SIMULTANEOUS MULTI-SLICE IMAGING OF MULTIPLE METABOLITES USING SPECTRAL-SPATIAL EXCITATION FOR HYPERPOLARIZED 13C EXPERIMENTS

Angus Z. Lau[1,2], William Dominguez-Viqueira[3], Albert P. Chen[4], Charles H. Cunningham[3,5], Matthew D. Robson[1], and Damian J. Tyler[1,2]

[1]*Department of Cardiovascular Medicine, University of Oxford, Oxford, United Kingdom,* [2]*Department of Physiology, Anatomy, and Genetics, University of Oxford, Oxford, United Kingdom,* [3]*Imaging Research, Sunnybrook Health Sciences Centre, Toronto, ON, Canada,* [4]*GE Healthcare, Toronto, ON, Canada,* [5]*Department of Medical Biophysics, University of Toronto, Toronto, ON, Canada*

Target. Hyperpolarized 13C and multiband imaging researchers.

Purpose. DNP-dissolution MRI is a novel method for imaging in vivo metabolism in real-time [1], with increasing clinical relevance following completion of the "first in-man" clinical trial [2]. Spectral-spatial excitation can be used to image single spectral lines using rapid single-shot imaging readouts [3], and full 3D volumes can be imaged in a multi-slice mode by cycling through each resonance and slice position. For substrates with many downstream metabolites (e.g. following infusion of pre-polarized [2-^{13}C] or [1,2-^{13}C] pyruvate, or multiple polarized substrates), excitation of metabolic resonances one at a time is challenging due to limited available scan time. Simultaneous multi-slice (SMS) imaging can reduce imaging time with limited g-factor penalty [4]. Here, we investigate the feasibility of combining SMS acceleration with spectral-spatial excitation.

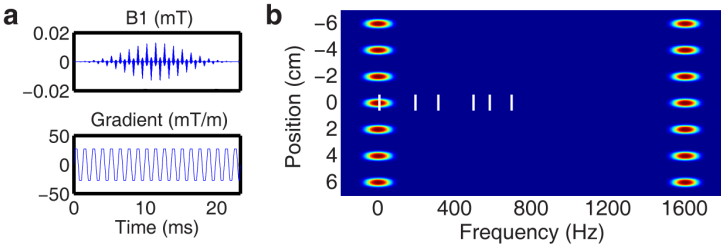

Figure 1. Frequency profile for the multi-slice RF pulse. (a) The pulse is constructed by summing individual spectral-spatial pulses, resulting in the spectral-spatial profile shown in (b). The overlaid vertical lines are the ^{13}C resonances derived from [1-^{13}C] pyruvate infusion in vivo.

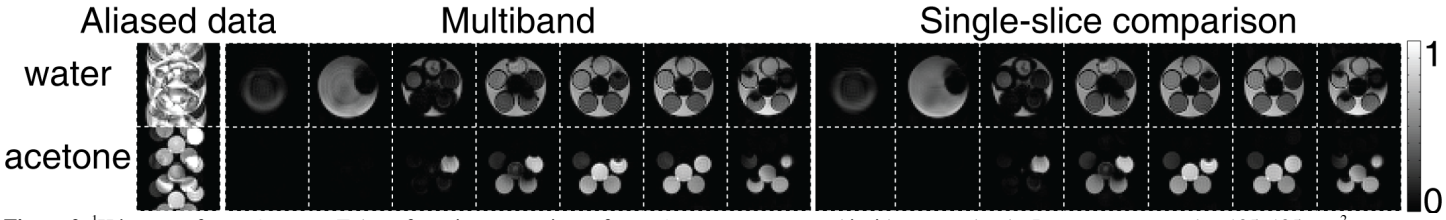

Figure 2. ^{1}H images of water/acetone. Tubes of varying proportions of water/acetone are arranged inside a water bottle. Images are cropped to 125x125 mm^2.

Methods. Pulse sequence. A SMS excitation pulse (Fig. 1) was constructed by summing phase-modulated spectral-spatial RF pulses [5] exciting single slices (duration 23 ms, passband 113 Hz, stopband 1600 Hz). The resulting spectral-spatial profile was found to be linear for flip angles between 0 and 90°. A single-shot EPI sequence was modified to include multiband excitation and CAIPI blips (Siemens 3T Trio, 7 slices, slice thk 6 mm, gap 20 mm, 96x48, FOV 250x125 mm^2, TR 1s, TE 30 ms, FA 90°, $B_{1,max}$ = 0.0019 mT/slice). Controlled aliasing was used to introduce a FOV/3 inter-slice shift to reduce g-factor noise amplification. ^{1}H data acquisition. A multi-compartment phantom containing tubes with varying proportions of water and acetone (v/v 0%, 25%, 50%, 75%, 100%; relative ^{1}H chemical shift 250 Hz) was scanned using a 32 channel head coil. ^{13}C data acquisition. Dynamic ^{13}C single-shot spiral images from SPF pigs were acquired [6] using a 5-channel ^{13}C cardiac array [7] and retrospectively regridded to a 36x18 matrix (2 slices, TR 2.5 s, FOV 360x180 mm^2, in-plane res 10x10 mm^2, slice thk 10 mm, gap 22 mm). A FOV/2 inter-slice shift was simulated and used to construct aliased data. Image reconstruction. Split slice-GRAPPA [8] (kernel: ^{1}H: 5x5, ^{13}C: 3x3 points, ^{1}H reference: water images, ^{13}C reference: 4th pyruvate frame) was used to unalias the multiband images.

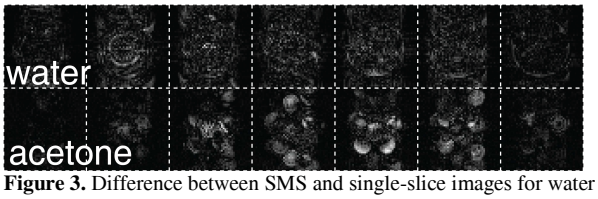

Figure 3. Difference between SMS and single-slice images for water and acetone (scaled 20x).

Results. Figure 2 shows images of the water/acetone phantom obtained using SMS excitation. The multi-slice spectral-spatial pulse selectively excites water and acetone, and the aliased data was successfully separated using the split slice-GRAPPA method. Figure 3 shows a 20-fold scaled difference image. Figure 4 shows retrospectively reconstructed images of pyruvate and bicarbonate in the porcine heart using SMS reconstruction.

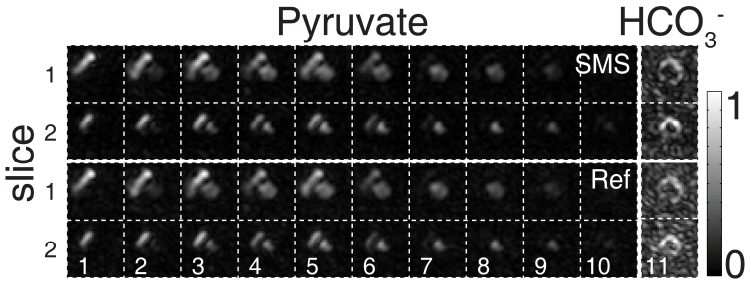

Figure 4. Images reconstructed from retrospectively undersampled in vivo ^{13}C data in the porcine heart. The pyruvate image from the 4th frame, which contained signal in both left and right ventricles, was used as reference data for SMS reconstruction. The time-resolved scan consists of 10 pyruvate frames to capture the first pass of the bolus, followed by 1 frame to image myocardial bicarbonate. Images are cropped to 120x120 mm^2. The bicarbonate images are scaled up 5x.

Discussion. The water/acetone phantom used in this study has a similar chemical shift to the 3T ^{13}C chemical shift between [1-^{13}C] pyruvate and [1-^{13}C] lactate or ^{13}C-bicarbonate, suggesting that our results are, in principle, directly translatable to the corresponding hyperpolarized experiment. We demonstrate that the water image can be used to encode the coil sensitivity for image reconstruction (7-fold acceleration). We also demonstrate that retrospectively aliased ^{13}C cardiac images obtained with a 5-channel array can be reconstructed using this method (2-fold acceleration). This strategy is similar to using the abundant pre-polarized [1-^{13}C] pyruvate signal to encode and measure imaging parameters such as transmit B_1^+ using the Bloch-Siegert effect [9]. The development of multi-nuclear receiver coil arrays for 13C imaging [10] will facilitate rapid translation of this method. While the duty cycle for the HP ^{13}C experiment is inherently low due to the need to preserve polarization, we anticipate that scan time reduction using SMS excitation will enable new applications. In particular, scan time is freed up to obtain additional information, including proton navigators (motion compensation), proton B_0 maps, B_1^+ maps, as well as enabling spectral-spatial excitation when many metabolites are present (e.g. [1,2-^{13}C] pyruvate or multiple polarized substrates).

Conclusions. We demonstrate the feasibility of using SMS spectral-spatial excitation to selectively image multiple metabolites, and that images of one metabolite can be used for GRAPPA reconstruction of images of another metabolite. We anticipate that the scan time reduction provided will enable new applications in hyperpolarized ^{13}C MRI.

References. [1] Ardenkjaer-Larsen et al., PNAS 2003. [2] Nelson SJ et al., Sci Transl Med 2013;5(198):198ra108. [3] Lau AZ et al., MRM 2010. [4] Setsompop K et al., MRM 2012;67(5):1210-1224. [5] Cunningham CH et al., JMR 2008. [6] Lau AZ et al., MRM 2013. [7] Dominguez-Viqueira ISMRM 2013. [8] Cauley SF et al., MRM 2013. [9] Lau AZ et al., MRM 2012;67(1):62-71. [10] Dominguez-Viqueira MRM 2012.