Fast Spectroscopic Imaging using uniform wideband parallel excitation on 7T

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Introduction: The benefits of 7T chemical shift imaging (CSI) include increased SNR and chemical shift dispersion compared to lower-field CSI. However, high field imaging suffers from severe B_1 inhomogeneities that manifest as SNR loss, which is a serious burden in CSI applications. In addition, for volumetric CSI, phase-encoded (PE) CSI suffers from intrinsically long acquisition times. CSI using spiral readout gradients [1] samples (k_x, k_y, k_f) space efficiently without SNR tradeoffs and addresses the encoding-time constraint of PE CSI at the cost of high-fidelity gradient hardware and non-trivial trajectory design and reconstruction algorithms. Prior work on *in vivo* 7T Spiral CSI [2] demonstrated the encoding efficiency of spiral CSI, but also illustrated the expected and significant signal variation across the FOV.

In this work we combine spiral CSI readouts with parallel RF transmission (pTx) to mitigate B_1^+ inhomogeneities. We limit this initial 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 [3]. The 8 transmit channels enable reduced-duration, slice-selective RF pulses that implement excellent on-resonance B_1^+ mitigation and can be optimized to yield B_1^+ mitigation over a 600 Hz bandwidth. The goal of this work is to demonstrate efficient spiral CSI encoding with B_1^+-mitigated spatial-spectral excitation over a spatial FOV and frequencies of interest for 1H brain spectroscopic imaging by spiral CSI acquisitions of the high-SNR water signal shifted to 5 different off-resonance frequencies.

Methods: Constant-density spiral 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). Eight orthogonal birdcage (BC) modes were driven via a Butler matrix transformation of a 16 channel stripline array [4]. After quantitative B_1^+ mapping, the pTx pulses were designed and optimized to provide B_1^+ mitigation for a uniform spatial-spectral excitation over a 5-cm slab in z and 600Hz spectral bandwidth. In addition, a B_0-correction optimization using a separately acquired B_0 map improved reliability of the spectral excitation [5]. The pTx duration was 1.76 ms.

The spiral readout encoded the (x,y,z,f) space for Cartesian grid of 32x32x8x512 points (x,y,z,f) with a 1600Hz bandwidth. The encoding used a 24-cm in-plane FOV and 8cm in z, for an overall voxel size of 0.56 cc. The maximum slew rate and amplitude were limited to a conservative 100T/m/s and 10mT/m, respectively, yielding imaging time of 1.75 minutes (TR=1s). The acquisition was repeated, in the absence of water suppression, for a series of off-resonance shift of the water peak, ranging from -300 to 300Hz. The spiral CSI data were received with 16 Rx channels, 2X-gridded with a Kaiser-Bessel kernel, and combined using complex weights from the spectroscopy data themselves.

Results and Discussion: In addition to spiral CSI, we collected gradient-recalled echo 2DFT images using the wide-band excitation. Figure 1 shows three images from these scans, each being from a different slice in z and different off-resonance frequency. After dividing out the receive profile, the transmit profile demonstrated excellent uniformity of signal in both space and frequency.

Due to the low-flip-angle domain of the pTx, and in order to yield high SNR for evaluation of the spectral and spatial evaluation of the pulse with spiral CSI we performed five spiral CSI scans on a single peak water phantom, in four of which we manually shifted the central frequency of the transmitter in order to get the off-resonance water at -300Hz, -150Hz, 100Hz and 200Hz. The resulting spectra seen in Figure 1 are obtained by combining the magnitudes of the individual off-resonance single peak spectra from the individual spiral CSI runs. Clearly seen from the selection of representative spiral-CSI voxels at several different locations, the peak amplitude as a function of frequency is only slowly varying.

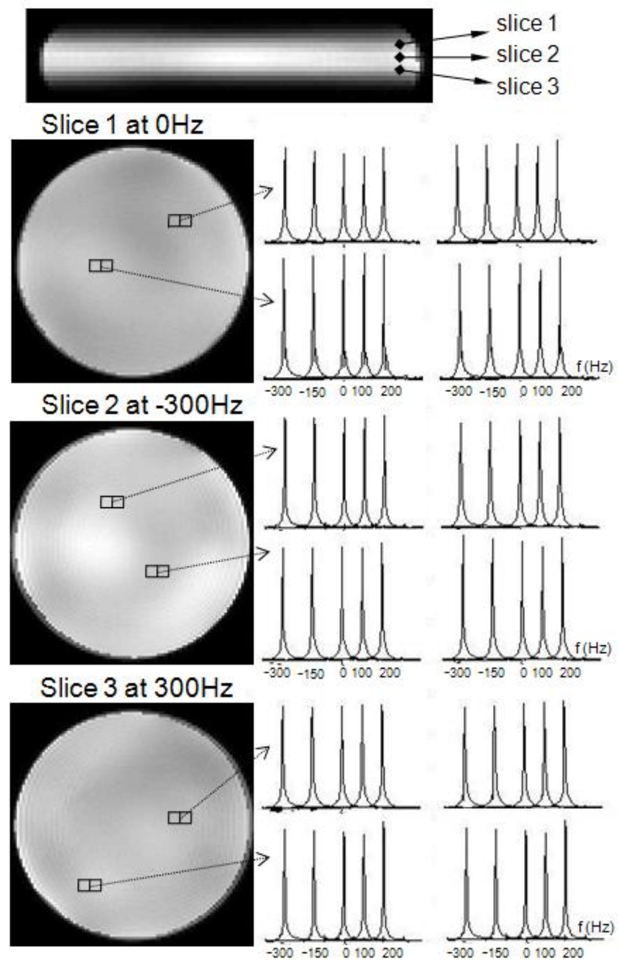

Fig. 1: Left: pTx excitation in 2DFT, corrected for receive profile variations, demonstrating B1+ mitigation at +/- 300 Hz. Right: Combination of high-SNR water spectra sampled with spiral CSI for several off-resonance settings of the transmitter. The magnitude spectra are combined from 5 separate spiral CSI scans at the different frequencies and demonstrate B_1^+ mitigation in frequency.

Conclusion and future work: We successfully demonstrated the feasibility of pTx with spiral CSI encoding using 8 transmit channels and 16 receive channels. These results provide strong motivation for extending the low-flip-angle developments to large-flip-angle pTx designs with the demonstrated wide-band pTx properties, a prerequisite for detection of low-concentration brain metabolites.

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