

Single-shot Acquisition of [1-13C]Pyruvate and Lactate on a 3T Clinical Scanner

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TARGET AUDIENCE: Researchers interested in rapid ¹³C metabolic imaging.

PURPOSE: Hyperpolarized ¹³C imaging offers the potential to dynamically probe metabolism *in vivo*. The most prevalent imaging methods include fast chemical shift imaging (CSI), frequency selective spectral-spatial (Sp-Sp) excitation [1] and IDEAL [2]. Recently, a joint spectral-spatial (k-t) technique was demonstrated on a small animal scanner, effectively combining CSI and IDEAL within a single shot [3]. Joint spectral and spatial encoding is achieved by oversampling the FOV during a spiral acquisition and performing a model based, least squares reconstruction. Large oversampling rates are required to improve the conditioning of the reconstruction problem; however, due to limited gradient performance, the oversampling rate necessary to resolve multiple metabolites within a single shot cannot be achieved on conventional clinical scanners. We propose to combine k-t oversampling with Sp-Sp excitation to reduce gradient demands and resolve separate images of [1-¹³C]pyruvate and [1-¹³C]lactate within a single-shot spiral readout.

METHODS: A numerical phantom was developed in Matlab to correspond directly with the standard GE ¹³C phantom. Its chambers contain formate, lactate, bicarbonate and alanine. Formate is used in place of pyruvate in the GE phantom. A spiral trajectory (16384pts, 125KHz BW, 65ms readout) was computed for an FOV of 10cm, corresponding to an oversampling factor of 2X. Analytical spiral k-space data was derived for each chamber, modulated to the respective chemical shifts and summed to generate the synthetic signal. The effect of Sp-Sp excitation on reconstruction was evaluated by generating data which excluded the bicarbonate and alanine signals. The signal equation can be cast as a linear system of equations $b = Ax$, where x is the vectorized concatenation of spatial profiles, and can be solved by least squares minimization. A dual-band, Sp-Sp pulse (figure 1) was designed to selectively excite formate/pyruvate and lactate simultaneously while minimizing sideband interaction with ¹³C-bicarbonate. Thermally polarized ¹³C data were acquired with a dual-tuned ¹H/¹³C quadrature rat coil using the same 10cm FOV spiral k-space trajectory as in the synthetic data. For the *in vivo* acquisition, 2.5mL of 80mM [1-¹³C]pyruvate, prepolarized using the SpinLab DNP polarizer (GE Healthcare), was injected into a healthy rat (GE MR750, FOV=15cm, TR/TE=5000/25ms, FA=10deg, BW=125KHz, 15 time points, 1 slice, 2cm thick). A fast spin echo axial anatomical image was acquired following the ¹³C acquisition (FOV=15cm, TR/TE 3500/102ms).

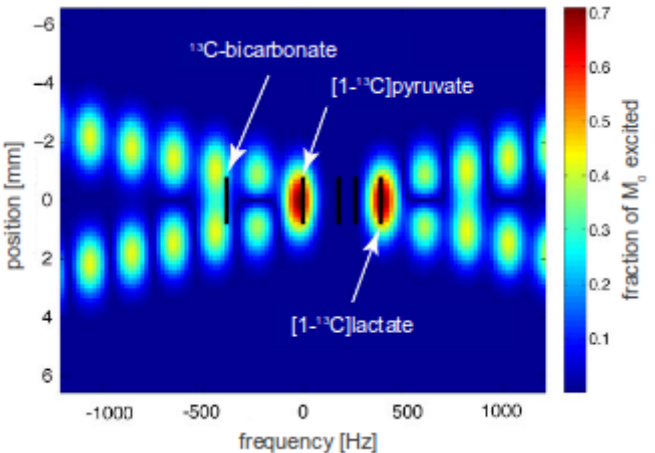


Figure 1 – Dual-band Spectral-Spatial excitation profile

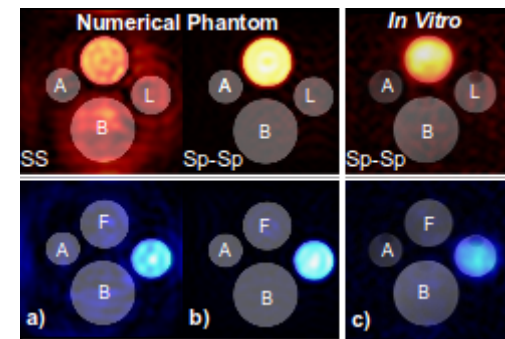


Figure 2 - A = Alanine, B = Bicarbonate, F = Formate, L = Lactate a) formate (red) and lactate (blue) images depicting signal contamination due to inadequate oversampling b) improved image reconstructions when alanine and bicarbonate are not excited c) Experimental GE ¹³C phantom data, TR/TE 5000/25ms, 150 averages

RESULTS & DISCUSSION: The simulated results indicate that an oversampling rate of 2X is insufficient for resolving four metabolites. Figure 2a reveals considerable contamination from bicarbonate and alanine within the formate (red) and lactate (blue) images. By excluding bicarbonate and alanine, formate and lactate are well resolved (figure 2b). The thermally polarized *in vitro* phantom images (figure 2c) acquired with the tailored Sp-Sp pulse are in good agreement with the simulation results. Time points 2 through 6 of the reconstructed pyruvate and lactate images are presented in figure 3. The peak SNR was estimated by taking the ratio of the maximum pixel intensity to the standard deviation of pixel intensities in the final image, which corresponds to thermal equilibrium polarization. Both metabolite signals are well localized to the kidneys, as is expected in a healthy rat. Preconditioning of the system of equations by unequal weighting is necessary *in vivo* to account for the large discrepancy in signal magnitudes between pyruvate and lactate. Without preconditioning, the least squares routine settles at a suboptimal solution where the lactate images are completely contaminated by off resonance pyruvate signal. Further investigation into the preconditioning requirement is necessary. The simultaneous excitation and acquisition of pyruvate and lactate reduces the number of TRs that would otherwise be necessary in a purely Sp-Sp acquisition. For a fixed spiral readout duration, image

resolution is effectively traded off for improved temporal resolution.

CONCLUSION: We have demonstrated a unified spectral-spatial excitation and encoding scheme which allows the simultaneous acquisition of pyruvate and lactate images on a clinical scanner. Further research into the optimal use of the spatial / temporal resolution trade off is underway.

REFERENCES:

- [1] Lau, Angus Z. et al. MRM 65.5 (2010): 1323-1331
- [2] Wiesinger, Florian et al. MRM 68.1 (2012): 8-16
- [3] Gordon, Jeremy W. et al, DOI:10.1002/mrm24796 (2013)

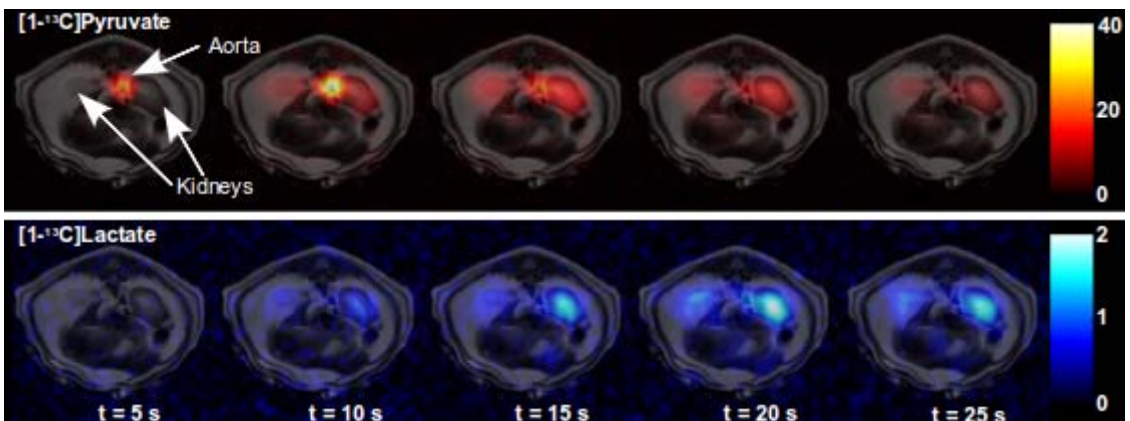


Figure 3 – Dynamic simultaneous acquisition of [1-¹³C]Pyruvate and [1-¹³C]Lactate. Images were cropped to a nominal FOV of 7.5cm. The peak SNR was estimated to be 100 for pyruvate and 20 for lactate, in accordance with prior experiments