely depends on the achievable signal-to-noise ratio (SNR). The PRESS technique [1,2] with short echo time TE is the gold standard as regards single voxel proton MRS with high SNR. In this study, we investigated the possibility to use two approaches which were successfully applied to spectroscopic imaging (SI) to increase the SNR, but which have not yet been used for single voxel 1D MRS. First, the fast SI method 'spectroscopic RARE' [3] uses a multiecho data acquisition technique. This method yields an increased SNR for metabolite signals if $T_2^* << T_2$, which holds for many metabolite signals, in particular at high magnetic field strength B_0. Second, it was shown that k-space weighted averaging applied to spatial phase encoding can improve both the spatial point-spread function and increase the SNR [4]. Based on these developments, a new pulse sequence for single voxel MRS has been developed which combines data acquisition as an FID and as an echo train. Additionally, this method allows to use k-space weighted averaging along k_ω.

Method: The proposed method is schematically displayed in Fig.1. After water suppression (not shown), a PRESS module selects the signals from one voxel. The duration $t_1=t_{10}+n\cdot\Delta t_1$ (n=0,1,...,N_1-1) with which the FID signal S_1 is detected is incremented in a series of N_1 measurements. After the observed FID, a train of N_2 180° RF pulses (bracketed by spoiler gradients and applied with an xyxy phase cycle [5] to reduce offset effects) yields a train of N_2 echo signals. A constant interecho delay ΔTE is used and the acquisition time per echo T_{ea} is maximized to optimize the SNR. As only parts of the required data along k_ω are acquired by each shot, the data are reordered after the experiment to form complete time domain (TD) signals along k_ω for the FID and the N_2 echo signals. Note the inherent k_ω-weighting of the FID-like signal. An additional k_ω-weighted averaging can be achieved if the number of accumulations depends on the encoding index n. All FT spectra of the separately processed N_2+1 TD signals can be added to maximize the SNR. Alternatively, only certain spectra can be evaluated to account for the T_2 dependence of the signals.

Experimental: The new pulse sequence (termed 'PRESSME', PRESS with MultiEcho refocusing) was implemented on a 4.7 T Biospec system (Bruker, Germany) equipped with self-shielded gradients (170 mT/m, 450 µs). A saddle-type RF coil (98 mm i.d.) was used for homogeneous RF excitation. The same coil was used for signal reception in measurements on a spherical phantom (40 mm i.d.) containing a solution of 25 mM N-acetyl aspartate (NAA) and 75 mM myo-inositol (Ins), whereas an 18 mm surface coil was used for in vivo studies on healthy rat brain. To improve water suppression, the PRESS module was modified consisting of a 1-2τ-5.4-τ-5.4-2τ-1 composite pulse ([6], t=1.25 ms, 80°) followed by three slice selective 180° pulses. The main sequence parameters were: voxel size: 8^3 or 4^3 mm^3 (phantom/*in vivo*); TE=22 ms; TR= 3 s; N_1=64 with t_{10}=1.6 ms and Δt_1=1.6 ms; 6 dummies. Beside the FID signal, N_2=64 echoes were acquired produced by 140 µs rectangular RF pulses with an xyxy phase cycle. Continuous data acquisition with a spectral width of 20 kHz was used blanking the receiver during the RF pulses. The interecho delay ΔTE was 5.0 ms and the acquisition time per echo 3.2 ms. After reordering the data, the FID and the N_2 echo signals were processed separately consisting of apodization (6 Hz line broadening), zero filling to 16K, FFT and automatic phase correction. Then spectra of the four echo groups corresponding to the used 4-step phase cycle were accumulated. Finally, the FT spectra of the FID and the four echo groups were accumulated. The achieved SNR was compared with FT spectra acquired by a standard PRESS sequence (TR=3.0s, TE=22ms, NA=64) and processed with similar parameters as the proposed new method.

Results and Discussion: Fig.2a compares the simulated SNR for a singlet signal [7] measured by PRESSME and PRESS using for both methods the parameters described above and assuming a T2' value corresponding to a line broadening of 8 Hz. The graph shows that a higher SNR can be achieved by PRESSME for metabolites with long T_2 (i.e. $T_2^* << T_2$) . This advantage increases with decreasing T2', i.e. at higher B_0. Fig.s 2b-d display phantom spectra measured by PRESSME, showing the spectrum of (b) the FID, (c) the first echo group and (d) all signals (FID + all echoes). Note the broader linewidth in the spectrum of the FID caused by the inherent k_ω-weighting. Fig.2e shows a PRESS spectrum for comparison. The SNR (signal intensity / SD(noise)) was estimated for the methyl signal of NAA. The SNR of PRESSME (using all signals) was about 40 % higher than for the PRESS consistent with the simulation results. Note that we have not yet used k-space weighted averaging which should allow a further SNR increase. However, the intensities of the J coupled resonances of Ins are lower in the spectra of the new method, probably because T_2 is shorter and J modulation is not completely prevented by the train of 180° pulses. An in vivo spectrum measured on healthy rat brain is shown in Fig.2f. Both uncoupled and J-coupled signal are well detected. However, while these in vivo results are good considering the voxel size of 64 µl and the total measurements time of 3.2 min, the spectrum quality and the SNR are not yet as good as one could expect based on the simulations and phantom measurements. The main experimental problem in vivo seems to be that, similar to the situation in spectroscopic RARE (cf. [3]), instabilities of water suppression cause noise in the spectrum and may cause additional artifact signals as seen in Fig.2f at a frequency offset $1/\Delta t_1$ to water. Therefore, an improved (stable) water suppression will be essential to use the great potential of the new method in vivo. Alternatively, these measurements may be performed without water suppression.

Conclusion: A new pulse sequence for single voxel MRS is presented which allows to increase the SNR of metabolite signals if $T_2^* << T_2$. Thus the new method is of particular interest for high field systems where T_2^* decreases because of increased B_0 inhomogeneities. Besides this inherent SNR advantage and unlike other 1D MRS methods, the new method allows to use k-space weighted averaging along k_ω to further increase the SNR.

References: [1] Bottomley PA, Ann. N.Y.Acad.Sci. 508, 333-348(1987). [2] Gordon RE and Ordidge RJ, Proc. SMRM, 1984, p.272-273. [3] Dreher W and Leibfritz D, Magn. Reson. Med. 47, 523-528(2002). [4] Pohmann R and von Kienlin M, Magn. Reson. Med. 45, 17-26(2001). [5] Maudsley AA, J. Magn. Reson. 69, 488-491(1986). [6] Starcuk Z and Sklenar V, J. Magn. Reson. 66, 391-397(1986). [7] Pohmann R, von Kienlin M, Haase A, J. Magn. Reson. 129, 145-160(1997).

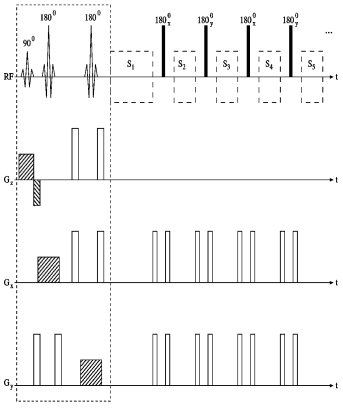

Fig.1: Scheme of the proposed new pulse sequence for single voxel 1D MRS. (water suppression not shown).

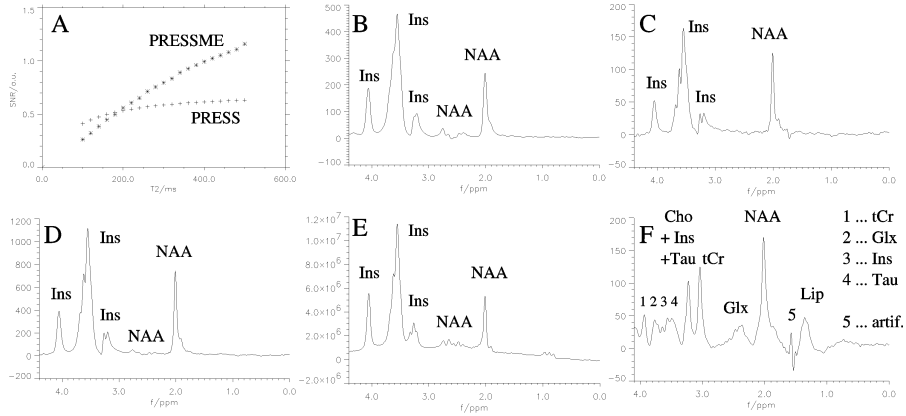

Fig.2: (a) Simulated SNR of the new method ('PRESSME') and standard PRESS vs. T2/ms (T2 '= 8Hz) (b-e) phantom spectra measured by the new method using (b) the FID, (c) the first echo group, (d) all signals and (e) measured by standard PRESS, (f) in vivo rat brain spectrum measured by PRESSME.