Quantification of CMRO2 and CBF using Simultaneous NIRS and fMRI

S. Tak[1], and J. Ye[1]

[1]Bio and Brain Engineering, KAIST, Daejeon, Daejeon, Korea, Republic of

Introduction : We introduce an accurate technique to estimate the cerebral metabolic rate of oxygen ($CMRO_2$) and cerebral blood flow (CBF) using simultaneously measured near infrared spectroscopy (NIRS) and blood oxygenation level dependent (BOLD) fMRI signals. Owing to simultaneous acquisition of both fMRI and NIRS, separate hypercapnia condition or arterial spin labeling (ASL) acquisition are not necessary to quantify CMRO2 and CBF, which greatly improves the accuracy of the proposed method. The dynamic coupling ratio of CBF changes to $CMRO_2$ changes has been also investigated. Experimental results using finger tapping task showed that the activation pattern of CBF calculated using NIRS-SPM software [1] is more specific to the primary motor cortex than fMRI BOLD and NIRS-HbR signal. Furthermore, the dynamic couple ratio coincides with the existing results from the literature [2].

Theory : A robust estimation of $CMRO_2$ is important to understand the neural-metabolic-hemodynamic relationship. fMRI approach of Eq. (1) estimates $CMRO_2$ from BOLD and CBF [3]. However, there are two main drawbacks in this approach. First, an ASL technique which measures CBF has low signal to noise ratio due to the small amplitude of the flow related MRI signal. Second, the hypercapnic condition is necessary to calibrate the scaling factor (M) between BOLD and HbR concentration. NIRS approach of Eq.(2) determines the $CMRO_2$ from HbR and total-hemoglobin (HbT) [4]. However, there exists many unknown hyperparameters that determine the accuracy of NIRS estimates.

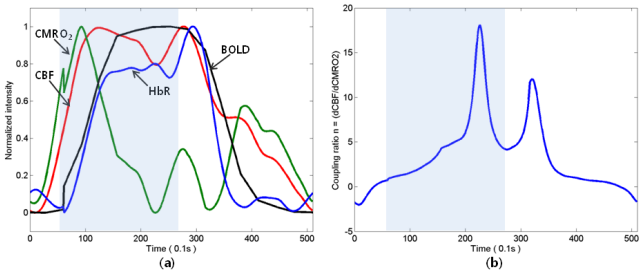

Fig. 1. Averaged time course of (a) CBF, $CMRO_2$, HbR, BOLD, (b) coupling ratio n.

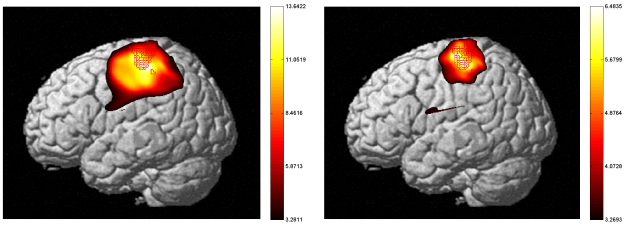

Fig. 2. Activation map of HbR and CBF, respectively (p< 0.05, tube formula correction).

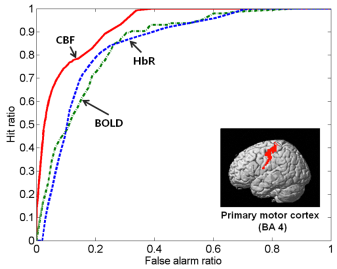

Fig. 3. Receiver operation characteristics (ROC) for CBF, HbR, and HbO.

$$\frac{rCBF(t)}{rCMRO_2(t)} = \begin{cases} \dfrac{1}{(1-\delta BOLD/M)^{1/\beta}(1+\delta CBV)^{-1/\beta}} & (1) \\ \dfrac{1+\gamma_T \cdot \delta HbT}{1+\gamma_R \cdot \delta HbR} & (2) \end{cases}$$

Interestingly, those approaches give the same normalized CBF:normalized $rCMRO_2$ ratio. By minimizing the difference of this value between two modalities, the optimal M value can be readily obtained without a hypercapnic episode. Furthermore, CBF [5] and $CMRO_2$ [3] are calculated as follows

$$rCBF(t) = (\tau_{MTT} + \tau)\frac{drCBV}{dt} + rCBV^{1/\alpha} \quad (3)$$

$$rCMRO2(t) = rCBF(t) \cdot X(t), \quad where\ X(t) = rCBV(t)^{-1/\beta}\left(1 - \frac{rBOLD(t)-1}{M}\right)^{1/\beta} \quad (4)$$

Result : We performed the right finger tapping experiment: a 21-sec period of activation alternated with a 30-sec period of rest. Experiment data was simultaneously measured using 24 channel NIRS (Oxymon MKIII) and 3.0T MRI system. Figure 1(a) shows the average time course of normalized CBF, $CMRO_2$, HbR, and BOLD. Figure 1(b) describes the dynamic coupling ratio of CBF changes to $CMRO_2$ changes. $CMRO_2$ rapidly increased before CBF increased and CBF changes were much higher than $CMRO_2$ changes during task period. More specifically, the peak of $CMRO_2$ change was approximately 2.39% and that of CBF changes was about 3.84 %. The average coupling ratio during stimulus was about 6.79, which coincides with the values in the literature [2]. Figure 2(a)(b) describe the activated areas found by HbR and CBF, respectively (p<0.05, tube formula correction), which were overlaid with BOLD activation. Note that the activation region of CBF was more consistent with the primary motor cortex than that of HbR. Quantitative comparisons between activation area and target region were performed by calculating receiver operation characteristics (ROC) for group analysis of CBF, HbR, and BOLD. Total number of subjects was five. The absolute coordinates of primary motor cortex (BA4) were assumed as ground-truth. ROC analysis in Fig. 3 showed that the area under ROC curve for CBF was largest, indicating CBF activation map are more correlated with neural activity.

Conclusion : We have estimated CBF and $CMRO_2$ from simultaneously measured NIRS and BOLD signals without hypercapnic condition and ASL measurements. Experimental results showed that $CMRO_2$ increased before CBF increased and the amplitude of CBF changes was much higher than that of $CMRO_2$. Furthermore, CBF activation was more correlated with neural activity than that of HbR and BOLD.

Reference

[1] Ye JC et al. NeuroImage 2008, doi: 10.1016/j.neuroimage.2008.08.036.

[2] Leontiev et al. NeuroImage 2007;35: 175-184.

[3] Davis TL et al. Proc. Natl. Acad. Sci. USA 1995;95: 1834-1839.

[4] Boas et al. Phys. Med. Biol. 2003;48: 2405-2418.

[5] Buxton RB et al. Magn. Reson. Med. 1998;39: 855-864.

Acknowledgement : This research was supported in part by a IT R&D program of MKE/IITA[2008-F021-01]. This work was also supported in part by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD)(KRF-313-D00593).