Effect of hyperbaric pressure on T1, T2, T2*, and Bo of the rat brain during MRI

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INTRODUCTION: Hyperbaric oxygen therapy has been used in the treatment of decompression sickness, carbon monoxide poisoning, and stroke. It is also being experimented to treat cerebral palsy and multiple sclerosis. The goal of this study is to characterize the effects of normobaric (NB) and hyperbaric (HB) conditions, under which oxygen partial pressure can be substantially increased, on MRI relaxation parameters. Oxygen has several effects on the measured MRI signals. Dissolved oxygen is paramagnetic which should shorten T1. Oxyhemoglobin is diamagnetic which should increase T2* and T2 and thus the BOLD signal. In addition, Bo field may be changed due to paramagnetic O2 in the chamber, which can cause unfavorable geometric distortions and intensity fluctuations (1). Therefore, we investigated T1, T2, T2*, and Bo field of the rat brain during NB and HB conditions in the same animals. The technical details for doing hyperbaric studies and challenges in monitoring animal physiology in the MRI scanner are also discussed.

METHODS: A custom-made hyperbaric chamber was constructed to be used in the MRI scanner, consisting of a cradle for the animal which slid into a PVC pipe that was then sealed on both ends. Cables of the coils, gas lines, and lines of physiological monitoring equipment were passed through tight fitting holes on the two ends of the chamber and sealed with grease and glue as needed. Male Sprague-Dawley rats (n=5, 254-313g) were anesthetized with 1.5g/kg urethane i.p. and imaged under spontaneous breathing conditions. Respiration and heart rate were monitored and rectal temperature maintained at 37^{o}C. Isoflurane gas anesthesia, arterial pressure, and blood gas measurement were not attempted due to the difficulty at high pressure inside the chamber, but remain to be explored. Animals were placed into the holder and put into the chamber. The chamber was pressurized with air to 4 atms absolute with a vent to allow fresh air flow.

MRI was performed at 7T with a surface coil (diameter=2cm) used for imaging. T1, T2, and T2* were measured from seven 1.5mm thick slices, with FOV=25.6x25.6mm, and matrix=96x96. Other parameters were, T1: inversion-recovery EPI, TR/TE=10,000/9.86ms, TI=23+400n ms with n=0-9; T2: multi-echo RARE, TR=3s, effective TE=25, 40, 75, 120ms; T2*: multi-echo FLASH, TR=1.5s, TE=3.1+2.2n ms with n=0-9. Bo maps was acquired with 3D multi-echo FLASH with FOV=25.6x25.6x30mm, matrix=64x64x75, TR=20ms, TE=2.35 and 8.06 ms. Statistical analysis used paired t-tests.

RESULTS: HB at 4 atm would increase the partial pressure of O2 from 160 to 638 mmHg. Water proton frequency was not statistically different between HB and NB conditions (differed by 5±13Hz (n=5)), showing negligible effect of higher O2 content on the magnetic field. There was also not substantial difference in Bo maps between HB and NB, although decreased Bo near the ear canals could usually be seen (**Fig 1**). Regional changes of Bo were analyzed in 3 ROIs, from the front of the cerebrum, back of the cerebrum, and cerebellum/brain stem, from mid-sagittal slices under NB and HB conditions. The respective Bo changes were -0.4±24.9, -2.6±35.1, and 18±29.6 Hz. Representative T1, T2, and T2* maps are shown in **Fig 2a**. Slight changes in position and shape of the brain were present in the images between HB and NB, particularly for EPI. Under HB, signal dropout was reduced in gradient-echo sequences, EPI and FLASH. T1 tended to decrease and T2* tended to increase under HB (**Fig 2b**). Whole brain T1, T2, and T2* at NB and HB are summarized in **Table 1**.

DISCUSSION: Increase in O2 partial pressure during HB condition had only minor effect on the frequency and Bo but does shift the images slightly. HB shortened brain T1, likely due to dissolved paramagnetic O2 acting as a T1 shortening agent, consistent with that reported previously (2). T2* was lengthened likely due to the BOLD effects from decreased deoxyhemoglobin (3). T2 also had a tendency to increase, although this was not as significant as T2*, likely because T2 has weaker BOLD effects from deoxyhemoglobin. These findings indicate that MRI under HB conditions should not be dramatically affected, paving the way for functional MRI studies under HB. Future studies will investigate the effects of hyperbaric oxygen conditions, measure CBF, and fMRI responses.

Reference: 1) Pilkinton et al, MRM 2011, 66:794. 2) Shen et al, Brain Res 2011, online. 3) Uematsu et al, J Comp Assist Tom 2007, 31:662.

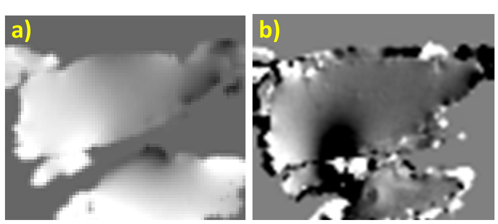

Figure 1. a) Mid-sagittal slice of a Bo map under NB (scaled -200 to 300 Hz). b) Difference between HB and NB Bo maps (scaled -50 to 50 Hz).

Table 1. T1, T2, and T2* of the whole brain, mean±SD.

	T1 (ms)	T2 (ms)	T2* (ms)
NB	1751 ± 38	52.3 ± 0.6	34.0 ± 1.5
HB	1721 ± 30	52.6 ± 1.3	36.1 ± 2.0
% Difference	-1.7 ± 1.2	0.6 ± 2.3	6.3 ± 3.5

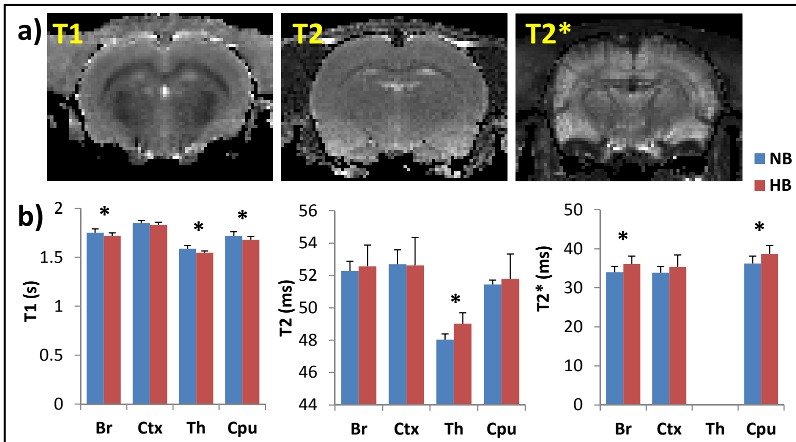

Figure 2. a) T1, T2, and T2* maps of the rat brain under normobaric air. b) Group averaged T1, T2, and T2* under NB and HB. Error bars are SD. *p<0.05. Br-whole brain, Ctx-cortex, Th-thalamus, caudate putamen-Cpu.