Short dual-band VAPOR-like pulse sequence for simultaneous water and lipid suppression for in vivo MR spectroscopy and spectroscopic imaging

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Introduction. The strong water and lipid content is a common problem in both clinical and research applications of short echo time in vivo proton MR spectroscopy and, especially, MR spectroscopic imaging. Their magnetization is overwhelming in comparison with the observed resonances of metabolites and is the major source of spectrum contamination from outside the volume of interest; the respective frequency bands are notorious for irreproducible artifacts, which may adversely affect spectral quantitation. For these reasons, various techniques have been developed to suppress such signals. To eliminate water, sequences of optimized water selective radiofrequency pulses interleaved with delays containing crusher gradients and preceding the localizing excitation are used most often. With such construction, the presaturation and excitation parts of the sequence are independent, and even very short echo times can be achieved. Among such methods, WET and VAPOR are the ones used most widely [1-6]. The original VAPOR, developed primarily for single-voxel MRS, uses up to 8 CHESS RF pulses and long interpulse delays. It has been predicted recently [7] that much shorter VAPOR-like sequences containing only 5 RF pulses (quick-VAPOR) and using very short interpulse delays can also even better performance if the flip angles and pulse widths are optimized. For brain measurements, lipid suppression is often based on the knowledge of the fat distribution geometry and outer volume suppression (OVS) is used for this purpose. Here we present experimental results of quick-VAPOR and suggest a very short dual-band VAPOR-like sequence applying the same construction method for water and lipids simultaneously.

Method. With a Bloch-equations simulator, quick-VAPOR sequences consisting of 5 RF-crusher modules were optimized independently for water and lipid suppression with the aim to superimpose the excitations, which is possible thanks to the narrow-band excitation in either sequence. RF pulse durations, flip angles, and delays were optimized under the constraint that RF pulses remained overlapped as much as possible so that the common gaps could be used in the combined sequence for hosting crusher gradients. All presaturation RF pulses were asymmetric amplitude-modulated minimum phase RF pulses developed for excitation in very short TE STEAM sequences. The superposition of water- and fat-excitation RF pulses results in amplitude- and phase-modulated dual-band RF pulses, whose shapes reflect the time shifts and amplitudes of the components. The end of the delay following the last presaturation pulse is the moment in which the longitudinal magnetization of both water and lipids should be zero and it is the synchronization point for both presaturations and the attachment point for the rest of the sequence. For the sake of SNR, it is advantageous to connect the 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 in 2 scans ($S_{slice}=S_{no\_inv}-S_{slice\_inv}$) and provide space for OVS modules, similarly to SPECIAL [6]. It is worth noting that with this scheme, out-of-VOI water/fat are compensated fully, while intra-VOI water/fat have a stable residue due to relaxation in the concatenation period. The sequence parameters of Table 1 are optimized for 3T, the total sequence length is around 240 ms.

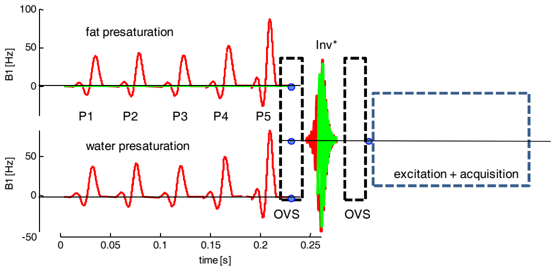

Figure 1. Pulse sequence (not to scale), showing the independently optimized presaturation sequences added with an offset.

Pulse number	1	2	3	4	5
Flip angle [°]	78.3/81.0	81.0/90.0	83.7/96.3	122.4/140.4	136.8/152.1
Pulse width [ms]	23	30	33	33	27
Delay [ms]	15	25	30	25/20	5

Table 1. Pulse sequence parameters (nth RF pulse followed by nth delay, W/F)

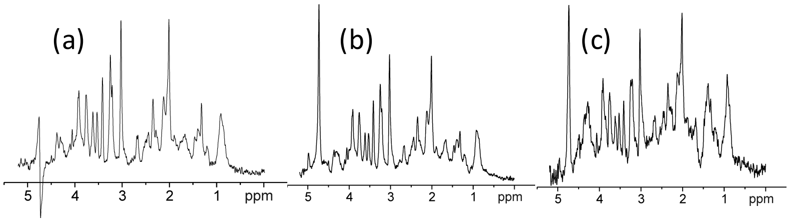

Figure 2. Mouse brain spectra obtained with SPECIAL preceded by the standard VAPOR, TR=4s – (a) and 'quick-VAPOR' with TR of 4 s (b) and 1 s (c) at 14 T. Only gaussian apodization was applied.

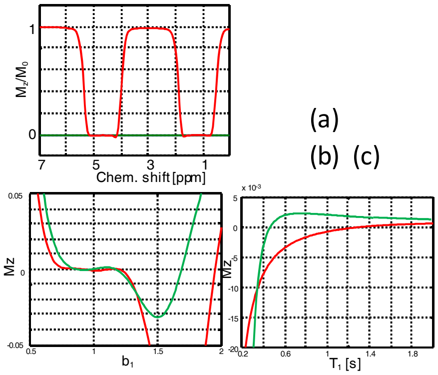

Figure 3.(a) Simulated excitation profile of metabolites (T_1=1400ms, T_2=200ms). Sensitivity of the residual water (T_1=1000ms, T_2=80ms, 4.7ppm) and fat (T_1=300, T_2=20ms, 1.2ppm) to (b) RF inhomogeneity (b_1) and (c) T_1.

Results. The performance of the proposed sequences, developed with a Bloch-equations simulator, was re-tested in the final form by a quantum-mechanics based simulator (jMRUI/NMRScope-B). The water saturation subsequence, re-optimized for 14 T, was tested on a phantom and a mouse on a Varian 14 T scanner, applying a quadrature surface T/R coil. The spectra were acquired in 20 16-scan blocks so that reproducibility could be assessed. This inspection confirmed the reliability of the water residue in the new sequence, in contrast with the randomly fluctuating signal in the old one. Examples of spectra obtained with 3 different sequences are shown in Fig. 2. In Fig. 3, the simulated dependencies of metabolite excitation profile and residual signal sensitivities to RF and T_1 variations are shown.

Discussion. The designed presaturation sequence is much shorter than the often used VAPOR sequences. It is characterized by a very low sensitivity to variations of B_1, T_1 and T_2. Experimental results testing the water suppression path in vivo confirmed that the residual water stability is much improved compared to VAPOR. Theory predicts that the residual signals result from the short period of relaxation inside the VOI in the concatenation period. These improvements are attributed to the short delays and the use of improved RF pulses providing excitation profiles with very restricted effect on metabolites. Naturally, the chemical shift selective presaturation of lipids removes other signals which may occur in this spectral region (lactate). 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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