Simultaneous Bloch-Siegert B_1 mapping and imaging of hyperpolarized pyruvate, bicarbonate, and lactate, in a single tracer bolus

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Introduction: Hyperpolarization of spins via DNP has been explored to non-invasively study real-time metabolic processes in vivo using ^{13}C labeled substrates [1-3]. In these studies, calibration of RF transmit power is required to efficiently utilize the rapidly decaying magnetization. Conventional transmit RF field (B_1^+) mapping methods are unsuitable for hyperpolarized (HP) magnetization due to the need for a fixed, known state (the steady state magnetization) prior to perturbation. Recently, a phase-based B_1 mapping method based on the Bloch-Siegert shift has been reported [4]. This method uses a B_1-dependent, M_z-independent shift in the resonance frequency of nuclei experiencing an off-resonance RF pulse. In this abstract, we investigate the feasibility of combining Bloch-Siegert B_1 mapping and imaging of metabolism of HP [1-^{13}C] pyruvate *in vivo*, in a single injection. The technique is demonstrated with phantom experiments and *in vivo* in a rat model.

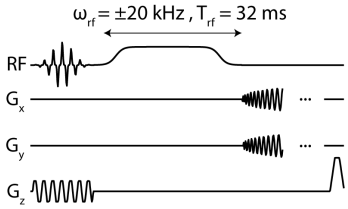

Fig. 1. ^{13}C spiral sequence used to obtain B_1 maps in the heart using the Bloch-Siegert shift. The sequence contains an off-resonance Fermi RF pulse inserted between the spectral-spatial RF pulse and the single-shot spiral readout. The spectral-spatial RF pulse is used to excite the pyruvate resonance during the B_1 mapping TRs.

Methods: Animals: All animal experiments were approved by the local animal care committee. ^1H and HP ^{13}C MR imaging was performed on a nude rat (weight 400 g).
Hardware, pulse sequences: Studies were performed on a MR750 3T GE scanner (GE Healthcare, Waukesha, WI) with a dual tuned $^1H/^{13}C$ volume coil. The sequence in Fig. 1 was used to acquire axial ^{13}C images (2 slices, 16384x1, T_{read} = 64 ms, TR 1 s, SlThk 15 mm, Spc 30 mm, FOV 48cm, in-plane res. 6x6 mm^2, the Fermi pulse was applied only during the acquisition of the B_1 map image pair). Bloch-Siegert B_1 maps were reconstructed from the image pair in Fig. 2 with in-plane resolution of 30x30 mm^2. The peak B_1 of the Fermi pulse was set to 212% of the B_1 required for a nominal 90° tip (Kbs=3.75 rad/G^2, $B_{1,max}$ = 0.1376 G). Data acquisition started at the beginning of the 2 ml/10 s bolus injection of HP [1-^{13}C] pyruvate. Phantom images using the same ordering scheme (TR 1s, SlThk 30 mm, 10x10 mm^2 in-plane res.) were acquired with a ^{13}C T/R surface coil on a 10 cm diameter sphere filled with HP [1-^{13}C] pyruvate.

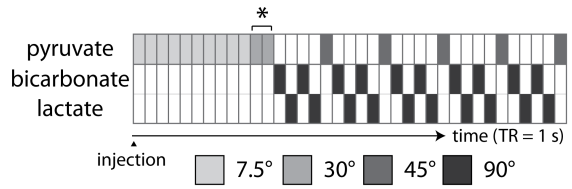

Fig. 2. Ordering scheme for simultaneous metabolic imaging and Bloch-Siegert B_1 mapping in vivo. Thirty-seven frames are acquired. The shaded boxes show the excited metabolite and nominal flip angle in each frame. The labeled pyruvate frames (*) contain an off-resonance Bloch-Siegert pulse as in Fig. 1. The flip angle is chosen to avoid saturation of signal in future frames and to maximize the SNR of each acquired image.

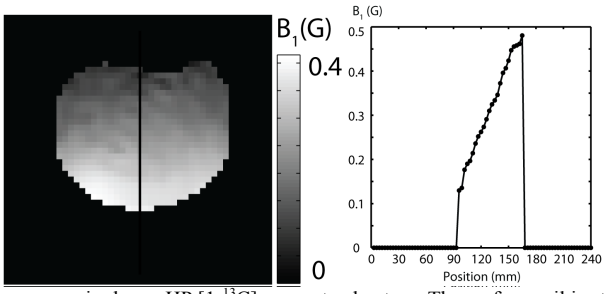

Fig. 3. B_1 map acquired on a HP [1-^{13}C] pyruvate phantom. The surface coil is at the bottom of the image; a cross-section through the B_1 map is shown. The transmit B_1 falls off with increasing distance from the coil.

Results and Discussion: HP phantom data is shown in Fig. 3. *In vivo* data are shown in Fig. 4. These data demonstrate the feasibility of the sequence in acquiring dynamic images of [1-^{13}C]pyruvate, [1-^{13}C]lactate, and ^{13}C bicarbonate, along with a transmit B_1^+ map, following a single bolus injection of the tracer. The metabolic images demonstrate that the additional Bloch-Siegert B_1 mapping frames do not significantly impact image quality. The reduction in measured B_1 between the kidney and heart locations is consistent with the heart position at the edge of the coil, and with the SNR variation in a sagittal proton image through both organs. The increased variability in measured B_1 in the heart is presumably due to motion-related phase inconsistency between the two frames, which may be removed with the use of cardiac gating. The acquired B_1 maps can be used for image intensity correction, prospective adjustment of transmit power, as input to kinetic modeling routines, for parallel transmit applications, and to calculate concentration of hyperpolarized substrates *in vivo*.

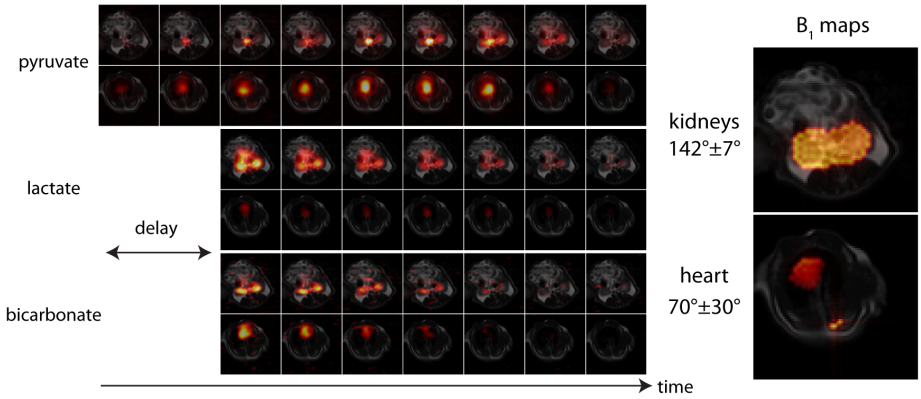

Fig. 4. (left) In vivo pyruvate, lactate, and bicarbonate images acquired following injection of HP [1-^{13}C] pyruvate. Pyruvate images are normalized by the nominal flip angle applied. **(right)** In vivo Bloch-Siegert B_1 maps acquired during the marked frames in Fig. 2. The calculated flip angle (mean±SD) delivered to each organ using a nominal 90° tip is also shown. The acquired images are cropped to 8x8 cm^2.

Conclusions: We have demonstrated the feasibility of simultaneously acquiring dynamic images of [1-^{13}C]pyruvate and ^{13}C bicarbonate, along with a transmit B_1^+ map, following a single tracer injection, by incorporating a Bloch-Siegert B_1 mapping pulse into a single-shot spiral imaging sequence. This approach is anticipated to improve quantitative measurements of HP ^{13}C *in vivo*.

References: [1]Ardenkjaer-Larsen et al. PNAS USA 2003;100(18):10158–10163. [2]Schroeder et al. PNAS USA 2008;105(33):12051–12056. [3]Golman et al. MRM 2008;59(5):1005-1013. [4] Sacolick et al. MRM 2010;63(5):1315-22. [5] Lau et al. MRM 2010;64(5):1323-31.

Acknowledgements: NSERC, CIHR, MCMM, GE Healthcare.