Simultaneous Proton and Hyperpolarized Carbon Imaging

E. Peterson[1], K. Wang[2], K. Kurpad[3], M. Erickson[2], I. Rowland[3], and S. Fain[2,3]
[1]Biomedical Engineering, University of Wisconsin - Madison, Madison, WI, United States, [2]Medical Physics, University of Wisconsin - Madison, Madison, WI, United States, [3]Radiology, University of Wisconsin - Madison, Madison, WI, United States

Introduction: In low spatial resolution spectral carbon imaging, a typical hyperpolarized carbon protocol involves acquiring a proton anatomical reference image, along with the carbon image. This works well when the anatomy is stationary, however, when the anatomy is moving, such as heart, lung, liver, or kidney, the carbon image may not be correctly localized, leading to spatial blurring and reduced spectral sensitivity. It is vital that the metabolic image is correctly localized, because if it is not, the metabolic data becomes suspect. Therefore, this work introduces a method which allows both proton and carbon data to be acquired simultaneously, with the potential for continuous localization during the proton scan. Several simultaneous imaging and spectroscopy papers have previously been published [1-3], however these have sought to reduce the scan time for non-hyperpolarized species, whereas this work seeks to provide continuous localization for hyperpolarized ^{13}C imaging.

Methods: A phantom experiment was designed to demonstrate the feasibility of a simultaneous acquisition and reconstruction. A 2D projection multi-echo spoiled gradient echo (SPGR) sequence was used. The scan was performed using 3 syringes, 1 with tap water, 1 with acidic hyperpolarized pyruvate (Cambridge Isotope Laboratories, Andover, MA, USA) in order to have two large spectral peaks, and the third contained 5 mM gadodiamide (Omniscan®, GE Healthcare, Waukesha, WI, USA) and 3.27 M urea. The polarization was performed using a DNP polarizer (HyperSense®, Oxford Instruments, Tubney Woods, Abingdon, Oxfordshire, UK) and the acquisition was done on a 4.7T Varian (Varian, Palo Alto, CA, USA) horizontal bore small animal scanner. Scan parameters were: TR of 40.15 ms, ΔTE of 1.2 ms, 32 full echoes, 64 projection angles, 64 readout points, ^{1}H slice thickness of 20 mm, ^{13}C slice thickenss of 80 mm, ^{1}H FOV of 80 mm by 80 mm, and a ^{13}C FOV of 320 mm by 320 mm. A surface coil which has both ^{1}H (5 cm diameter) and ^{13}C (3.8 cm diameter) sensitive channels was used.

The acquisition software was not modified but was set to a multi channel receive, single channel transmit mode using the Vnmrj 2.3A environment. The transmit channel was modified by adding a slice-selective RF pulse centered on the ^{13}C frequency to the decoupling channel, such that proton and ^{13}C slice selective RF-pulses were transmitted simultaneously. In this experiment, the carbon RF pulse was 4 times as thick as the proton slice, but the pulses can be independently controlled to have arbitrary thickness or excitation volume. The carbon receive line was then re-wired such that the demodulation line was directed to the mixer for the carbon channel. By performing these modifications, two times the amount of data was collected as a typical carbon or proton acquisition. The data were then reconstructed by filtered back projection for the proton and carbon channels separately, and resized separately to compensate for the gyromagnetic ratio difference between carbon and proton.

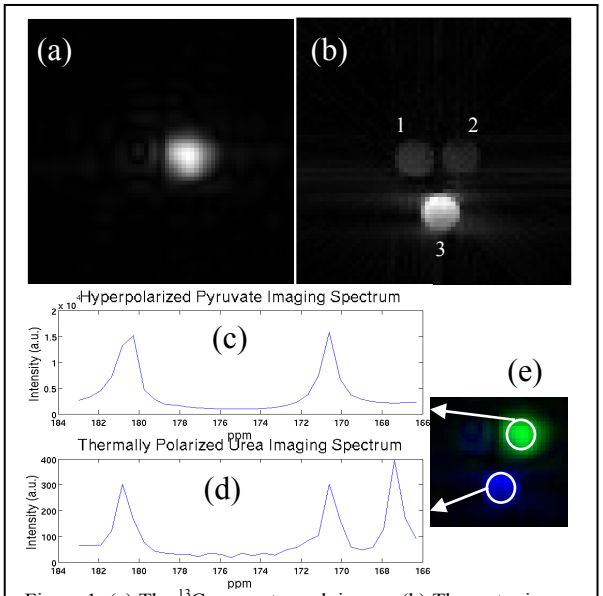

Figure 1: (a) The ^{13}C pyruvate peak image. (b) The water image showing the 3 syringe phantom. Syringe 1 contained tap water, syringe 2 contained hyperpolarized pyruvate, and syringe 3 contained 3.27M urea at thermal equilibrium and 5 mM gadodiamide and therefore has signal enhancement. (c) Carbon spectra from the pyruvate syringe and (d) carbon spectra from the urea syringe. The pyruvate peaks, which are almost an order of magnitude lower than the source in syringe 2, are observed to than the actual pyruvate signal are observed to alias into syringe 3 due to spatial undersampling. (e) Cropped color coded results with water (blue) and pyruvate (green) image.

Results and Discussion: As seen in **Fig. 1 a,b,e**, the spectral acquisition of simultaneous carbon and proton channels occurs without interference, and therefore allows for the simultaneous acquisition, with SNR on both channels comparable to separate carbon and proton imaging on both channels. An important point to note is that due to the ratio of the gyromagnetic ratios being almost 4, k-space is sampled much closer to the center and therefore the ratio of the field of views is also almost 4, with the proton FOV about 4 times smaller than that of the carbon. The effect of this is that despite acquiring the same number of data points, the resolution of the carbon image is 4 times lower than the proton image for the same FOV. This is acceptable, and perhaps even desirable due to the abundance of signal in the proton channel, and the relative lack of signal in the carbon channel. **Fig. 2** shows a pre imaging spectrum from the carbon channel; note that both pyruvate and pyruvate hydrate are visible. **Fig. 1 c** shows a carbon imaging spectrum from the hyperpolarized pyruvate; note how it matches well with the global spectrum in **Fig. 2** due to the overwhelming hyperpolarized signal. **Fig. 1 d** shows the thermal urea phantom signal, which is present at an extremely low intensity. Also visible in the urea syringe are pyruvate and pyruvate hydrate peaks with an intensity about an order of magnitude less than the source intensities in syringe 2, which are believed to be aliasing from the spatially undersampled acquisition. The spectral resolution and spectral width are determined by the number of echoes and ΔTE, and therefore the spectral characteristics are the same for both species. A possible issue with simultaneously acquiring proton and carbon channels is the possible effects of decoupling. Decoupling is typically performed when doing carbon spectroscopy, but not typically performed during hyperpolarized experiments. There has been one paper [4] on the effects of decoupling during hyperpolarized carbon experiments, which reported reduced line widths using WALTZ-16 [5] decoupling. It should be noted that the technique proposed in this abstract only excites the sample on both carbon and proton channels at the same time, and therefore no RF excitation occurs during the readout. This differs from most decoupling schemes, such as WALTZ-16, where the majority of the decoupling power is emitted during the readout, and therefore the decoupling for the proposed sequence is believed to be minimal.

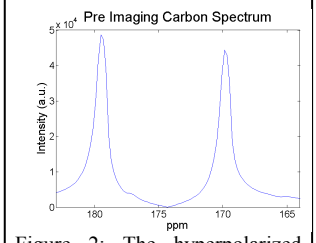

Figure 2: The hyperpolarized pyruvate spectrum acquired prior to imaging.

Conclusion: The simultaneous acquisition of carbon and proton signals shows promise, and as both channels are obtained with little extra effort, this has the potential to aid the quantification and localization of the carbon images. It would be possible, for instance, to monitor motion with the proton image simultaneous to the MR spectroscopic imaging experiment or to simply improve spatial localization, and calibration of the excitation volume and flip angle. In the case that motion does not appear to occur, the proton image could be used for an anatomical image overlay, or to verify that no motion occurred. Initial future work will be to correct for spectral blurring with species specific demodulation, and an exploration of spatially targeted reconstructions in order to limit spatial aliasing. Other future work will be to apply this technique to *in vivo* studies of dynamic metabolic processes, such as cardiac and lung imaging.

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Acknowledgements: GE Healthcare, NIH