MRI Estimation of Global Brain Oxygen Consumption Rate

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Introduction

Aerobic metabolism of glucose is the primary metabolic fuel for energy production in the human brain, making the brain extremely sensitive and vulnerable to even small alterations in oxygen supply [1]. This makes a measure for assessing global cerebral metabolic rate of oxygen consumption ($CMRO_2$) very important. In this study we present a rapid non-invasive method for quantifying $CMRO_2$ by simultaneously estimating oxygen saturation using MR susceptometry-based oximetry and cerebral blood flow using phase contrast MRI in the major vessels draining and feeding the brain.

Methods

MR-susceptometry based oximetry [2, 3] relies on a measurement of relative magnetic susceptibility, $\Delta\chi$, of intravascular blood and surrounding tissue. The magnetic susceptibility of most tissues (including brain at the probed field strength) is very close to water and can serve as a calibration free reference. If the blood vessel is modeled as a long paramagnetic cylinder, the relative incremental field ΔB is given as $\Delta B = \frac{1}{2}\,\Delta\chi B_o(\cos^2\theta - 1/3)$. ΔB is obtained from a phase difference image $\Delta\phi = \gamma\Delta B \cdot \Delta TE$, where ΔTE is the echo-spacing between two successive gradient echoes. For whole blood $\Delta\chi = \Delta\chi_{do} Hct\,(1 - HbO_2)$ (in SI units), where $\Delta\chi_{do} = 4\pi(0.27$ ppm) [4] is the susceptibility difference in SI units between fully deoxygenated and fully oxygenated erythrocytes, HbO_2 is the fraction of the oxygenated hemoglobin, hematocrit (Hct) is the volume fraction of the packed erythrocytes in whole blood and θ is the tilt angle of the vessel with respect to the main field B_o. All MR experiments were performed on a 3T Siemens Tim Trio system. An interleaved gradient-recalled echo (GRE) sequence programmed in SequenceTree™ [5] was used to obtain simultaneous oxygen saturation and cerebral blood flow measurements. The sequence consisted of four interleaves. All but the fourth interleave (VENC=60 cm/s) was flow compensated and the interleaves alternated between acquiring data at the level of the superior sagittal sinus (SSS) and mouth orifice to measure oxygen saturation and total cerebral inflow, respectively. The $CMRO_2$ measurement was repeated three times in five healthy volunteers at intervals of 5 minutes and the subject was asked to rise from the scanner table and repositioned each time. Scan parameters: FOV = 208 × 208 × 5 mm^3, voxel size = 1 × 1 × 5 mm^3, dwell time = 15 µs, flip angle = 25°, VENC = 60cm/s, total scan time = 28s.

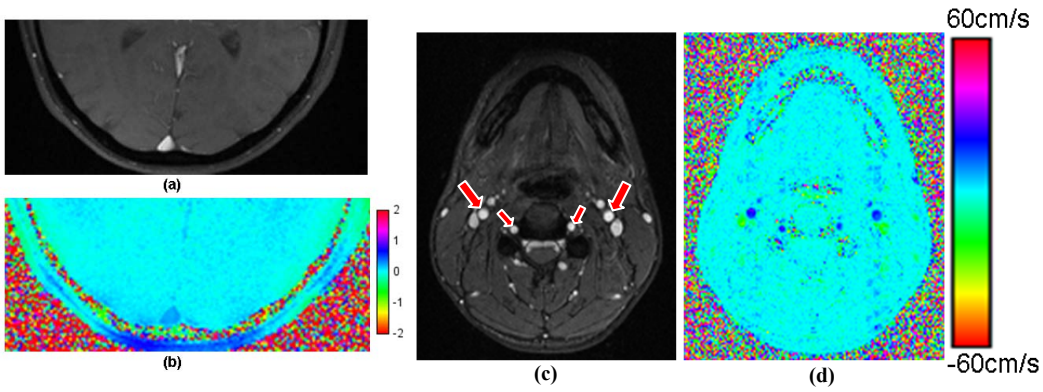

Figure 1: **(a)** Axial magnitude image of the brain showing the major draining vein (superior sagittal sinus; red arrow)**;** and **(b)** phase difference image for HbO_2 quantification; **(c)** axial magnitude image of neck. Major inflow vessels used for cerebral flow (internal carotid and vertebral arteries) are indicated with arrows; **(d)** corresponding velocity map.

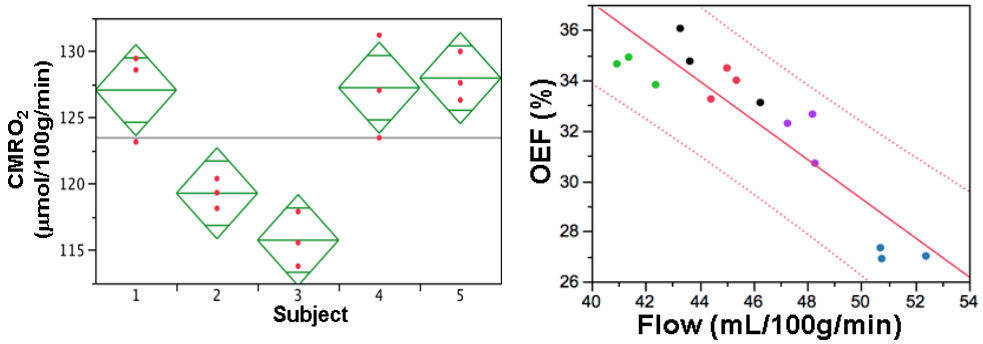

Figure 2: (a) Plot of $CMRO_2$ variation in each subject over three scanning sessions demonstrating high reproducibility of the technique **(b)** Scatter plot depicting the correlation between oxygen extraction fraction (OEF) and total cerebral blood flow in the five subjects ($r^2 = 0.82$, $p<0.0001$) (different colors represent different subjects). Note that subjects with higher flows tend to have lower venous oxygen saturation which corresponds to lower OEF.

Results and Conclusions

Oxygen saturation and flow measurements (**Figure 1**) in the 3 sessions for the 5 subjects varied maximally by 2% HbO_2 points and 1.7 mL/100g/min, respectively. The average values of venous oxygen saturation, cerebral blood flow and $CMRO_2$ for the group were 66 ± 3 %, 46.1 ± 3.7 mL/100g/min and 123 ± 6 µmol/100g/min, respectively (**Figure 2**). The measured whole-brain $CMRO_2$ values are in excellent agreement with those reported in the literature [6].

In conclusion, we have demonstrated a noninvasive, robust and reproducible MRI-based approach for the estimation of global whole-brain $CMRO_2$ based on simultaneous measurement of blood flow and oxygen saturation in major inflow and outflow vessels to the brain.

References

[1] Greene et al. J Neurochem 86:529-37 (2003); **[2]** Haacke et al. Human Brain Mapping 5:341-346 (1997); **[3]** Fernandez-Seara et al. MRM 55:967–973 (2006); **[4]** Spees et al MRM 45: 533 – 542 (2001); **[5]** Magland,Seattle,WA. Poc.ISMRM 578 (2006) **[6]** Nagdyman et al., Int Care Med 31: 846-50 (2005)

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