Switch-Tuned Dual-Frequency Birdcage RF Coil for ^{13}C and ^{1}H Imaging

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Introduction

The development of hyperpolarized ^{13}C-enriched endogenous compounds for use as injectable contrast agents has enabled new methods of molecular imaging with MRI. Information about cellular function obtained from spectroscopic imaging of these hyperpolarized compounds and their metabolites are co-registered with high-resolution morphological detail, which is the hallmark of proton MRI. This requires dual-tuned RF hardware that is capable of imaging both ^{13}C nuclei and protons without moving the subject or changing RF coils. The technological challenge is to develop a single RF coil that combines the same imaging performance as two independent coils dedicated to either nucleus. We have developed a prototype switch-tuned ^{13}C-^{1}H RF coil that is electronically switched between configurations as a low-pass ^{13}C and a band-pass ^{1}H birdcage volume coil for *in vivo* animal imaging research. The efficiency of the switch-tuned coil is systematically compared with identical single-frequency coils for each nucleus. This hardware is partly based on a concept by Wang *et al.*[1] (previously proposed by Boskamp *et al.* [2]), which was designed for ^{3}He and ^{1}H imaging of the lung in a small animal model.

Methods

To prove the efficacy of this multi-nucleus design, three identical eight-rung birdcage coils were constructed: 1) 32.1 MHz low-pass coil, 2) 127.7 MHz band-pass coil, and 3) switch-tuned combination of coils 1 & 2. The coils were constructed on 8.9-cm diameter by 26.7-cm long acrylic tubes. Switching of the combination ^{13}C-^{1}H coil was accomplished by biasing PIN diodes in parallel with the end-ring capacitors. The DC switching bias was filtered through RF chokes from additional end-ring pairs on either end of the RF coil. A linear bias power supply provided a 0.26A forward bias to each PIN diode switching the coil from a band-pass (^{1}H) to low-pass coil (^{13}C). The electrical schematic of the switch-tuned coil is shown in Figure 1. These coils have been interfaced to a GE Healthcare MR750 3T imager. Imaging with phantoms was used to compare SNR of the switch-tuned coil operating in either ^{1}H or ^{13}C mode with a single-frequency coil of identical dimensions. For *in vivo* experiments, healthy Sprague Dawley rats were injected with 80mM buffered solutions of [1-^{13}C] pyruvate hyperpolarized to 15% by an Oxford Instrument HyperSense polarizer under a protocol approved by the Animal Use Subcommittee at UWO.

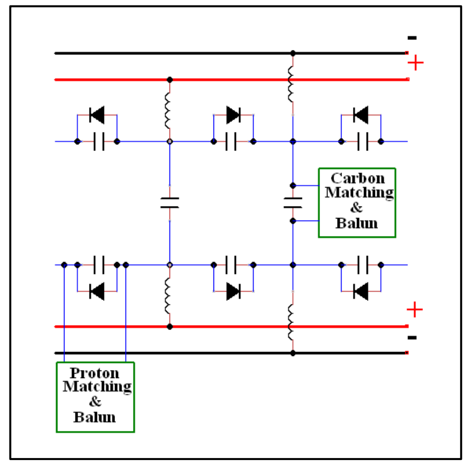

Figure 1. Simplified electrical circuit diagram of switch-tuned ^{13}C - ^{1}H RF birdcage coil. Only three rungs are shown out of eight rungs.

Results

Proton and ^{13}C images were obtained using a broadband fast gradient echo (bbFGRE) pulse sequence. SNR of proton images were 1100 and 1094 respectively for the ^{1}H coil and switch-tuned RF coil in proton mode. SNR for images with the carbon phantom were 46 and 43 for the ^{13}C coil and switch-tuned RF coil in carbon mode. ^{13}C-pyruvate spectra were also obtained using a free induction decay chemical shift imaging (FID-CSI) pulse sequence. SNR of ^{13}C spectra were 1.49 and 1.56 for the same comparison. *In vivo* imaging of a healthy rat brain was performed with hyperpolarized pyruvate. FID-CSI spectra are overlaid on proton morphology (bbFGRE) and shown in Figure 2.

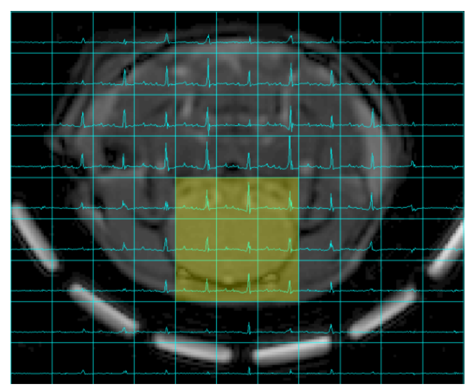

Figure 2. 2D FID-CSI spectra of hyperpolarized [1-^{13}C] pyruvate in a healthy rat brain overlaid on axial proton image. The region of the brain is highlighted in yellow. (The bright line segments below the head are from warming water in the animal support tray.)

Discussion

Despite the increased complexity of the switch-tuned design, carbon and proton imaging do not suffer significant SNR degradation compared with an identical single-nucleus RF coil. Furthermore, the ability to image either nucleus without changing coils or repositioning animals is a substantial advantage that more than compensates for any minor difference in SNR. The switch-tuned coil also facilitates field shimming on the animal through the proton channel, which provides increased resolution for ^{13}C spectroscopy. Dynamic ^{13}C spectra from a healthy rat brain show that the hyperpolarized pyruvate signal was measurable for at least 80 sec after the injection, which provides sufficient time to see the increased concentration of lactate from the metabolism of pyruvate. We will use this RF hardware with a high-performance gradient insert in future experiments to monitor the response of Glioblastoma to therapy in the rat's brain. Rapid frequency tuning inherent in this design will allow this coil to be used as a transmit-only ^{13}C coil for use with an existing 8-channel parallel-receive coil for ^{13}C imaging of rodents.

References

[1] J-X. Wang *et al.*, ISMRM (2008) 1117, [2] E.B. Boskamp *et al.*, ISMRM (2001) 1127.