Quantification of Regional Cerebral Metabolic Rate of Oxygen Consumption in the Middle Cerebral Artery Territory

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Introduction: The human brain predominantly relies on the aerobic metabolism of glucose to meet its enormous energy requirements [1]. A robust method for quantifying regional cerebral metabolic rate of oxygen consumption (rCMRO₂) would be of significant clinical utility in the workup of numerous vascular pathologies affecting the brain. For example, such a paradigm could be extended to identify patients with vascular territorial compromise at risk for ischemia or stroke. The few available MR based methods for absolute rCMRO₂ estimation are hampered by long scan times and complex signal models with several underlying assumptions [2]. Alternate imaging methods such as positron emission tomography (PET) are limited in their use due to invasiveness and expense [3]. Here, as an extension to the recently reported method for determining global CMRO₂ [4], we demonstrate the feasibility of determining lateralized rCMRO₂ corresponding to the middle cerebral artery (MCA) territory by measuring regional cerebral blood flow (rCBF) in the MCA and regional venous oxygen saturation (rSV₂O) in the largest superficial cortical vein draining into the superior sagittal sinus (SSS) corresponding to the MCA vascular territory.

Methods: rS₂O₂ quantification relies on the measurement of relative magnetic susceptibility, Δχ, of intravascular blood and surrounding tissue by modeling the vessel of interest as a long paramagnetic cylinder [3,4]. Oxygen saturation (%HbO₂) is determined as %HbO₂ = (1 - Δvo2B₀(ω2θ - 1/3)/Hct)) × 100 where Δφ is the average phase difference between intravascular blood and surrounding tissue, ΔχB₀ = 2π(0.27 ppm) [5] is the susceptibility difference in SI units between fully deoxy/oxygenated erythrocytes, 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 B₀. rCBF was measured in the M1 segment of MCA using phase contrast MRI. All MR experiments were performed on a 3T Siemens Tim Trio system. Scan parameters: FOV = 176 × 176 × 2 mm³, voxel size = 0.5 × 0.5 × 2 mm³, flip angle = 25°, TR=35ms, echo spacing = 2. A double oblique localization strategy was used to ensure measurements perpendicular to the vessels. The tilt angle of the cortical vein with the B₀ field was calculated for rS₂O₂ quantification based on a double-oblique localization strategy (Figure 1). An average MCA territory volume of 230 cm³ was used to quantify rCMRO₂ per 100 g of brain mass [6]. Additionally, the sensitivity of the method to a task-based stimulation involving cerebral processes specific to the MCA territory was evaluated. The subject was asked to perform fine-coordinated finger movements of the right hand and count forwards and backwards while imaging of the contra-lateral side was conducted.

Results and Conclusion: rS₂O₂, rCBF and rCMRO₂ in three healthy male adults (age: 28 ± 2 years) 67±2%, 125±6 ml/min and 139±7 μmol/100g/min, respectively, in agreement with previous results [7,8]. During the task based stimulation, rCBF and rS₂O₂ increased by 7.3 % and 5.8 % (Figure 1). Average rCMRO₂ during rest and task was 142±4 and 137±7 μmol/100g/min, respectively.

In conclusion, we demonstrate the feasibility of MR susceptibility-based oximetry to quantify rCMRO₂ corresponding to middle cerebral artery territory. Our preliminary data during a motor task-based activation demonstrates changes in rCBF and rS₂O₂ in agreement with previous studies [3]. However, a larger sample size and the ability to determine rCBF and rS₂O₂ simultaneously will be needed to better evaluate changes in rCMRO₂ during task-based activation.

References

Figure 1 (a) Coronal MIP highlighting the largest superficial cortical vein in the left MCA territory and draining into SSS; (b) axial magnitude image; (c) phase image; (d) angiogram of left and right MCA’s; (e) paracoronal angiogram of left MCA; (f) velocity map showing MCA (square); (g) time resolved measurements of rSV₂O₂ (g) and rCBF (h) during a motor activation task (blue = rest; pink = task).