SNR improvement of a ^{13}C-cryo-coil in comparison with room-temperature coils

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Introduction

MRS studies typically require a high signal-to-noise ratio (SNR), especially for ^{13}C-spectroscopy where the low natural abundance of ^{13}C (1.1%) is a problem. Since the SNR depends on the third power of the Larmor frequency, the relative small frequency of ^{13}C increases this limitation for ^{13}C in comparison with ^{1}H-MRS. There are methods to enhance the signal like polarization transfer. Another way is to lower the noise. Cryo-coils use the fact that there are two noise sources, which can directly be diminished. Noise arising from the coil itself and the preamplifier can greatly be lessened by lowering its operating temperature. Thus mainly the noise from the sample itself is left. We present in vitro and in vivo data from one of the first ^{13}C-cryo-coils for mouse brain.

Methods

We compared a ^{13}C-cryo-coil prototype for mouse brain imaging (Bruker, Ettlingen, Germany, Fig 1c) with a standard surface coil from the same supplier (Fig 1a) and a home-built coil with an optimized geometry for mouse brain imaging (Fig 1b) on a 9.4 T horizontal bore animal scanner (Bruker, Ettlingen, Germany).

The ^{13}C-cryo-coil consists of an anatomically-shaped ^{13}C element and a ^{1}H saddle coil for decoupling. Due to its geometry only small animals like mice can be scanned (Fig 1c). The ^{13}C element as well as the narrow band pre-amplifier are encapsulated in an insulated vacuum chamber and are helium cooled to lower their operating temperature down to approximately 30K. To avoid injuries the contact area of the coil is heated. The standard surface coil consists of a double tuned flat single loop (20mm diameter) with manual tuning on both frequencies.

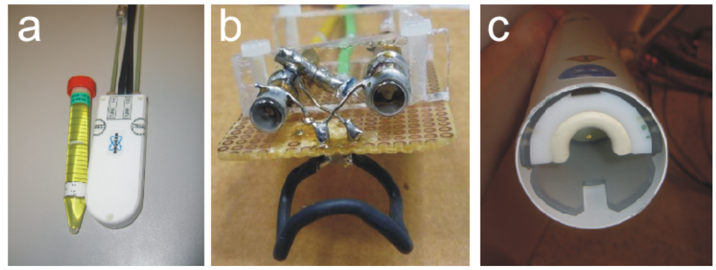

Fig.1: a) Image of the standard surface coil and the phantom containing DMSO. b) Home-built ^{13}C transceiver surface coil with anatomically-shaped square element. c) ^{13}C-cryo-probe; anatomically shaped and additional ^{1}H saddle coil

The home-built ^{13}C transceiver surface coil (Fig. 1b) was constructed to approximate the cryo-coil's geometrical design. It was build from 1mm thick silver wire insulated by heat shrink, with one square element of side length 18 mm, which was anatomically-shaped by bending it on a 15 mm diameter cylindrical former. Variable capacitive tune and match facilities were part of the circuit design. As a phantom we used a 15ml flask filled with 5 ml dimethyl sulfoxid (DMSO), 10 ml destilled water and NaCl (4.3g/L). After second order shimming on the proton channel and adjustment of the ^{13}C transmitter to obtain the maximum signal, an unlocalized single pulse experiment on the ^{13}C channel was conducted with a flip angle of 90° (rectangular pulse, t_p=100µs, NEX=1) with each coil.

Results

The phantom measurements yield a SNR of 7.9 and 14.6 for the standard surface coil and the home-built coil, respectively. Whereas the cryo-coil reached an SNR of 92. Thus the signal enhancement is at least 6.3 (Fig 2).

Figure 3 shows our first localized mouse brain *in vivo* spectra with the cryo-probe. The mouse was anesthetized with isoflurane and administered a bolus 1 ml glucose solution ([1-^{13}C] 99% enriched, 1.0 M) i.p. before it was placed in the scanner. Using ^{1}H spin echo images for positioning (care was taken to avoid subcutaneous fat in the region of interest) localized spectra were acquired via an ISIS sequence (90° rectangular excitation pulse BW_{90} = 99ppm, adiabatic slice selective refocusing pulses BW_{180} = 200ppm, 128 averages, 1024 total ISIS acquisitions, TR = 1s, total time 17 min 20s.). The spectra were acquired 120 min and 260 min after administration of the [1-^{13}C]-enriched glucose and the SNR of the ^{13}C-cryo-coil was still high enough to obtain a sufficient signal of the two glucose peaks at 96.9 ppm and 93.1ppm.

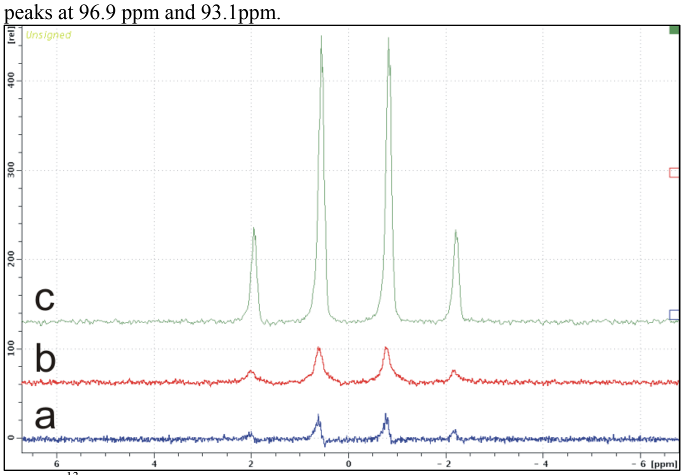

Fig. 2: ^{13}C spectra of the DMSO phantom obtained by a single pulse sequence. a) Standard surface coil, b) home-built transceiver coil and c) ^{13}C-cryo-probe.

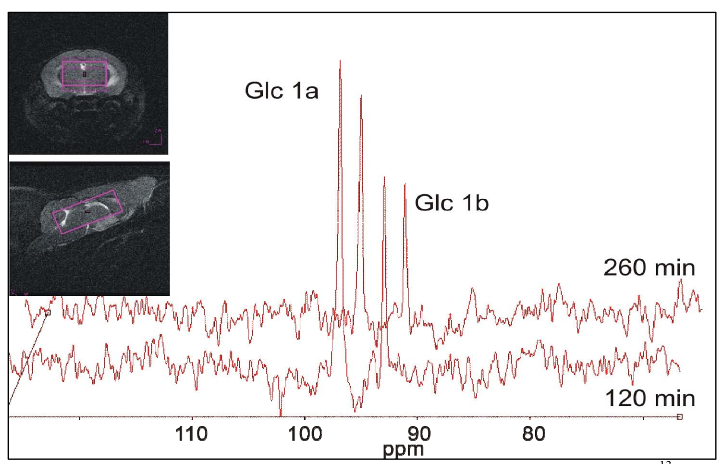

Fig. 3: Localized in vivo spectra of a mouse brain after administration of [1-^{13}C]-enriched glucose. On the left: voxel position.

Discussion

Besides the noise reduction through the low temperature, the high SNR gain of the ^{13}C-cryo-coil has several other reasons. We could determine that a factor 1.8 is owed to the optimized anatomically shaped geometry through building a coil with a comparable design. Another important factor is the optimized narrow bandwidth receiver chain that is connected to the cryo-probe, which also improves the SNR compared to the other coils which use the standard broad-band receiver. The SNR gain by these factors allows considerably shorter acquisition times and higher spatial resolution. Additionally, due to the low resistance the high quality factor Q of the coil allows the application of comparable short RF pulses and thus can increase the bandwidth of the signal excitation, which allows the acquisition of a wider range of resonances in a single experiment.