Determining rCMRO2 Changes During Brain Activation by Measuring Venous Blood-Oxygenation with MR Phase Imaging

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Introduction

The measurement of changes in the regional cerebral metabolic rate of oxygen ($rCMRO_2$) during neural activation has been well established by positron emission tomography (PET) in the past two decades (1, 2). The $rCMRO_2$ obtained by PET is determined by the multiplication of the relative oxygen extraction ratio (rOER) and the relative cerebral blood flow (rCBF). In the fMRI field, the arterial spin labeling (ASL) methods for measuring rCBF are well established. By using MR phase imaging, rOER can also be determined. Therefore, $rCMRO_2$ could be obtained by fMRI with the PET strategy of multiplying rOER and rCBF. This study shows our fMRI result for the determination of $rCMRO_2$ and its comparison to PET-obtained $rCMRO_2$ results.

Methods

Theory: The phase difference between a venous blood vessel and surrounding brain parenchyma in the flow-compensated image can be determined by the following equation (3):

$$\Delta\phi = 2\pi \cdot \gamma \cdot B_0 \cdot \Delta\chi \cdot (\cos^2\theta - 1/3) \cdot TE \qquad [1]$$

where $\gamma = 2.67\times10^8$ rad/sec/T is the gyromagnetic ratio of the proton, TE is the echo time, and θ represents the angle between the cylinder axis of the vessel and the static field B_0. The susceptibility difference $\Delta\chi$ is related to the blood saturation Y by the following equation:

$$\Delta\chi = \Delta\chi_{do} \cdot Hct \cdot (1 - Y) \qquad [2]$$

where $\Delta\chi_{do}$ is the susceptibility difference per unit hematocrit between fully deoxygenated and fully oxygenated blood and has been measured to be 1.8×10^{-7} (4), Hct is the fractional hematocrit in the pail vain and has an average value of about 0.4 (5), and

$$OER = 1 - Y \qquad [3]$$

The relative $CMRO_2$ then can be expressed as equation [4] based on Fick's principle:

$$\frac{CMRO_2}{CMRO_{2\,0}} = \frac{OER}{OER_0} \times \frac{CBF}{CBF_0} \qquad [4]$$

where subscript o denotes each corresponding value at resting state.

Experiment: Experiments were performed on a whole-body 3T Siemens Trio MRI scanner. Six healthy volunteers participated in this study. In the resting state, the volunteers were relaxed, while in the activated state they tapped fingers to thumb in a self-paced, consistent, and repetitive manner. A high-resolution low bandwidth conventional gradient echo sequence with flow compensation was employed for phase imaging. Phase images were acquired during both resting and activation states. The phase imaging parameters were TR/TE/θ = 100ms/40ms/15^0, slice thickness = 3mm, in-plane resolution = 0.5×0.5mm corresponding to a FOV of 256 × 256mm, bandwidth = 49 Hz/pixel, 2 minutes for each acquisition and two acquisitions for both resting and activation states. One oblique transverse brain slice through the primary motor cortex was selected for functional imaging. Care was taken to position the imaging slice as close as possible to perpendicularity with a chosen blood vessel as shown in Figure 1.

Data Analysis: The phase difference between a venous blood vessel and surrounding brain parenchyma is determined by averaging those phase values in the center of the vessel (sometimes up to 4 pixels contribute) and subtracting from this the surrounding brain tissue phase. This phase difference is then substituted into Equation [1] in order to calculate $\Delta\chi$ in both resting and activation states. The oxygen saturation values are found by using Equation [2] and OER_{rest} and OER_{act} values by using Equation [3]. The relative OER is determined by dividing OER_{act} by OER_{rest}. The relative CBF is 1.54 that is obtained from a previous publication (6). The $rCMRO_2$ is then determined by Equation [4].

Results

The average measured OER values in this study are 0.38 ± 0.07 and 0.26 ± 0.04 during resting and activation states, respectively. These values are in good agreement with the reported values (Table 1) from previous PET and MRI measurements. Figure 2 shows a single subject $rCMRO_2$ functional map. The average value of $rCMRO_2$ during the motor task over 6 subjects is 4.7%. This is well matched to the values obtained by previous PET measurements (Table 2).

Conclusion

Our preliminary result demonstrates that $rCMRO_2$ estimated by fMRI measurement is in excellent agreement with the value measured by PET. Considering the advantages of fMRI over PET - high spatial resolution and efficiency - fMRI-determined $rCMRO_2$ functional maps will find more use in basic research and clinical applications.

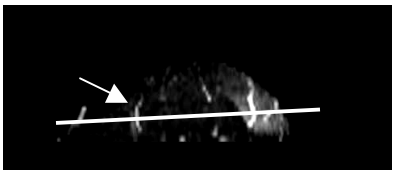

FIG 1. Sagittal view of a venogram reconstructed from 2D TOF angiography. Image slice is selected as close as possible to perpendicularity with the vessel indicated by the arrow head.

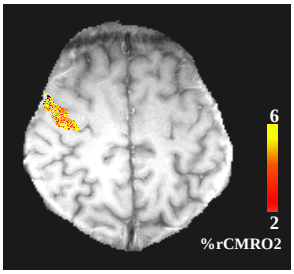

FIG 2. $rCMRO_2$ functional map.

Table 1.

Method	References	OER_{rest}	OER_{act}
PET	Fox et al.(1)*	0.36	0.25
MR	Hoogenradd et al.(7)**	0.45 ± 0.12	0.29 ± 0.08
MR	Oja et al. (8)	0.30 ± 0.06	0.20 ± 0.07
MR	Golay et al. (9)	0.38 ± 0.04	0.18 ± 0.06
MR	This study	0.38 ± 0.07	0.26 ± 0.04

*Calculated using $CMRO_2$=1.5μmol/g/min,Hct=0.41,and CBF=0.5 ml/g/min.
**Calculated from published Y values determined by MR phase imaging.

References

1. Fox PT et al., Science, 241: 462-464 (1988)
2. Mintun MA et al., NeuroImage, 16: 531-537 (2002)
3. Haacke EM et al., Human Brain Mapp, 5: 341-346 (1997)
4. Weisskoff RM et al., Magn. Reson. Med. 24: 375-383 (1992)
5. Guyton AC. Textbook of Medical Physiology, 7th ed .(1986)
6. Ye FQ et al., Magn. Reson. Med. 42: 404-407 (1999)
7. Hoogenradd FGC et al., Magn. Reson. Med. 39: 97-107 (1998)
8. Oja JME et al., J Cereb Blood Flow Metab. 19: 1289-1295 (1999)
9. Golay X et al., Magn. Reson. Med. 46: 282-291 (2001)

Table 2.

Method	References	% $rCMRO_2$ $=CMRO_2/CMRO_{2\,0}-1$
PET	Fox et al.(1)	5 %
PET	Mintun et al. (2)	4.7 %
MR	This study	4.7 ± 3.6 %