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. ^{17}O-MRI offers the opportunity to directly measure the ^{17}O 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 ^{1}H due to the small natural abundance of ^{17}O of 0.037% and the low gyromagnetic ratio of the quadrupolar nucleus ^{17}O of 5.77 MHz/T accompanied by very short T_1, T_2 and T_2* 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 ^{17}O-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 preciously for different proton RF coils [2, 3]. In this study we present a cryogenic RF coil for the use of ^{17}O-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 ^{17}O was a single loop of 12 mm diameter made of 0.3 mm thick copper. The cryogenic ^{17}O 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 ^{17}O 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 ^{17}O signal. The applied power for a 90^{o} pulse was typically 3.5 W. The sample for phantom measurements was an Eppendorf vial of 5 mm inner diameter filled with distilled water. In-vivo experiment were performed on female Bl6 mice with a body weight of 23-25 g. The animals were intubated and respirated with a 1:4 mixture of oxygen and air and 1.5% isoflurane. Free induction decays were acquired for the whole head without localization. 3D-FLASH images of natural abundance $H_2{}^{17}O$ were done with the following parameters: TE/TR=1.763/10 ms, BW 18 kHz, FOV 32x32x16 mm^3, matrix 32x32x8, acquisition duration 1.775 ms, scan duration 10 min 55 s. No zero filling or line broadening was applied to the data. SNR of the FID's was calculated as 2.5 times signal peakdevided by the difference between the maximum and the minimum noise.

Results: The quality factor of the home-built room temperature coil (RT) was calculated as 88, the Q of the cryogenic ^{17}O coil (CRP) was 480 with no difference in the loaded and the unloaded state. The linewidth, resulting T_2*, SNR of the acquired FID's as well as the variance of the signal amplitude are summarized in the following table:

Phantom RT	71 Hz FWHM	T_2*=4.48 ms	SNR 22.98 ±2.10 (9.14%)	S variance 0.07% (std 2.8%)
Phantom CRP	72 Hz FWHM	T_2*=4.42 ms	SNR 121.81±9.28 (7.62%)	S variance 0.0012% (std 0.34%)
In-vivo mouse	185 Hz FWHM	T_2*=1.72 ms	SNR 19.00 ±1.27 (6.67%)	S variance 0.04% (std 1.95%)

The linewidth and T_2* 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 ^{17}O-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 $H_2{}^{17}O$ 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 $H_2{}^{17}O$ 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 mm^3 (Fig. 3).

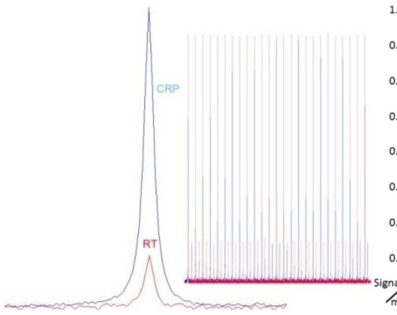

Figure 1: Comparison of an FID from a cryogenic (CRP, blue) and a room temperature coil (RT, red) and a series of 25 FID's

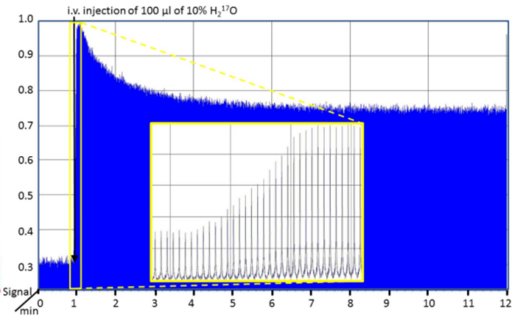

Figure 2: Global $H_2{}^{17}O$ signal in a mouse head sampled at 250 ms. Injection of 100 µl of 10% $H_2{}^{17}O$ after 1 min. Insert shows enlarged the signal rise after the injection

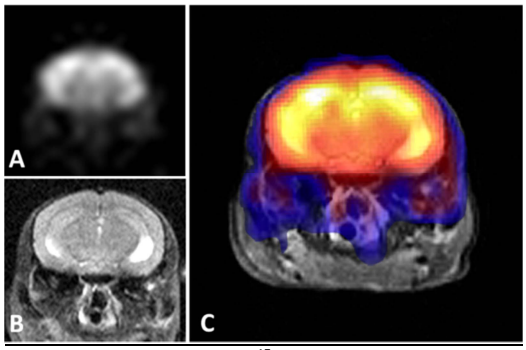

Figure 3: A:3D-FLASH $H_2{}^{17}O$ signal in a mouse head with 1x1x2 mm^3 resolution and 11 min scan time. B: Corresponding T2-weighted Turbo-RARE image acquired with integrated ^{1}H coil. C: Overlay of zero-filled (64x64) and color coded ^{17}O image onto the anatomical ^{1}H image.

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 ^{17}O-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 therapeutical approaches.

References: [1]Zhu,MRM (2013),[2]Ratering,MRM (2008),[3]Baltes,NMRBiomed. (2009),[4]Lu,MRM (2012),[5]Zhu,MRM (2001)