Increase in sensitivity and signal stability in 17O MRI using a cryogenic RF probe
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Introduction: The assessment of oxygen consumption within the brain at high spatial and temporal resolution promises an attractive tool to investigate and understand the metabolic processes in diseased tissue like tumors or in healthy brain tissue in the active and resting state. Indirect approaches like the BOLD effect that measures blood oxygenation are hampered by accompanying changes of other hemodynamic parameters. 17O-MRI offers the opportunity to directly measure the 17O water signal in the body without a background signal. The major drawback of this approach is a signal which is more than 34000 times smaller compared to that of 1H due to the small natural abundance of 17O of 0.037% and the low gyromagnetic ratio of the quadrupolar nucleus 17O of 5.77 MHz/T accompanied by very short T1, T2 and T2* values. Nevertheless, efforts have been made to successfully develop a method to measure the oxygen extraction within the rodent brain noninvasively [1]. Despite this successful application of 17O-CSI in the rodent brain, the method still suffers from the inherent low SNR. The reduction of coil noise by operating coil and preamplifiers at very low temperature and thereby substantial increases in SNR have been reported previously for different proton RF coils [2, 3]. In this study we present a cryogenic RF coil for the use of 17O-MRS and MRI at 54.27 MHz and compare such a coil to a home-build room temperature coil.

Methods: All experiments were performed on a Bruker BioSpec 94/30 (Bruker BioSpin MRI, Ettlingen, Germany) small animal system equipped with a 400 mT/m gradient with minimum rise time of 80 μs. The custom-built room temperature coil for 17O was a single loop of 12 mm diameter made of 0.3 mm thick copper. The cryogenic 17O coil had a diameter of 16 mm bent on a ceramic former and was cooled to 30 K. Integrated in the carrier of this coil was a saddle type RF coil at room temperature for proton imaging. Both coils were surrounded by an RF shield. Similar to a recent report on differences in SNR and signal variance [4] we used a single-pulse-acquire sequence to acquire a series of global free induction decays of the 17O signal. Parameters were 20 kHz spectral width, 1024 points per FID, 60 ms repetition time, 128 signal averages, 25 repetitions. A block pulse of 0.1 ms length or 12800 bandwidth was adjusted to maximize the 17O signal. The applied power for a 90° pulse was typically 3.5 W.

We observed a new stable signal amplitude are summarized in the following table:

| Phantom RT | 71 Hz FWHM | T2* = 4.48 ms | SNR 22.98 ± 2.10 (9.14%) | S variance 0.07% (std 2.8%) |
| Phantom CRP | 72 Hz FWHM | T2* = 4.42 ms | SNR 121.81 ± 28 (7.62%) | S variance 0.0012% (std 0.34%) |
| In-vivo mouse | 185 Hz FWHM | T2* = 1.72 ms | SNR 19.00 ± 27 (6.67%) | S variance 0.04% (std 1.95%) |

The linewidth and T2* for a whole mouse head was in good agreement with previous rodent studies. The values in the phantom experiments were substantially different from what has been reported before [5]. The SNR of a 17O-FID on a natural abundance water phantom was a factor of 5.3 higher for the cryoprobe than for the custom-made coil (Fig. 1), not even taken into account the advantage of the RT coil owed to the smaller diameter which can be calculated to approx. 1.3 within 1 mm depth from the coil surface. We injected 100 μl of 10% enriched H2 17O i.v. in a 25 g mouse and followed the time course of the global signal from the animal head at a temporal resolution of 250 ms (Fig. 2). We observed a new stable baseline 5 min after the injection with increased H2 17O signal by 145 % compared to the baseline signal before the injection. 10 min after the injection we acquired a 3D-FLASH scan at a resolution of 1x1x2 mm3 (Fig. 3).

Conclusion: We have demonstrated the possible SNR gain when using a cryogenic RF coil to image 17O at 54.27 MHz. Also the signal variability in the natural abundance water phantom was substantially decreased by more than a factor of 8 compared to a custom-made RF coil operated at room temperature. This gain in SNR and signal stability might allow an important advancement in the applicability of 17O-MRS and MRI in preclinical imaging. Higher temporal and/or spatial resolution might make it possible to investigate short-term processes of oxygen metabolism with regional specificity for deeper insight e.g. in tumor development and different therapeutic approaches.
