Hyperpolarized ^{13}C MRI with a Triple-Frequency RF Coil

S. J. Wood[1], B. K. Rutt[1], J. Piel[2], D. B. Whitt[2], K. M. Fish[2], W. T. Dixon[2], and I. Hancu[2]

[1]Robarts Research Institute, the University of Western Ontario, London, ON, Canada, [2]GE Global Research Center, Niskayuna, NY, United States

Introduction

Hyperpolarized, ^{13}C labeled molecules are expected to advance MRI into the realm of true metabolic imaging. Imaging ^{13}C labeled compounds, however, requires new MR hardware capabilities. ^{1}H imaging is needed for anatomical localization and shimming of the region of interest (ROI). Accurate flip angle (FA) calibration is difficult or impossible at the ^{13}C frequency due to the lack of signal prior to injection and variable signal following injection. A FA calibration method for ^{13}C hyperpolarized scans has been recently demonstrated [1] using the natural abundance ^{23}Na tissue signal, along with a low pass birdcage coil, with one channel operating at the ^{13}C frequency, and the other at the ^{23}Na frequency. In the initial implementation of this method, however, 30% signal loss was incurred for ^{13}C scans, as the birdcage was operating linearly at each frequency. An additional ^{1}H coil, for ROI anatomical localization and shimming, was also needed in this approach. We demonstrate here a single RF resonant structure, capable of operating at all three frequencies of interest for hyperpolarized ^{13}C scans: linearly at the ^{1}H frequency, and in quadrature for both the ^{23}Na and ^{13}C frequencies. The use of this coil at its three frequencies (^{1}H for anatomical localization and shimming, ^{23}Na for both FA calibration and ^{23}Na imaging, and at ^{13}C for imaging of hyperpolarized ^{13}C pyruvate) is demonstrated in vivo.

Methods

The design of the triple-frequency rat coil, of 16 cm length and 8 cm diameter, is based on a dual-frequency design presented previously [2]. The two outermost rings and 2 rungs (180 degrees apart) form a ^{1}H "half-Helmholtz" coil operating at 63.89MHz (1.5T). The innermost coil, with its end rings spaced 2 cm away from the ^{1}H end rings, and eight rungs (two of them shared with the proton coil) form a low pass birdcage coil, tuned at the ^{13}C frequency (16.06MHz). A coupling loop, that can be electrically opened or closed with a rod accessible from outside the coil, is also tuned to the ^{13}C frequency. This loop is securely attached to the coil in a position that is equally spaced between the two drive ports of the birdcage coil (in order to affect both channels equally). Figure 1 presents the coil (without its cover), with the red arrow pointing to the coupling loop switch. With the switch open, the birdcage operates at the ^{13}C frequency. When closed, the coupling loop splits the resonance of the ^{13}C birdcage, and the coil is operational at the ^{23}Na frequency (16.89 MHz). The reflection coefficient, S_{11}, for one of the birdcage channels, measured with a HP87511A network analyzer, is presented in Figure 2, with the switch of the coupling coil open (Figure 2a) and closed (Figure 2b). The second coil channel exhibits behavior similar to that shown in Figure 2 in each configuration (switch open and closed). The two quadrature channels of the birdcage are connected through a quad-hybrid to the same transmit/receive chain. Due to the close proximity of the ^{13}C and ^{23}Na resonant frequencies at 1.5T (830kHz apart), the same quad hybrid, preamplifiers and T/R switches are used at both frequencies.

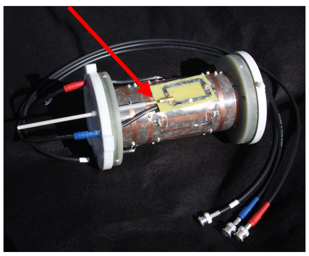
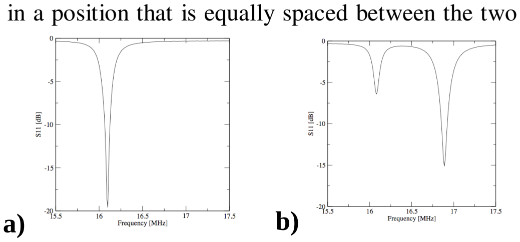


Figure 1: *Coil with tuning switch*



a) **b)**

Figure 2: *Magnitude of the reflection coefficient S_{11} [dB] vs. frequency [MHz] for one of the coil channels operating at the* ***a)*** *^{13}C frequency (switch open) and* ***b)*** *^{23}Na frequency (switch closed).*

Results

The linearity between the power needed to obtain a given flip angle at the ^{13}C frequency and power needed to obtain the same flip angle at the ^{23}Na frequency was initially verified for this coil, using a number of different loading phantoms in vitro, in a manner similar to [1]. The coil was then used for in vivo imaging of rats injected with hyperpolarized ^{13}C labeled pyruvate (5ml/kg of 80mM pyruvate). Anatomical imaging and shimming were performed at the ^{1}H frequency, using a steady state free precession pulse sequence. Flip angle calibration was then performed at the sodium frequency. A sodium image was also acquired for the same region studied in the ^{13}C exam. Last, the coil was switched to ^{13}C operation by a simple pull-rod operation, and a ^{13}C image was acquired after the injection of hyperpolarized compounds. Imaging details for the non-proton exams include a FIDCSI sequence, with a field of view of 8cm, 10mm slice thickness, 24x24 in plane resolution, TR=80ms, 5 degree flip angle and one average for the ^{13}C exam, and 90 degree flip angle and 8 averages for the ^{23}Na exam. Figure 3 presents the proton (a), sodium (b), lactate (c) and pyruvate images acquired in this exam. The non-proton exams are overlaid on the proton exams for clarity purposes. As expected, high ^{23}Na and ^{13}C signals are visible over the kidneys.

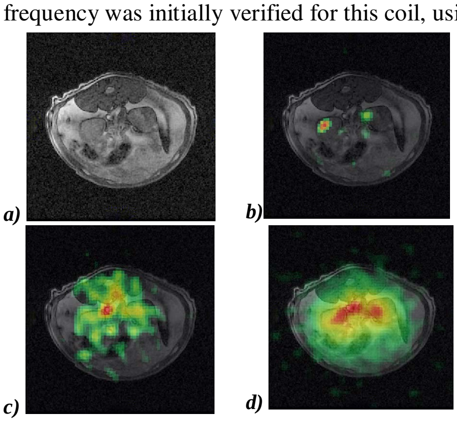


Figure 3: *In vivo rat axial kidney images showing* ***a)*** *anatomical,* ***b)*** *with sodium overlay,* ***c)*** *with lactate overlay, and* ***d)*** *with pyruvate overlay*

Discussion and Conclusions

We have presented a linear ^{1}H, and switch-tuned (^{23}Na/^{13}C) birdcage coil optimized for imaging of ^{13}C hyperpolarized compounds. A simple physical switch was implemented to switch between ^{13}C and ^{23}Na modes, allowing quadrature operation at both frequencies. All images acquired with this coil can be taken in succession without moving the subject. In order to further simplify the process, a voltage controlled PIN diode switch can be used to activate the coupling loop and switch between frequencies. We have used this coil to obtain ^{1}H, ^{23}Na and ^{13}C images of rats injected with hyperpolarized compounds. We have also used the sodium channel for accurate FA calibration for the ^{13}C scan.

References

1. Hancu et al, Magn Reson Med, pp 128, (2007); **2.** Derby, Tropp et al, J Magn Res, pp 645, (1990)