Transmit-only receive-only operation of a switch-tuned ^{13}C-^{1}H radiofrequency coil for improved in vivo ^{13}C spectroscopy

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Target audience MRI, Hyperpolarized ^{13}C, RF coil, Multi-frequency, Transmit-only & Receive-only, Small animal imaging

Purpose Non-invasive measurement of *in vivo* metabolism using hyperpolarized ^{13}C-enriched endogenous molecular probes combined with detailed morphology from proton magnetic resonance imaging is a power combination to study disease models. Hyperpolarization of these substrates compensates for the limited natural abundance (1.1%) and reduced gyromagnetic ratio of ^{13}C to facilitate magnetic resonance spectroscopic imaging of ^{13}C-labelled substrates. Despite dramatic improvements in polarization, quantification of regional distribution of these substrates and their metabolites is almost always desirable, driving improvements in probe formulations and RF coil designs to improve the overall SNR (signal-to-noise ratio). Hyperpolarized ^{13}C molecular information is co-registered with a conventional ^{1}H image and this dataset can be compared with other MR contrasts such as T_2-weighted imaging or dynamic contrast enhanced imaging. Construction of a dual-frequency RF coil often requires compromises that result in reduced SNR for one or both of the resonant channels. This work outlines the operation of a switch-tuned ^{13}C – ^{1}H birdcage coil capable of rapid switching between anatomical imaging (^{1}H) and metabolic imaging (^{13}C) modes using an applied DC bias. This ability was further enhanced to include operation of the birdcage coil as a transmit-only ^{13}C volume coil with a local receive-only ^{13}C surface coil to enhance ^{13}C SNR. The combined system is capable of improved ^{13}C imaging SNR using transmit-only, receive-only (TORO) operation for ^{13}C imaging and ordinary transmit/receive (TR) operation as a proton coil.

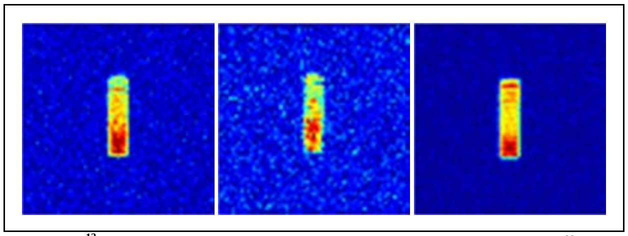

Figure 1. **^{13}C-enriched sodium acetate phantom images acquired using three different RF coils: (from left) ^{13}C standalone RF coil, switch-tuned ^{13}C - ^{1}H RF coil and switch-tuned with a surface ^{13}C RF coil in TORO operation**

Methods The design and construction of a switch-tuned ^{13}C - ^{1}H RF coil using PIN diodes for frequency tuning has been previously reported [1]. In addition to this hardware, an actively decoupled ^{13}C receive coil was constructed for receive-only operation. A stand-alone ^{13}C RF coil with identical physical dimensions as the switch-tuned RF coil was constructed and used as a baseline for SNR comparisons. All coils were engineered for compatibility with a GE Signal MR750 3T imager. A 7M ^{13}C-enriched sodium acetate phantom doped with a gadolinium-based contrast agent was imaged using a broad-band fast-gradient echo (bbFGRE) pulse sequence with a 128-mm x 128-mm field of view, 2-mm isotropic resolution, 8-mm slice thickness, TR = 34 ms, 64 averages. ^{13}C-enriched pyruvic acid was hyperpolarized with an Oxford Instruments HyperSense dynamic nuclear polarizer, buffered to a concentration of 80 mM and given as a tail vein bolus injection to a healthy Wistar rat. A 12 x 12 spectral imaging matrix using TR = 80 ms, BW = 5 kHz, 2048 pts, was recorded using a free-induction decay chemical-shift imaging (FID-CSI) pulse sequence covering the rat head with a 60-mm by 60-mm field of view, axial slice thickness = 3 mm. All animal procedures were approved by the University Council on Animal Care, Animal Use Subcommittee at Western University.

Results ^{13}C images of the phantom were obtained for SNR comparison using TR operation of the single-tuned ^{13}C RF coil and switched-tuned ^{13}C-^{1}H coil with the TORO combination of switched-tuned and surface coils. (See Figure 1). SNR for these coils were 11.82 ± 0.07, 6.51 ± 0.04 and 27.83 ± 0.08 respectively. RF transmit pulse power for a 90° flip angle was calibrated manually. An *in vivo* axial ^{1}H image of a diseased rat brain, co-registered with 2D ^{13}C spectra is presented in Figure 2.

Discussion The advantage of a switch-tuned RF coil strategy is that the imaging or spectroscopy from two different nuclei (^{13}C and ^{1}H) can be obtained without changing RF coils or repositioning the animal. This facilitates trivial and exact co-registration of imaging and spectroscopy data from different nuclei. The added complexity of multi-nuclear construction can lead to compromises for SNR; however, the ^{13}C-TORO setup more than compensates for the loss of SNR. The combined TORO system has been optimized specifically for ^{13}C imaging. A DC bias available from the scanner during ^{13}C transmission is used to trigger a MOSFET switch that gates sufficient current from an external power supply to rapidly switch the birdcage coil to its ^{13}C resonant mode. The switching time afforded by the method is less than 10 µs, considerably less than the 1800-µs RF pulse width. For ^{13}C transmission, the DC bias is switched on leading to an active de-tuning of the ^{13}C receive-only surface coil. During ^{13}C reception, the DC bias is absent resulting in the birdcage coil being resonant at the proton frequency and the decoupled surface coil receiving ^{13}C signal. Phantom experiments comparing ^{13}C SNR for TORO and TR operation of the switch-tuned RF coil indicate that the TORO SNR is 4.3 times higher. This higher SNR can be exploited for increased spatial resolution for ^{13}C imaging. With this improved SNR, multiple ^{13}C spectra can be obtained over a region of interest as illustrated in Figure 2. Differences in metabolic activity can then be compared on a voxel by voxel basis and correlated with morphology obtained from the ^{1}H images.

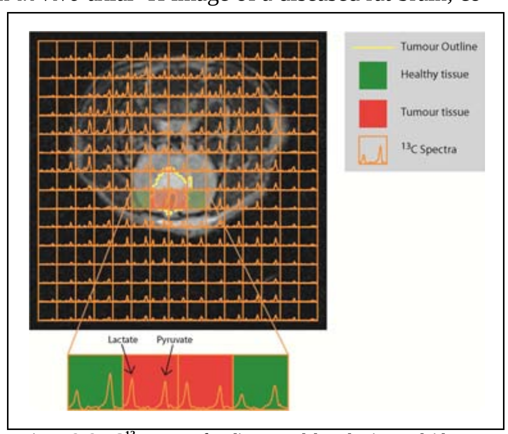

Figure 2. 2D C^{13} spectra of a glioma model rat brain overlaid on an axial proton image. Voxels highlighted in red and green each indicate the region of tumor and healthy brain.

Conclusion TORO operation for the switch-tuned ^{13}C & ^{1}H RF coil with a surface-receive ^{13}C coil produced 4.3 times higher ^{13}C SNR than the switch-tuned ^{13}C channel over a limited volume. This apparatus has been used with hyperpolarization techniques to successfully image pyruvate metabolism in the brain and co-register these data with morphology obtained by conventional proton imaging. This apparatus will be used to quantify the effects of chemo- and radiotherapy in a rat model of glioblastoma multiforme using pyruvate/lactate metabolism as a biomarker for therapeutic response.

Reference [1] Heeseung Lim *et al.* *"Switch-Tuned Dual-Frequency Birdcage RF Coil for ^{13}C and ^{1}H Imaging". ISMRM 20th Scientific Meeting, Melbourne; May 2012, p. 4300.*