Spectroscopic imaging using wideband parallel RF excitation at 7T

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Introduction: Imaging at 7T suffers from severe B_1 inhomogeneities that manifest as signal to noise ratio (SNR) loss, which is a particularly serious burden in chemical shift imaging (CSI). Parallel RF transmission (pTx) is an emerging technology to mitigate B_1^+ inhomogeneity during RF excitation, where, typically, 8 RF amplifiers play 8 independent RF waveforms, enabling more complicated RF excitation patterns using shorter RF waveforms compared to single-channel systems. Previous work in this field includes successful 7T in-vivo B_1^+ mitigation [1]. For CSI related applications however, the B_1^+ mitigation constraint extends over the frequency bandwidth of the metabolites of interest and presents a more challenging RF design problem.

In this work we demonstrate a phase-encoded (PE) CSI readout with a pTx mitigation excitation over a 600Hz spectral bandwidth and a 3 cm thick slab [2]. Due to current hardware constraints, we limit this demonstration to the low flip-angle domain where excitation k-space analysis holds, and apply spokes-based slice selective RF design to an eight channel transmit system at 7T using a spectroscopy phantom containing physiological concentrations of the major brain metabolites of interest. pTx water suppression was achieved with a Gaussian-shaped pulse preceding the excitation. The goal of this work is to demonstrate that compared to the regular birdcage (BC) mode excitation, the proposed pTx wideband excitation provides spatial uniformity of metabolite signals in a phantom with physiological brain metabolite concentrations.

Methods: PE CSI readout was used in a gradient-echo (TE=5ms) 8-channel pTx pulse on a 7T scanner with whole-body gradients (40mT/m, 180 mT/m/ms). Butler matrix transformation of a 16 channel stripline transmit-receive array was used to drive eight orthogonal birdcage (BC) modes [3]. After quantitative B_1^+ mapping from three different 5mm thick slices (at 0cm, +1cm, and -1cm), the pTx pulses were designed and optimized to provide B_1^+ mitigation for a uniform spatial-spectral excitation over a 3 cm slab in z and 600Hz of spectral bandwidth. In addition, the design algorithm included B_0-correction optimization that used a separately acquired B_0 map. The pTx excitation RF pulse duration was 1.76ms and the flip angle was 20º. For comparison, CSI acquisition using a conventional BC sinc-shaped excitation was also performed.

Moreover, using the quantitative mapping, eight 9ms long Gaussian-shaped pulses were designed in an attempt to provide spatially uniform suppression of the strong water signal. These spectrally-selective-only pulses had a spectral bandwidth of 100Hz and a flip angle of 74º. The single slice PE CSI readout encoded the (x,y,f) space for Cartesian grid of 20x20x1024 points (interpolated to 32x32x1024) with a 3200Hz bandwidth. The encoding used a 20-cm in-plane FOV for an in-plane voxel size of 1.0 cc. With TR = 1.5s, the total scan time was 10 minutes. The data from the 16 receive coil elements were combined by using constant phase term for each coil. No spatial or spectral apodization was applied.

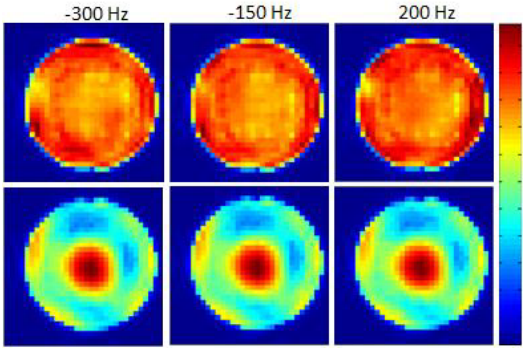

Fig 1: CSI acquisitions with unsuppressed water using pTx pulse excitation at -300, -150 and 200 Hz. After dividing out the receive profile, the spokes-based design (top raw) shows successful B_1^+ mitigation in space and frequency, clearly superior to the BC-sinc excitation (bottom row).

Results and Discussion: Before running a CSI metabolite-detection acquisition, four additional CSI scans (TR = 1s) without any water suppression were acquired by shifting the central frequency of the excitation pulse at -300Hz, -150Hz, 0Hz and 200Hz, in order to show the spectral-spatial feasibility of the excitation at high SNR. Figure 1 shows images at three off-resonance frequencies from the spokes-based (top row) and BC-sinc (bottom row) acquisitions. These images, obtained by summing over the magnitude of the spectra from each spatial location and dividing by the previously obtained receive profile, clearly show the superiority of the pTx wideband spoke pulse. Figure 2 shows CSI acquisitions using the weak water suppression for the two mentioned excitation schemes overlaid on a BC 2DFT image of the phantom (not corrected for the receive profile). A water postprocessing (Siemens Spectroscopy toolbox) was applied and specra are displayed over 1.5ppm-3.5ppm (~600Hz). The BC sinc-RF signal dropout (Fig. 2, left) is apparent, as is the substantial mitigation due to the wideband spokes design (Fig. 2, right).

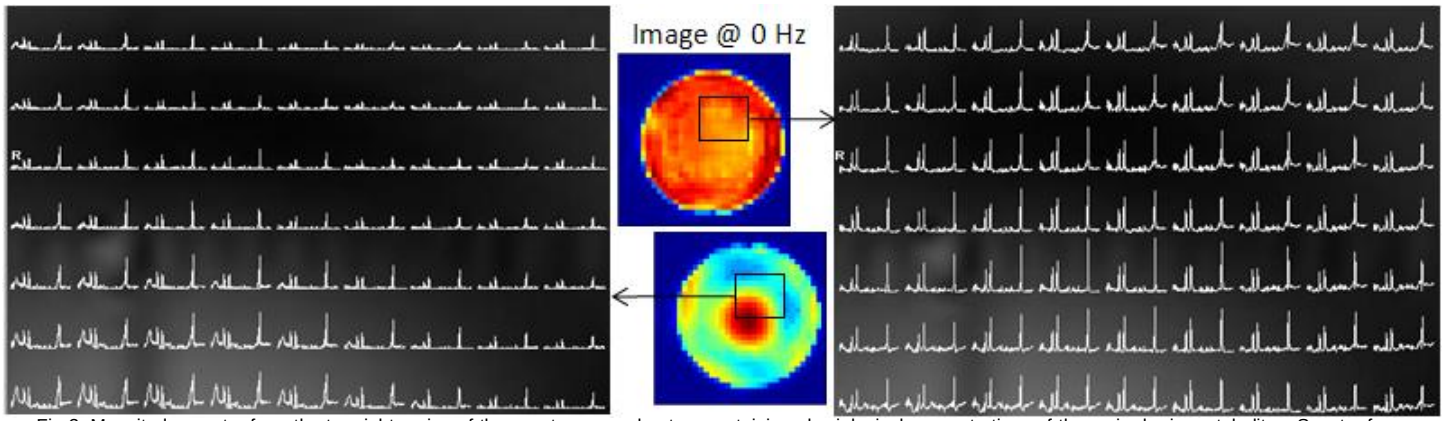

Fig 2: Magnitude spectra from the top right region of the spectroscopy phantom containing physiological concentrations of the major brain metabolites. Spectra from the spokes-based design (right) demonstrate uniform excitation compared to the sinc BC excitation (left).

Conclusions and future work: We have successfully applied wideband uniform pTx excitation over 600Hz of spectral bandwidth and 3cm thick slab on a spectroscopy phantom containing physiological concentrations of brain metabolites. Current hardware limitations prevented us from applying larger flip angles for both excitation and water suppression. Future work includes large-flip-angle mitigation designs, SAR evaluation and monitoring, and the integration of spiral CSI with pTx RF pulses aiming towards in vivo pTx CSI.

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References: [1] Setsompop K., MRM, in press; [2] Setsompop K., MRM, in press; [3] Alagappan, MRM, 57(6), p. 1148-58, 2008;