SNR Comparison of EPI and Spiral 3D Time Resolved Imaging of Hyperpolarized [1-^{13}C]Pyruvate and [1-^{13}C]Lactate

Benjamin J. Geraghty[1,2], Justin Y.C. Lau[1,2], Albert P. Chen[3], William Dominguez-Viqueira[1], and Charles H. Cunningham[1,2]

[1]*Imaging Research, Sunnybrook Health Sciences Centre, Toronto, Ontario, Canada,* [2]*Dept. of Medical Biophysics, University of Toronto, Toronto, Ontario, Canada,* [3]*GE Healthcare, Toronto, Ontario, Canada*

Purpose: Metabolic MRI via injected hyperpolarized ^{13}C substrates such as [1-^{13}C]pyruvate show promise as minimally invasive prognostic marker of various disease states. Time resolved acquisitions offer increased robustness to the variable timing of bolus arrival and metabolic conversion following injection and provide richer metabolic data than static / single time point acquisitions. The tradeoff is that each measurement is lower SNR in order to preserve the magnetization across the time course. Therefore, dynamic imaging techniques that offer maximal sensitivity are desirable for clinical translation of hyperpolarized ^{13}C. Cartesian echo-planar imaging (EPI) trajectories have been commonly used for their robustness to off resonance effects and straightforward reconstruction in frequency selective acquisitions[1]. Spiral trajectories are favored in multi-echo IDEAL[2] acquisitions due to their high encoding efficiency and short echo-time. In this work, we've developed a novel experimental design for evaluating the attainable SNR for EPI and spiral readouts following spectral-spatial excitation. By interleaving the two acquisitions within a single injection, confounding variables such polarization, perfusion, injection timing and metabolism were effectively eliminated.

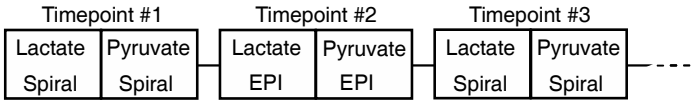

Figure 1: Schematic illustrating experimental paradigm. During a single injection / time course, odd time-points were encoded with a spiral trajectory while even time-points were encoded with an EPI trajectory

Methods: All gradient waveform design and image reconstruction was implemented in Matlab (The MathWorks Inc., Massachusetts). A 3D EPI trajectory was designed to encode a 72×18×18 cm^3 volume with 5mm isotropic resolution using in-house scripts (TR / TE = 56 / 26 ms). Interleaved 18.8ms spectral-spatial pulses[1], each with 36 slice encoding steps, were used for volumetric imaging of [1-^{13}C]pyruvate and [1-^{13}C]lactate (min. temporal resolution ~4s). A spiral trajectory was designed to cover the same field-of-view (18×18cm^2) and resolution using Brian Hargreaves Variable Density Spiral script. Rewinder gradients were appended using trapezoids. The spiral waveform was iteratively redesigned by reducing the max slew rate in order to match the total readout length to that of the EPI readout (34ms). Both trajectories shared the same slice encoding waveforms. The waveforms were incorporated into a generic 3D gradient echo sequence and the trajectories were toggled according to the paradigm displayed in figure 1. Even time points were encoded with the EPI trajectory while odd time points were encoded with the spiral trajectory. Imaging was performed on a GE MR750 3T MR scanner using a dual tuned ^{1}H/^{13}C dual tuned birdcage coil (GE Healthcare, Waukesha, WI). *In vivo* Sprague Dawley (520g) rat images were obtained in accordance with a protocol approved by the institutional animal care and use committee. The net magnetization consumption per volume for pyruvate and lactate was 14% and 98%, respectively (net FA = 8°/80°). Imaging commenced as 3mL of 80mM pre-polarized [1-^{13}C]pyruvate was injected over 12s. A delay of 420ms was included between acquisitions to provide a temporal resolution of 5s. 2D axial T_2 weighted FSE images were acquired for anatomical reference. Spiral data was gridded and corrected for off resonance effects using a multi-frequency auto-focusing reconstruction[3]. EPI data was arranged into a matrix and ghost corrected using an image-based scheme[4]. Lactate images were generated by summing the volumetric data across the first 5 time points, while the pyruvate images were summed across the first 3 (figure 2). A region-of-interest was traced around the right kidney for SNR evaluation. Quoted SNR values were calculated by taking the ratio of mean magnitude signal within the ROI divided by the standard deviation of the magnitude signal within a background region.

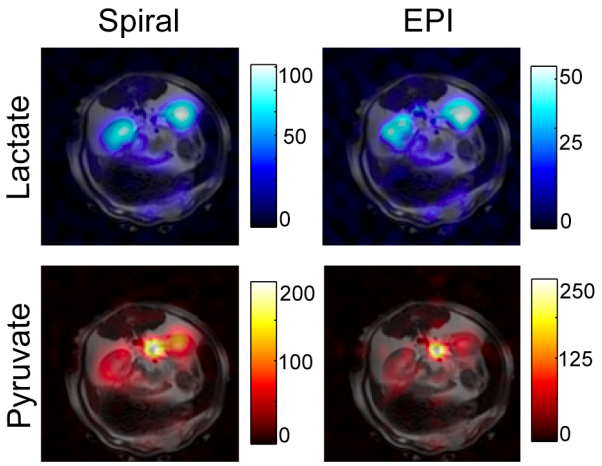

Figure 2: Lactate and Pyruvate images encoded with spiral (*left*) and EPI (*right*) readout trajectories. The colorbar represents SNR of the summed images (details in methods).

Results & Discussion: Prior to analyzing the *in vivo* data, the point spread function for each trajectory was simulated. The nominal resolution of the EPI trajectory was 5×5mm, while the nominal resolution of the spiral trajectory was 6×6mm. The reduced resolution of the spiral trajectory should contribute to a gain in SNR of ~44%. Additionally, the SNR gradient efficiency of the EPI readout was 80% while spiral was 97%. The theoretical SNR gain for this spiral trajectory, neglecting signal loss during the readout, was ~60%. Voxel SNR time course data (figure 3) for each metabolite and trajectory was spline interpolated to approximate the values at the missing time points of each data set. The difference in SNR was estimated by first computing the mean SNR for each interpolated curve and then taking the ratio of mean spiral SNR to mean EPI SNR. The rationale for this analysis was that SNR differences due to metabolic conversion are normalized across the full time course. The increase in SNR for lactate and pyruvate for the spiral acquisition was ~2.1X and ~2.3X, respectively. Correcting for the discrepancy in resolution, the SNR gain observed in the spiral acquisition was ~75%. This gain can be attributed to the short echo time and SNR gradient efficiency intrinsic to spiral trajectories. The major limitation of this analysis is that it cannot account for SNR differences due to instantaneous polarization decay. This limitation could be reduced in future experiments by increasing the temporal resolution or by attempting to measure polarization decay with an internal hyperpolarized reference[5].

Conclusions: We have demonstrated a novel experimental paradigm for comparing readout trajectories in the context of time resolved volumetric hyperpolarized imaging. Spiral showed an SNR improvement over EPI on the order of ~75%. Sensitivity is one of the most significant challenges for successful clinical translation of metabolic ^{13}C MRI, so choosing encoding strategies to maximize attainable SNR is vital.

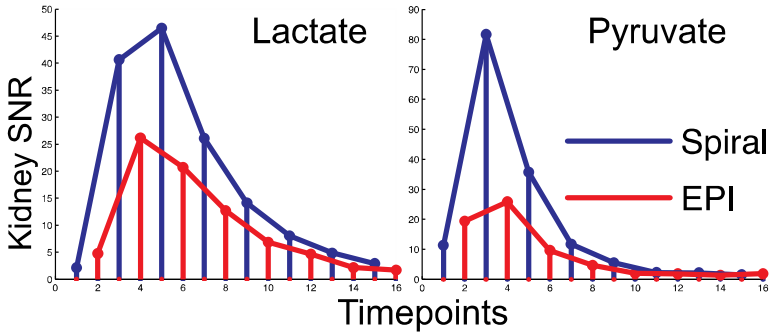

Figure 3: Lactate and Pyruvate SNR estimated inside an ROI confined to a single kidney. Vertical stems indicate the time-points at which each trajectory was used to encode the volumetric imaging data.

References: [1] C.H. Cunningham et. al., (2008) JMR 193(1): 139. [2] F. Wiesinger et. al., (2012) MRM 68(1): 8. [3]A.Z. Lau et. al., (2010) MRM 64(5): 1323. [4] N.K. Chen et. al., (2011) MRM 66(4): 1057 [5] Y.C. Lau et. al., (2014) Proc ISMRM 22: 3805