Fast water suppression for high resolution MRSI by frequency selective spokes pulses at 7T

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Introduction:
In brain MRSI, spatial resolution is limited by a relatively inefficient MR sequence because most localization methods require long repetition times (TR). Recently, a drive to more efficient localization techniques, such as ring mode selective excitation [1], have been developed. With these developments, the duration of the water suppression (WS) sequence becomes the limiting factor for fast MRSI. Because of the inhomogeneous B_1-field at 7T, the main challenge for adequate WS is to achieve high suppression factors over the whole brain. In this work an ultra short WS method is achieved by using frequency selective spokes pulses to correct for B_1-inhomogenieties. In this way the TR can be further reduced, and an increase in spatial resolution becomes possible for brain MRSI at 7T, which potentially increases the diagnostic applicability of MRSI at ultrahigh field strengths.

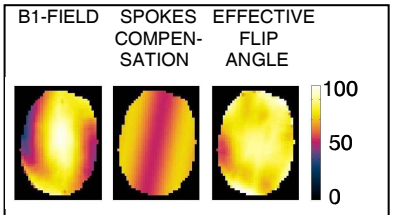

Fig1: B_1 intensity in pct. FLTR: B_1-map, compensating field by 2 spokes, homogeneous B1 field after compensation

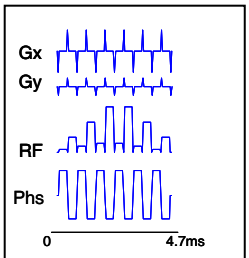

Fig2: Spokes pulse consisting of 6 spokes pairs: GR, RF and phase

Sequence: A pair of two spokes block pulses is used to homogenize the B_1-profile of a transverse slice through the brain (fig1). A frequency selective spokes pulse was designed by fitting six pairs of spokes pulses to a Gaussian shaped envelope (fig2) with a total duration of only 4.7 ms. Three consecutive frequency selective spokes pulses, with varying gradient spoilers in between, are used for WS before excitation followed by acquisition. The duration of the total WS sequence including gradient crushers is 26ms.

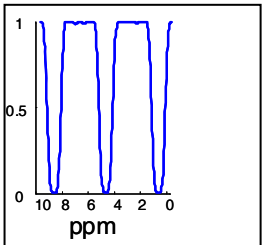

Fig3:Mz frequency profile after water suppression with spokes pulses

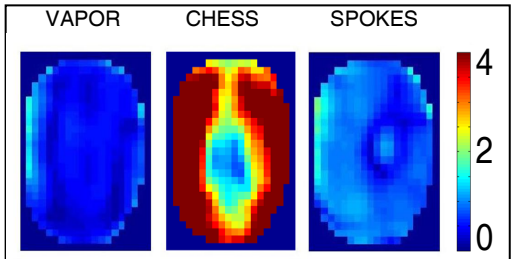

Fig4: Water residual over a transverse slice through the brain after water suppression in ptc

Methods: Simulations to determine the water suppression profile were performed. An outer volume crusher coil [2] was used for fast lipid suppression and placed inside a 16-channel (Nova Medical, USA) RF receiver array and a volume transmit head coil (Nova Medical, USA). A B_1-map was recorded with the actual flip angle method [3] and used to optimize the RF and gradient amplitudes and phase difference of a 2-spokes pulse [4]. While crushing the lipid signal with the crusher coil, slice selective pulse-acquire (SSPA) 2D MRSI was recorded using the designed spokes pulses as three WS pulses with nominal flip angles of 90, 100 and 110°. For comparison, SSPA 2D MRSI scans were applied with the commonly used 8-pulse VAPOR [5] (800 ms duration) and 3-90°pulse CHESS [6] (35 ms duration) WS methods. For all scans: voxel size=6x6x10mm, TR=850ms, scan time=3min. Additionally, a very high resolution SSPA 2D MRSI with spokes WS pulses was obtained (3x3x10mm, TR=120ms, 2 averages, scan time=9min). All scans were performed on a 7T whole body MR system (Philips, USA).

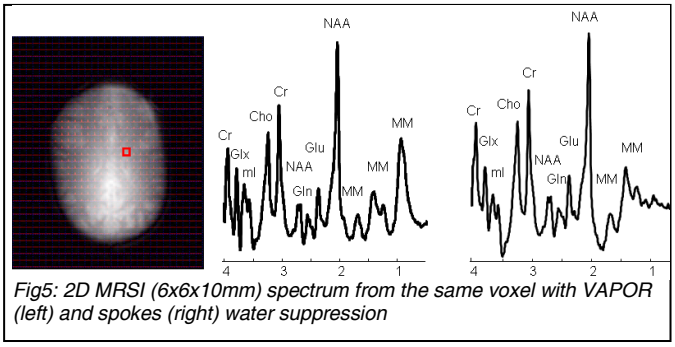

Fig5: 2D MRSI (6x6x10mm) spectrum from the same voxel with VAPOR (left) and spokes (right) water suppression

Results: The simulated frequency profile shows that suppression of the signal with spokes pulses will occur only on resonance with a bandwidth of 300Hz (fig3). Due to the subsampling with only 6 spokes pairs, this pattern repeats every 1.2 kHz. After WS with VAPOR, on average 0.5% of the original water signal remains (fig4a). WS with CHESS is only sufficient in the center of the brain where the flip angle reaches 100% (fig4b). WS with spokes pulses maintains a water residual of 1% on average over the whole slice (fig4c). The spectra of the VAPOR and spokes scans are virtually identical (fig5), apart from the suppression of the macromolecule at 1.2 kHz offset (0.9 ppm). Very high resolution imaging still shows sufficient SNR to detect brain metabolites [fig 6].

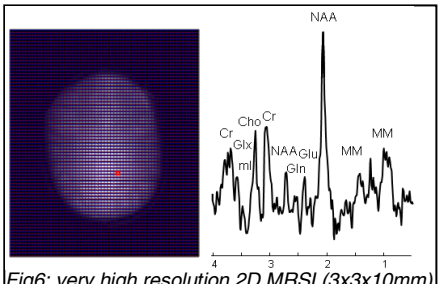

Fig6: very high resolution 2D MRSI (3x3x10mm) with spokes water suppression (TR=119ms) acquired in 9 minutes.

Discussion & Conclusion: Over a whole slice, water suppression with the fast spokes pulses is almost identical to VAPOR water suppression. As expected by the frequency profile simulations, not only water is suppressed but macromolecules at 0.9 ppm are suppressed as well, which can be avoided by subsampling the guassian envelope with more than 6 spokes pairs. Since the duration of the water suppression sequence is much faster than compared to VAPOR (26 vs 800 ms) scan times can be reduced and spatial resolution can be boosted as was shown by the very high resolution MRSI scan obtained in only 9 minutes. This may open up new possibilities for diagnostic applicability of MRSI.

References:
[1] Hetherington MRM 2010; [2] Klomp ESMRMB 2013; [3] Insko JMRSA 1993 [4] Grissom MRM 2012; [5] Tkac MRM 1999; [6] Haase Phys Med Biol (1985);