Oxygen Extraction Fraction Measurement using Quantitative Susceptibility Mapping in Patients with Chronic Cerebral Ischemia: Comparison with Positron Emission Tomography

Kohsuke Kudo[1,2], Tian Liu[3], Jonathan Goodwin[2], Ikuko Uwano[2], Fumio Yamashita[2], Satomi Higuchi[2], Noriyuki Fujima[1], Yi Wang[3], Kuniaki Ogasawara[4], Akira Ogawa[4], and Makoto Sasaki[2]

[1]Diagnostic and Interventional Radiology, Hokkaido University Hospital, Sapporo, Hokkaido, Japan, [2]Ultra-High Field MRI, Iwate Medical University, Morioka, Iwate, Japan, [3]Radiology, Weill Cornell Medical College, NY, United States, [4]Neurosurgery, Iwate Medical University, Morioka, Iwate, Japan

Target Audience: Neuroradiologists and other researchers who are interested in non-invasive measurement of oxygen metabolism in the brain.

Purpose: Oxygen extraction fraction (OEF) represents an important parameter of brain metabolism, which can provide information about the relative deficiencies in cerebral blood supply with the tissue's demand for oxygen (misery perfusion). Positron emission tomography (PET) is generally considered to be the gold standard for OEF measurements; however, PET has several disadvantages such as limited availability and radiation exposure. The purposes of this study are, to establish oxygen extraction fraction (OEF) measurements using quantitative susceptibility mapping (QSM) of MRI, and to compare QSM-OEF data with the gold standard ^{15}O positron emission tomography (PET) in patients with unilateral chronic steno-occlusive disease.

Methods: Twenty-six patients with chronic unilateral stenosis or occlusion of internal carotid artery (ICA) or middle cerebral artery (MCA) were studied. MRI scans were conducted using a 3.0 Tesla scanner with a 3D-SPGR sequence (FA/TE/TR, 18/30/44; NEX, 1; FOV, 256 mm; slice thickness, 2 mm; number of partitions, 30; acquisition matrix, 384 × 160; and reconstruction matrix, 512 × 512). The magnitude, real, and imaginary images were reconstructed. QSM images were created using the morphology enabled dipole inversion (MEDI) method, and OEF maps were generated from QSM images using extraction of venous susceptibility (Δχ) induced by deoxygenated hemoglobin.

$$\Delta\chi = \Delta\chi_{do} \times \text{Hct} \times (1 - Y) \times \frac{1}{Pv}$$

where $\Delta\chi_{do}$ (1.8×10^{-7}) is the susceptibility difference between fully deoxygenated blood and fully oxygenated blood. We assumed a hematocrit (Hct) value of 0.45, and a correction factor for partial volume effects (Pv) was introduced. OEF maps of ^{15}O-PET were also obtained, and registration of PET-OEF and QSM-OEF images was performed. Automated measurement of regions-of-interest (ROIs) was conducted, and the values of QSM-OEF and PET-OEF were compared. Increased QSM-OEF was defined as OEF ratio above mean + 2SD of normal subjects. Correlation between QSM-OEF and PET-OEF was assessed using relative OEF ratio (relative to contralateral side).
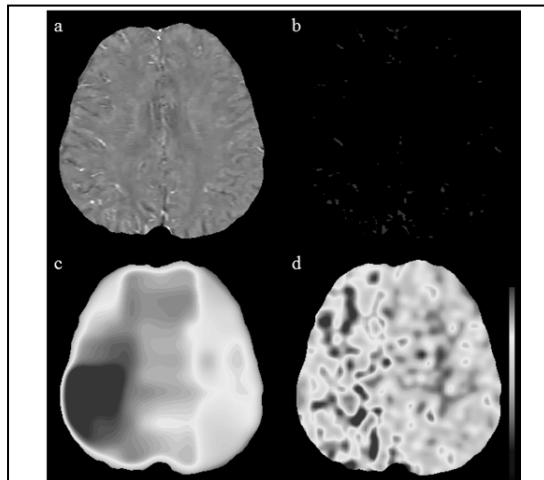

Figure 1. Creation of OEF Map
Bright veins are noted in the right hemisphere on QSM image (a). After venous masking (b), OEF map (c) is created from susceptibility value of these veins. OEF increase in the right side corresponds well to PET-OEF (d).

Table 1. OEF values

		PET-OEF			QSM-OEF		
		mean	±	SD	mean	±	SD
Patients	Affected Side	46.9	±	8.6	36.1	±	5.6
	Contralateral Side	44.6	±	7.5	34.7	±	5.2
Normal Subjects		N.A.			34.3	±	2.1

Results: QSM-OEF value in the affected hemisphere (36.1 ± 5.6) was significantly higher than the contralateral hemisphere (p = 0.01) (Table 1). In the comparison between PET-OEF and QSM-OEF, the differences were statistically significant both for affected (p < 0.001) and contralateral sides (p < 0.001). Five patients had increased PET-OEF, in which four had increased QSM-OEF. Twenty-one patients had preserved PET-OEF, and among them, two had increased QSM-OEF and 19 had preserved QSM-OEF. Chi-square test revealed that the relationship was statistically significant. The sensitivity of QSM-OEF was 0.80 (4/5) and the specificity was 0.90 (19/21), for the detection of increased OEF. Good correlation of OEF ratio between QSM-OEF and PET-OEF was observed (r = 0.60, p = 0.001) (Figure 2).

Discussion: The OEF quantification is based on local concentration of deoxy-Hb. Previous MRI methods utilizing T2*/T2' shortening due to susceptibility effect of deoxy-Hb in the brain parenchyma have potential inaccuracy due to the presence other paramagnetic substances (such as iron and hemorrhage) that cause spin dephasing, and therefore may alter T2*/T2' relaxation times and the subsequent accuracy of OEF values. The other method using phase shift of venous pixels has an advantage to minimizing such an effect from paramagnetic substances in the brain tissue other than deoxy-Hb; however, it is difficult to quantify OEF because the phase value of vein depends on not only the concentration of deoxy-Hb, but also venous angle to main field. QSM is a technique to calculate quantitative magnetic susceptibility without the effects associated with the geometry of the measured veins, thereby allowing absolute quantification of OEF in the veins. Although our method measures OEF in the vein instead of the brain tissue, the elevation of OEF in the affected hemisphere could be seen in patients with elevated OEF confirmed by PET.

Conclusion: OEF quantification is feasible by using QSM. Good correlation was achieved between QSM-OEF and PET-OEF in the identification of elevated OEF in affected hemispheres of patients with unilateral chronic steno-occlusive disease.
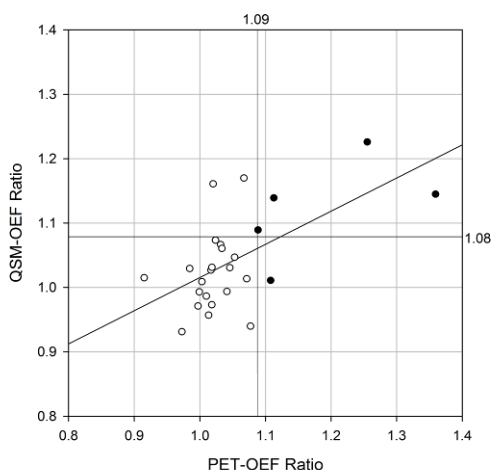

Figure 2. Relationship of OEF Ratio
Upper limit of normal ranges are 1.09 for PET-OEF and 1.08 for QSM-OEF. Five patients have significant increase in PET-OEF (●), and others had normal PET-OEF (○). There is a significant correlation between QSM-OEF and PET-OEF. (p = 0.001, r = 0.60, and y = 0.52 x + 0.50).

References:
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