Non-Invasive, Whole-Brain $CMRO_2$ Mapping of the Human Brain

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Purpose: As the brain is obligatorily an aerobic organ, the cerebral metabolic rate of oxygen consumption ($CMRO_2$) is a direct measure of its overall health and function. An MR-based method for whole-brain $CMRO_2$ mapping that accounts for brain tissue mass and incorporates a new biologically based model of metabolic water production and persistence is demonstrated in the human brain. Unlike the existing positron emission tomography (PET) based approaches, this technique allows $CMRO_2$ maps to be obtained from humans without radioactive tracers or invasive measurements. This new model for $CMRO_2$ mapping improves on existing MR-based approaches by accounting for the mass of brain tissue in each voxel and reflects the current understanding of brain metabolism.

Methods: Co-registered 23-sodium (23Na) and 17-oxygen (17O) MR imaging were performed on a healthy human volunteer on a custom-built 9.4 Tesla MR scanner using a modified Twisted Projection Imaging (TPI) sequence and reconstructed by conventional gridding. Spatially-resolved brain mass values were estimated from the 23Na data by computing the cell volume fraction based on the difference of intracellular (~10 mM) and extracellular (~140 mM) sodium concentrations [1] and multiplying by the density of brain tissue. Serial 17O MR imaging was performed for approximately 48 minutes, during which the subject inhaled 53% 17O enriched oxygen gas for 10 minutes. A complete brain volume was acquired every 42 seconds. The initial 3.5 minutes of 17O MR imaging data collected prior to inhalation of the enriched gas were used to compute the moles of naturally occurring 17O-labled water in each imaging voxel. A biologically based, multi-compartment model of metabolic water production and persistence that accounts for both water generation and consumption, as well as wash-in and wash-out, was fitted to each 17O voxel time-course and combined with the brain mass and water quantity data to determine the rate of oxygen consumption in each voxel.

Results: A whole-brain $CMRO_2$ map of the human brain was obtained with an isotropic resolution of approximately 1 cm using only non-invasively acquired data and without any radioactive tracers. Figure 1 shows the computed maps of grams of brain tissue per voxel, moles of 17O-labled water per voxel due to natural abundance 17O, and $CMRO_2$ in µmoles/g brain/min. The obtained $CMRO_2$ values agree well with literature values obtained using the traditional PET methods (gray matter: 1.65 µmoles/g brain/min; white matter: 0.64 µmoles/g brain/min) [2]. Figure 2 shows two representative time-courses and the fit of the new biologically based model, which is able to accurately describe both time-courses despite their vastly different metabolic rates.

Conclusion: MR imaging of 17-oxygen during inhalation of 17-oxygen enriched gas and sodium MR imaging of endogenous tissue sodium concentration can be used to compute a quantitative $CMRO_2$ map of the human brain corrected for brain mass.

References: **[1]** KR Thulborn et al. Magnetic Resonance in Medicine.1999; 41:351-359. **[2]** KL Leender et al. Brain. 1990: 113:27-47.

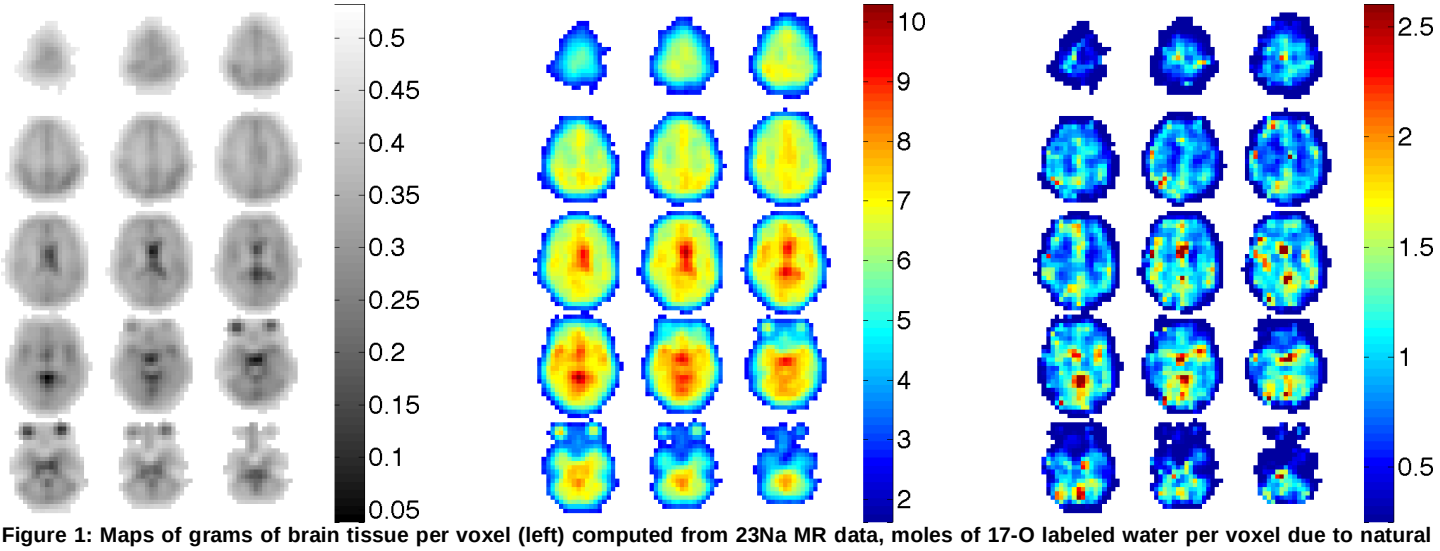

Figure 1: Maps of grams of brain tissue per voxel (left) computed from 23Na MR data, moles of 17-O labeled water per voxel due to natural abundance (middle) computed from 17O MR data, and $CMRO_2$ in µmoles/g brain/min (right).

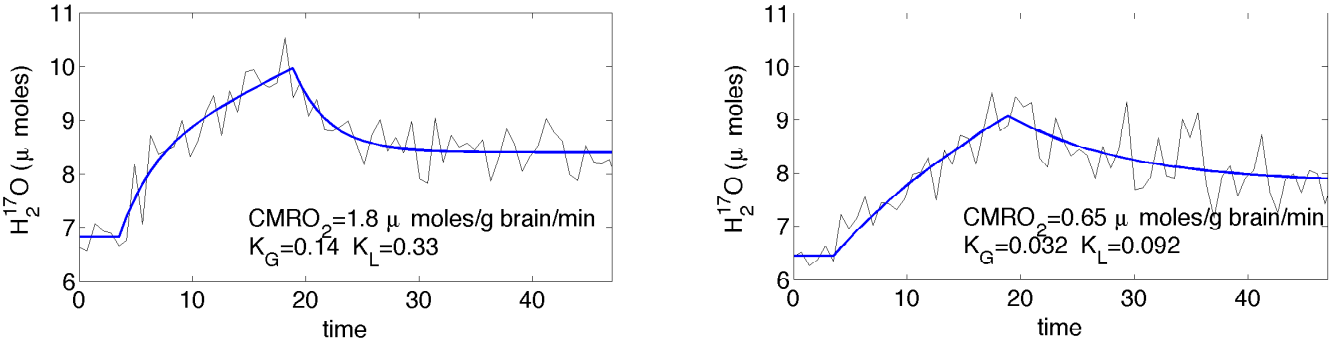

Figure 2: Representative 17O time-courses corresponding high (left, gray matter) and low (right, white matter) metabolic rates. The biologically based model of metabolic water production (blue) is able to accurately describe the 17O MR data (black).