<u>Short VAPOR-like water suppression with improved water suppression performance suitable for high field MRS and MRSI exploiting the residual water signal as a reference</u>

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<u>Introduction</u>. In vivo proton MR spectroscopy (MRS) is a technique invaluable for non-invasive detection and quantification of a number of biochemical compounds in the brain tissue. Use of high magnetic fields for MRS is extremely advantageous because of the achievable increase of detection sensitivity and spectral resolution. However, these benefits may be weakened by problems related to high field: increased RF inhomogeneity, shorter T_2 and longer T_1 relaxation times, increased B_0 field inhomogeneity due to the heterogeneity of magnetic susceptibility, increased chemical shift displacement and increased SAR. In particular, these problems may compromise the efficiency of the suppression of the strong water and lipid signals. During the last decade, VAPOR sequences [1-5] have gained popularity because of the low sensitivity of their performance to B_1 inhomogeneity and to the dispersion of T_1 relaxation time of water. Here we propose an alternative, characterized by reduced length and improved excitation performance.

<u>Method</u>. VAPOR sequences consist of several (6-8) modules, each containing a chemical-shift selective asymmetric RF pulse and a delay with a crusher gradient. Their efficiency is secured by optimized flip angles and delays. Due to the rather long interpulse delays involved in the most often used VAPOR sequences, the repetition times must be relatively long to incorporate the 0.6-0.8 s of water suppression. We have found that considerably shorter VAPOR-like sequences (duration 0.27 s, table 1) may be constructed that have practically identical or superior suppression performance. For this purpose, optimization of flip angles and pulse widths with fixed short delays proved useful. Naturally, the short delays (15 ms) require that more attention be paid to crusher gradients. The asymmetric presaturation RF pulses are similar to those applied in VAPOR; a slight modification ensures a more rectangular chemical-shift selection profile and, to some extent, reduces the dependency on B_1, T_1 and T_2. Similarly to VAPOR, the last delays of the new sequence may accommodate outer volume saturation modules comprising several suitable RF pulses (such as hyperbolic secant or chirp) and crusher gradients, in order to suppress the signal from subcutaneous lipids. We propose to concatenate the water presaturation to the excitation part of the sequence by an adiabatic inversion pulse, acting as a single T_1 mirror [3], which may simultaneously provide 1D ISIS localization, similarly to SPECIAL [6]. In such a case, two scans would be acquired, inverting the whole spectrum bandwidth once nonselectively, once only inside the volume of interest, so that the added signal may be localized to a slice. The durations of the intervals surrounding the robust inversion may be manipulated, which makes these intervals suitable for optional outer volume saturation.

Pulse number	1	2	3	4	5	6	Inv
Flip angle [°]	66.6	90	90	90	120.6	163.8	180
Pulse width [ms]	30	30	28.2	30	30	24.6	20
Delay [ms]	15	15	15	15	15	35.5	19.9

Table 1. Pulse sequence timing (n^{th} RF pulse followed by n^{th} delay)

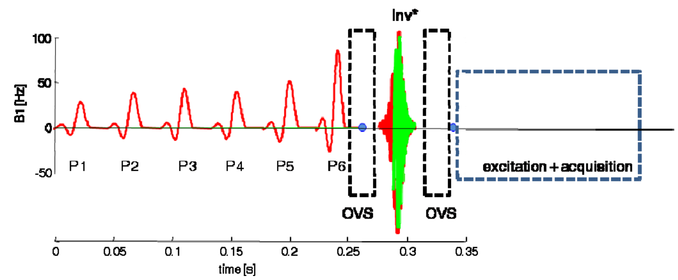

Fig. 1. Pulse sequence scheme (Inv pulse not to scale)

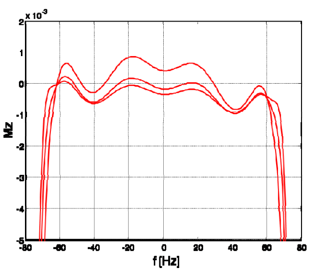

Fig 2. Water suppression profile– offset dependence for various T_1.

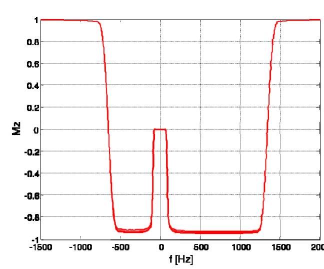

Fig. 3. Metabolite excitation – whole spectrum for various T_1.

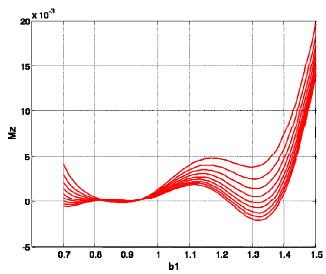

Fig. 4. Water suppression as a function of B_1 for various T_1.

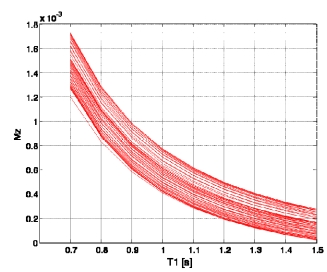

Fig. 5. Residual water as a function of T_1 for several offsets.

<u>Results</u>. The performance of the proposed modification of VAPOR sequences were simulated numerically by a Bloch-equation simulator with the sequence described in Table 1 and depicted in Figure 1. The timing of the part between the dots marking M_z=0 can be easily adapted. Figure 2 demonstrates the offset dependence of water excitation, assuming T_1=0.7, 1.0, 1.3 s, T_2=0.1 s; the suppression factor is 1000 or more. In Figure 3, the whole spectral range is shown in a simulation appropriate to metabolites with T_1=1.0, 1.3, 1.6 s, T_2=0.2 s. The inversion RF pulse offset has been introduced in order to invert the whole spectrum bandwidth at 7T with a conventional hyperbolic secant pulse with γB_1<500Hz. The low sensitivity to B_1 inhomogeneity is illustrated by Figure 4, showing for T_1=0.7-1.5 s and T_2=0.1 s the dependence of M_z after the water presaturation on the RF field strength. The dependence of the residual water signal on T_1 for offsets -25..25 Hz is given in Figure 5.

<u>Conclusion.</u> The designed water suppression sequence is much shorter than the mostly used VAPOR sequences and is characterized by very similar B_1 and T_1 sensitivity. The reduction of delays and the use of an improved RF pulse result in improved excitation profiles with very restricted effect on metabolites. Used in a 2-step scheme, it may provide 1D volume selectivity at its end, i.e. at the start of the excitation module. Thanks to the easy control of residual water by adjusting the intervals surrounding the inversion and thanks to its T_1 dependence, it is expected that internal reference water signal can be obtained in together with metabolite spectra and used for artifact correction and/or tissue segmentation. Outer volume suppression may be added in a fashion similar as in VAPOR. We believe that this technique may provide efficient water suppression as needed for precise and accurate evaluation of spectra acquired at high fields. Thanks to the reduced length and reduced impact on metabolites, it may improve spectrum quantifiability and be more suitable for spectroscopic imaging.

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<u>References.</u> [1] Starčuk Z et al., Proc. 3rd SMR Meeting, Nice 1995, p. 1966; [2] Starčuk Z et al., MAGMA 1997: Suppl 5, p .1666; [3] Starčuk jr. Z et al. , Proc. ISMRM 5th Annual Meeting, Vancouver, 1997, p.1459; [4] Tkáč I et al., Magn Reson Med 1999; 41: 649-656; [5] Tkáč et al., Appl Magn Reson 2005; 29, 139-157; [6] Mlynárik V et al., Magn Reson Med 2006; 56: 965-970.