Optimized CT-PRESS for Localized Proton NMR Spectroscopy of the Human Brain at 3 Tesla

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Introduction: The pulse sequence CT-PRESS [1] has gained increasing interest for localized ^{1}H MR spectroscopy (MRS) of the human [2-4] or animal brain [5,6]. Different to short echo time (TE) STEAM [7,8] or PRESS [9] measurements, where prior knowledge is extensively used during data quantification to separate and assign overlapping signals, CT-PRESS is essentially a 2D J-resolved MRS sequence and allows for improved signal separation as a result of effective homonuclear decoupling occurring in diagonal spectra. Furthermore, the sequence parameters can be optimized for certain metabolite of interest, particularly by choosing an appropriate tc value which corresponds to the mean TE. However, as compared to short TE MRS, CT-PRESS suffers from the reduced signal-to-noise ratio (SNR) because rather long TE values cause signal losses by T_2 relaxation. Therefore, we investigated different means to maximize the SNR of CT-PRESS if applied to the human brain at 3 Tesla.

Method: The optimization of CT-PRESS considered four aspects: (i) realization of rather short tc values, (ii) the use of weighted averaging in the t_1 direction, (iii) correcting for spatial B_1 inhomogeneities to avoid deviations from the nominal flip angles of 90° or 180°, and (iv) improving data processing by optimized apodization in t_1 direction.

The CT-PRESS sequence was derived from a short TE PRESS sequence. In a series of N_1 experiments, the temporal position of an additional non-selective RF pulse is shifted by $\Delta t_1/2$. Compared to standard PRESS where phase cycling is used during accumulation, the spoiler gradients were increased to (2 ms, 27 mT/m). Thus unwanted coherence pathways are suppressed making phase cycling obsolete and allowing weighted averaging schemes in t_1 to increase the SNR as compared to a constant number of accumulations [10]. The local B_1 field was determined by applying a non-selective rectangular RF pulse followed by spoiler gradients prior to the 90° pulse of the PRESS module. By minimizing the acquired water signal, the required correction factor was derived by comparing the optimized transmitter value with the value determined by the spatially global RF transmitter adjustment (supplied by the manufacturer and being routinely used). Alternatively, the correction factor was derived from the correction factor determined during the experimental adjustment of water suppression pulses. Finally, data processing was modified by using the S-TRAF function along t_1. This apodization function was developed specifically to minimize truncation artifacts while maintaining the spectral resolution [11]. In CT-PRESS, truncation artifacts may easily occur in f_1 if the acquisition period in t_1 is not much longer than T_2*.

Experimental: All experiments were performed on a 3 T Magnetom Allegra head scanner (Siemens, Germany) equipped with standard gradients (max. 40 mT/m and 400 mT/m/ms, used ramp time 0.25 ms) and a standard CP Birdcage RF head coil used for RF transmission and reception. The sequence parameters were: PRESS module: TE=18 ms, voxel size: 20x20x20 mm^3, additional rectangular 400 µs 180° pulse (-210 Hz offset) that is shifted in N_1=23-35 t_1 steps, spectral width:1250 Hz in f_2 and 156.25 Hz in f_1 (8-fold undersampling in t_1), TR=3 s. A constant (N_A=4) or a t_1 dependent number of averages was used varying between 8 and 2 according to a sine-bell. Measurements were performed on phantoms filled with solution of metabolites and on healthy volunteers, the voxel covering predominantly white matter. Data processing was done using programs written in IDL (ITT, USA).

Results and Discussion: In the CT-PRESS sequence (Fig.1), a short TE PRESS module (TE=18 ms) was used with strong spoiler gradients to avoid phase cycling. Thus rather short tc values of e.g. tc≥100 ms for a t_1 range of +/- 70 ms could be realized allowing a better trade-off between optimized tc values and limited T_2 losses. The use of an additional 180° pulse instead of changing the position of the second slice selective 180° pulse of the PRESS module was preferred to avoid artifact signals in case of undersampling in t_1. Weighted averaging in t_1 allows an increase in the SNR per unit measurement time [10], by about 8 % in the case described above. However, since this rather small gain was not consistently reproduced in all phantom studies (the reason is under investigation) and the use of t_1 dependent averages reduces the flexibility of the apodization in t_1, a constant number of four averages was used for in vivo studies. For apodization in t_1, the S-TRAF function with the internal parameter T_{acq}/T_2*=0.33-1.0 yielded better results than the cosine function used before. The truncation artifacts in t_1 were below the noise level for in vivo spectra, and a good spectral resolution was maintained (cf. Fig. 2 and 3). The multiplet structures of signals of J-coupled spins are well detected (Fig.3). As described in [3,12], the separate detection of glutamate (Glu) and glutamine (Gln) is achieved by CT-PRESS. Besides the singlet signals of N-acetyl aspartate (NAA), total creatine (tCr) and total choline (tCho), signals of myo-inositol (m-Ins) and scyllo-inositol (s-Ins) [13] are detected. The detection of s-Ins is less evident in the diagonal spectrum (Fig.2). However, the 2D contour plot (Fig.3) and cross section spectra at 3.34 ppm are better suited, indicating that data evaluation should not be restricted to diagonal spectra. The most important step towards maximizing the SNR of CT-PRESS was the local RF transmitter adjustment to avoid deviation from the nominal flip angles. Correction factors between 0.8 and 1.15 were found for phantom and in vivo studies. Thus signal losses of up to 30 % caused by RF misadjustments can be avoided emphasizing that local RF adjustments are essential for high quality MRS at high field strength.

Conclusion: The quality of CT-PRESS spectra acquired on the human brain at 3 T can be further improved by optimizing systematically both the pulse sequence and data processing. Thus CT-PRESS is a useful alternative to either short TE 1D MRS or localized 2D MRS.

References: [1] Dreher W et al.,MRI 17, 141(1999). [2] Schulte RF et al., MRM 53, 275(2005). [3] Mayer D et al., MRM 54, 439(2005). [4] Mayer D et al., MRM 55, 974(2006), [5] Dreher W et al., MRM 45, 383(2001). [6] Mayer D et al., Psychiatry Res. 154, 267(2007). [7] Tkac I et al., MRM 41, 649(1999). [8] Tkac I et al., MRM 46, 451(2001). [9] Zhong K et al., MRM 52, 898(2004). [10] Kühn B et al., MRI 17, 1193(1999). [11] Spencer LR et al., Applied Spectr. 52, 139(1998). [12] Dreher W et al., Proc. ISMRM, 1998, p.357. [13] Michaelis T et al. NMR Biomed. 6, 105(1993).

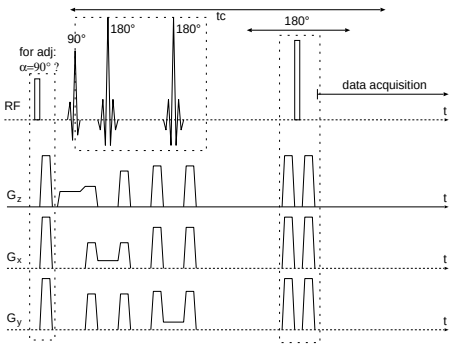

Fig.1: Scheme of the optimized CT-PRESS sequence implemented at 3 Tesla (not to scale).

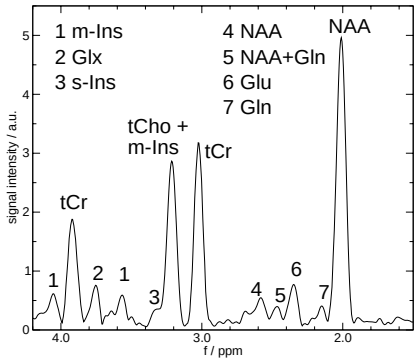

Fig.2: CT-PRESS diagonal spectrum (+/-10 Hz) (tc=151 ms, N_1=31) of the human brain.

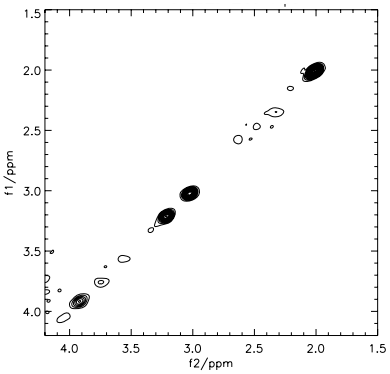

Fig.3: 2D CT-PRESS contour plot from which Fig.2 was derived.