Simulation Tool for Modeling of Hyperpolarized ^{13}C Metabolic Imaging: Application to Optimizing ^{13}C-Fructose Acquisitions

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Introduction Hyperpolarized ^{13}C MR has emerged as a powerful new imaging technique for monitoring metabolic processes *in vivo*. In this method, optimal data acquisition schemes are critical since the magnetization achieved through hyperpolarization undergoes nonrenewable diminution caused by repetitive RF excitations and T_1 relaxation of magnetization to its thermal equilibrium[1]. In this project, a specialized simulation tool was developed to calculate optimal sampling schemes. This approach was applied and tested for improving the acquisition of hyperpolarized [2-^{13}C]-fructose, which has recently been proposed as a novel hyperpolarized ^{13}C probe [2] but is limited by a relatively short T_1.

Purpose In this study, we investigated through simulation and empirical testing different data acquisition strategies for hyperpolarized ^{13}C-fructose 3D-MRSI and evaluated them in terms of signal-to-noise ratio (SNR) and image quality.

Methods 1) Theoretical simulations were performed using MATLAB to examine the effects of various RF excitation schemes on SNR and spatial blurring of the final image. Assuming TR=215ms and T_1=13.5s for ^{13}C-fructose[2], three different flip angle schemes were tested: 5° constant flip angle (CFA), variable flip angle (VFA) and T_1 compensated variable flip angle (compT_1-VFA). A matrix size of 16×16 was chosen and a set of 256 flip angles for optimal magnetization usage in each case were calculated[3]. Applying concentric encoding, k-space data were weighted based on the magnitude of the transverse magnetization at each step of RF excitation. Finally, point-spread-functions (PSF) were acquired by transforming k-space data. **2)** Three phantom experiments were carried out with the different RF flip angle schemes and compared to the simulation results. 3D-MRSI data were acquired from a 5mL syringe filled with hyperpolarized ^{13}C-fructose with TE=140ms, TR=215ms, FOV=4cm×4cm and spatial resolution of 2.5mm. Fructose spectra were overlaid on top of a 2D axial image of the syringe and 1D profiles were obtained by interpolating the peak values from the spectra. **3)** Another set of phantom experiments were performed by employing compT1-VFA but this time changing the number of phase encoding steps: 256 excitations for a matrix size of 16x16, 64 excitations for 8x8 and finally 76 excitations for 16x16 with compressed sensing[4].

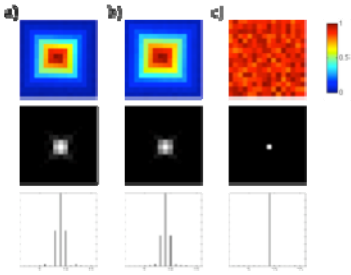

Fig. 1. Simulated results of k-space weighting (top row), PSF (center row) and 1D profile of PSF (bottom row) for a) 5° CFA, b) VFA, and c) compT1-VFA. 2D complex random noise was generated to match SNR=100 for CFA and added to k-space data in all three cases.

Results 1) From the simulation results, CFA and VFA show uneven weighting in the k-space that leads to spatial blurring of the PSF (Fig. 1). On the other hand, compT_1-VFA shows evenly weighted k-space resulting in a theoretically optimal PSF. CFA and VFA utilizes larger flip angles in the beginning of the RF excitations. As a result, relatively high SNR is achieved by compromising the spatial resolution, represented by full width at half maximum value (FWHM) (Table 1). compT_1-VFA maintains a constant transverse magnetization throughout the phase encoding steps and achieves no blurring. **2)** Results from phantom experiments (Fig. 2) show a good match with simulation data in that compT_1-VFA has the least blurred 1D profile. CFA and VFA show higher SNR but the profiles are much more blurred out. **3)** By applying compressed sensing together with compT_1-VFA, we were able to increase the SNR and still preserve the sharp profile (Fig. 3).

	Initial Flip Angle	FWHM	SNR
CFA	5°	1.94	100
VFA	3.58°	1.71	88
comp T_1-VFA	0.17°	1	19.3

Table 1. Simulated FWHM and SNR

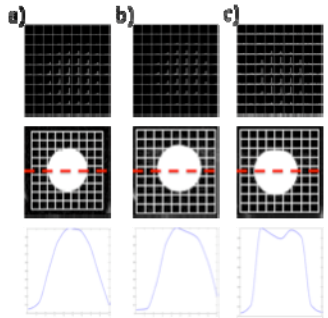

Fig. 2. An axial image of syringe phantom (center row) with corresponding spectra (top row) for a) 5° CFA, b) VFA, and c) compT1-VFA. Note the sharp 1D profile (bottom row) of compT1-VFA compared to other schemes.

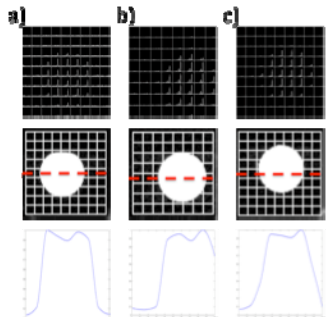

Fig. 3. compT_1-VFA scheme with different number of phase encodings. a) 256, b) 64 and c) 76. Phantom image from b) is slightly off the center because of misplacement of the syringe in a smaller FOV of 2cmx2cm.

Discussion Since T_1 relaxation of ^{13}C-fructose is shorter than other ^{13}C substrates such as ^{13}C-pyruvate, hyperpolarized ^{13}C-fructose imaging could impose additional challenges in designing data acquisition strategies. Here, we have optimized an acquisition scheme using a specialized simulation tool and showed that compT_1-VFA together with compressed sensing can yield minimized spatial blurring with high SNR enough for *in vivo* ^{13}C-fructose metabolic imaging.

References

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