Transmit Gain Calibration for Hyperpolarized ^{13}C Patient Studies

Galen D. Reed[1], Peder E.Z. Larson[1], James Tropp[2], Albert P. Chen[3], Adam B. Kerr[4], Mark van Criekinge[1], Douglas A. C. Kelley[5], John M. Pauly[4], Kayvan R. Keshari[1], John Kurhanewicz[1], Sarah J. Nelson[1], and Daniel B. Vigneron[1]

[1]Radiology and Biomedical Imaging, University of California San Francisco, San Francisco, California, United States, [2]GE Healthcare, Fremont, California, United States, [3]GE Healthcare, Toronto, Ontario, Canada, [4]Electrical Engineering, Stanford University, Stanford, California, United States, [5]GE Healthcare, San Francisco, California, United States

Introduction

Following the intial clinical trial that evaluated safety and defined the maximum tolerated dose, the current focus is on the clinical translation of hyperpolarized ^{13}C magnetic resonance imaging. Proper calibration of the transmitter power is crucial for these hyperpolarized MRI experiments to avoid polarization loss from radio frequency (RF) saturation. This study presents both phantom and hyperpolarized ^{13}C patient experiements to characterize the transmit B_1 field.

Methods

To test the transmit inhomogeneity *ex vivo*, a cylindrical phantom was constructed with a concentric inner cavity (ID = 3 cm, OD = 12 cm). The phantom was filled with ethylene glycol, and the endorectal receiver was inserted within the cavity. A Bloch Siegert B_1 mapping sequence was developed [4,5] using a 6 ms Fermi window K_{BS}= 5.2 rad/G^2 applied symmetrically at ±3 kHz off resonance. An interleaved 3D flyback EPI readout followed the Bloch Siegert pulse, with the first echo midpoint at 15 ms after excitation. A 32x32x10 image was acquired with 4 averages and a voxel size of approximately 1.2 cc. The ^{13}C spectrum of ethylene glycol is J-coupled to the methylene protons with J_{CH} = 145 Hz. Using 4 interleaves with an echo spacing of $1/J_{CH}$=7 ms, a the central portion of the FOV was not corrupted by the J-coupling image ghosts. The peak B_1 was calculated as

$$B_{1,peak} = \sqrt{\frac{\phi_{BS}}{K_{BS}}}$$

where ϕ_{BS} is the phase difference of the two acquisitions, and K_{BS} is the proportional constant relating the Bloch-Siegert induced phase shift to the square of the B_1 transmit field.

In vivo ^{13}C data were acquired using a dedicated transmit saddle coil approximately 30 cm by 35 cm: one element of the saddle is embedded in the patient table, and one is on a hinge to the patient's anterior (Figure 1). A dual tuned ^{13}C endorectal probe and a 4-channel flexible ^{1}H torso array were used for signal reception. Transmitter attenuation was calibrated by finding the 180° signal null of a syringe placed inside the endorectal probe containing approximately 1 mL 8 M ^{13}C urea. Using the dissolution DNP method [1,2], the volunteer patient was injected with 45 mL of 250 mM hyperpolarized [1-^{13}C] pyruvate 70 seconds post dissolution, and a 3D spectroscopic acquisition using a progressive flip angle schedule [3] was initiated 25 seconds after the end of the saline flush. After acquisition, two slice-resolved spectra were acquired: one at a calculated 45° flip angle, and the second at 90°. Including RF saturation but ignoring T_1 decay between acquisitions, the flip angle imparted to pyruvate was determined by

$$\theta = \cos^{-1}\sqrt{\frac{S(2\theta)}{2S(\theta)}}$$

where S(θ) is the magnitude of the signal at the calibrated 45° flip, and S(2θ) is the magnitude when the pulse height was doubled.

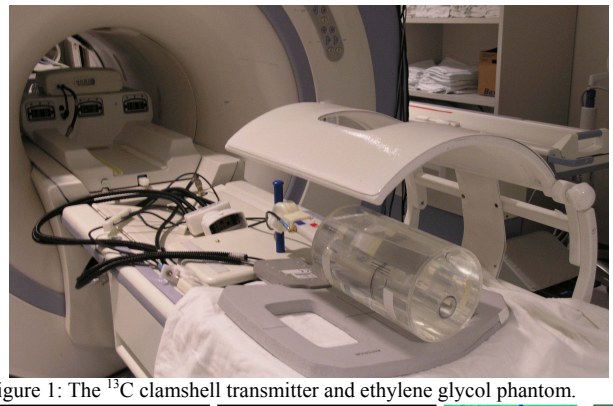

Figure 1: The ^{13}C clamshell transmitter and ethylene glycol phantom.

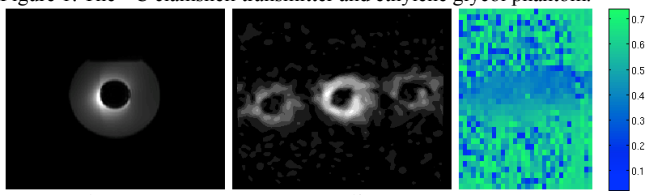

Figure 2: ^{1}H localizer (left), magnitude ^{13}C image (center), and calculated B1 map (right) using the Bloch Siegert shift. Image ghosts are due to heteronuclear coupling for the ethylene glycol phantom solution.

Results

The spatial variance of the B_1 field was measured in Bloch Siegert experiments on the ethylene glycol phantom. The mean B_1 calculated at the A/P location of the urea syringe was 0.12±0.005 G, while at the typical location of the prostate center (30 mm anterior of the syringe), the calculated field was 0.01±0.005 G. Based on these ex vivo measurements, the transmitter attenuation was reduced by 2 dB after calibration on the urea syringe during the patient exam. The double angle slice-selected spectra acquired from the patient gives a measured flip angle of 42°, coinciding well with the calibrated 45°.

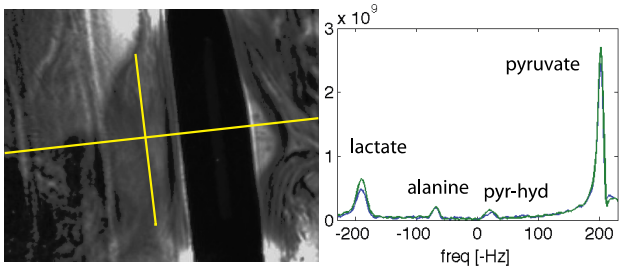

Figure 3: Sagittal FSE localizer (left) showing locations and thickness of the slice. The urea insert is visible inside the probe. ^{13}C Spectra (right) show signal amplitudes at 45° (blue) and 90° (green). The calculated flip is 42° when the 2 dB attenuation is removed.

Conclusion

Mapping the transmit field and determining the optimal transmit power is crucial for hyperpolarized NMR experiments, and this task poses a major challenge for low gamma and low natural abundance nuclei. This study presents a B_1 field mapping method using the Bloch Siegert shift with ethylene glycol phantoms for the characterization of transmitter nonuniformity. This nonuniformity was incorporated into the patient study as a 2 dB attenuation adjustment, and the accuracy of this approach was demonstrated via slice selective double angle spectra in the human prostate.

References [1] J. H. Ardenkjaer-Larsen, et al., Proc Natl Acad Sci U S A 100, 10158 (2003). [2] J. Kurhanewicz, et al., Neoplasia 13, 81 (2011). [3] K. Nagashima, J Magn Reson 190, 183 (2008). [4] L. I. Sacolick, et al., Magn Reson Med 63, 1315 (2010). [5] R. F. Schulte, et al., NMR Biomed 24, 1068 (2011).