Rapid Volumetric Imaging of Cardiac Metabolism

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Introduction: Hyperpolarization of spins via DNP has been explored as a method to non-invasively study real-time metabolic processes in vivo using ^{13}C labeled substrates [1]. Hyperpolarized ^{13}C has recently been used to image cardiac metabolism non-invasively *in vivo* in rat [2] and pig [3]. Conventional 3D spectroscopic imaging methods require in excess of 100 excitations, making it challenging to acquire a full cardiac-gated, breath-held, whole-heart volume. In this abstract, we describe a rapid multi-slice cardiac-gated spiral ^{13}C imaging pulse sequence consisting of a large flip-angle spectral-spatial excitation RF pulse [4] with a single-shot spiral k-space trajectory for rapid imaging of cardiac metabolism. This sequence allows for whole-heart coverage (6 slices, 8.8 mm in-plane resolution) in any plane, with imaging of the metabolites of interest, [1-^{13}C] pyruvate, [1-^{13}C] lactate, and ^{13}C bicarbonate, within a single breathhold. The sequence was demonstrated with phantom experiments and *in vivo* testing in a pig model.

Methods: Animals: All animal experiments were approved by the local animal care committee. ^{1}H MR imaging and hyperpolarized ^{13}C MRS was performed on normal female pigs (mean weight 25 kg). The pigs were fasted the night prior to the scan and were given a 1L electrolyte-sugar solution (25g glucose) (Life Brand) to drink 2 hours prior to the scan to raise blood glucose levels.

Hardware, pulse sequences: Studies were performed on a MR 750 3T GE scanner (GE Healthcare, Waukesha, WI) with a custom-built ^{13}C transmit/receive surface coil placed on the chest wall. For anatomical landmarking, cardiac-gated Fiesta (SSFP) cine images were acquired in the short axis view (TE/TR = 1.8ms/4.2ms). The sequence in Fig. 1 was used to acquire cardiac-gated ^{13}C images in the short axis view (6 slices, single-shot 16384x1, T_{read} = 64 ms, nominal FA = 90°, SlThk 10 mm, Spc 1 mm, FOV 24cm, in-plane res. 3.7x3.7 mm^2). The transmit and receive frequencies are shown in Fig. 2. Respiratory motion was removed by breath-holding 22s after the start of injection. The sequence was started 25s after injection.

Analysis: The spiral k-space data was smoothed using an exponential filter with time constant 8 ms, and gridded using a K-B gridding kernel (width 1.5, overgrid factor 2). An automatic off-resonance correction algorithm [5,6] was applied to estimate a low-resolution field map to unblur the image data. The in-plane reconstructed resolution was 8.8x8.8 mm^2.

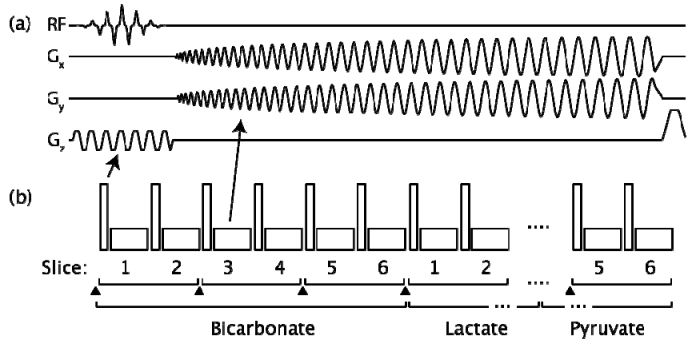

Fig. 1. ^{13}C spiral sequence used to image metabolites in the heart. (a) Spectral-spatial RF excitation pulse followed by a single-shot spiral readout trajectory. (b) Multi-slice, spectrally-interleaved order used to resolve volumes corresponding to bicarbonate, lactate, and pyruvate in the myocardium. The filled triangles indicate cardiac triggers, and two slices are resolved 350 ms after the trigger in a 150 ms diastolic window per R-R interval.

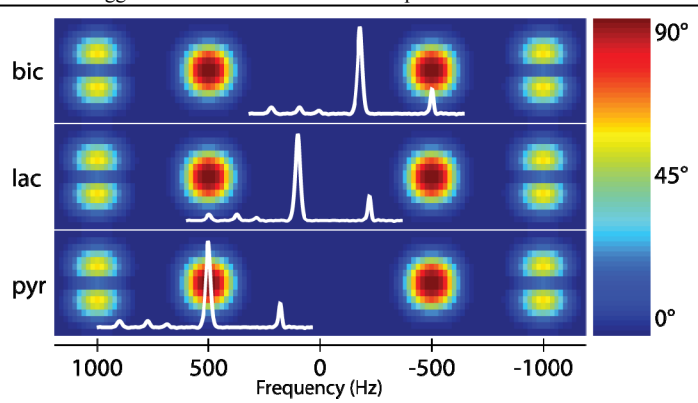

Fig. 2. Placement of the spectral passband of the spectral-spatial RF excitation pulse for each metabolite.

Results and Discussion: Phantom and in vivo data are shown in Figs. 3 and 4. These data demonstrate the feasibility of the new sequence in acquiring images with whole-heart coverage within 27 heartbeats. Pyruvate is localized to the blood chambers, while bicarbonate is localized to the myocardium. The SNR fall-off in the posterior region of the images is due to the B_1 and reception profiles of the surface coil used for imaging. However, the geometry of the short axis view brings some of the slices closer to the coil than others, and this is seen in the increased SNR in the central slices of the bicarbonate images.

Conclusions: The new sequence allows for whole-heart coverage (6 slices, 8.8 mm in-plane resolution) in any plane, with imaging of the metabolites of interest, [1-^{13}C] pyruvate, [1-^{13}C] lactate, and ^{13}C bicarbonate, within a single breathhold. This sequence is anticipated to be useful in the non-invasive monitoring of changes in spatial distribution of metabolites in disease.

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]Cunningham et al. JMR 2008;193(1):139-46. [5] Man et al. MRM 1997;37(6):906-13. [6] Man et al. MRM 1997;37(5):785-92.

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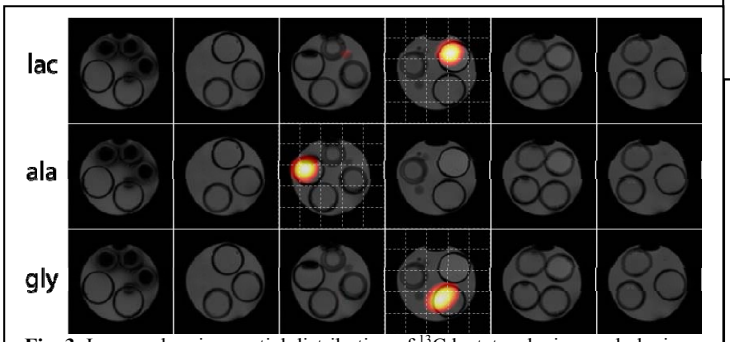

Fig. 3. Images showing spatial distribution of ^{13}C lactate, alanine, and glycine in a small phantom. The FOV of each image is 8 x 8 cm^2. The resolution of the overlaid reconstructed images is 1.6x1.6 cm^2 in-plane with a 1 cm slice thickness. The dashed grid indicates the in-plane reconstructed resolution.

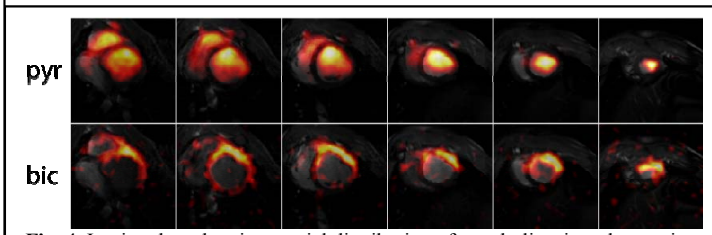

Fig. 4. In vivo data showing spatial distribution of metabolites in a short-axis view of the heart. Bicarbonate, lactate, and pyruvate volumes were acquired over 9 heart beats, and the sequence was repeated for 3 time points. The entire scan was completed within 18 seconds. The FOV of each image is 12 x 12 cm^2. The final in-plane reconstructed resolution is 8.8x8.8 mm^2.