Effects of Hyperventilation and CO$_2$ Inhalation on Cerebral Oxygen Metabolism of Moyamoya Disease Measured by Near-Infrared Spectroscopy

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Introduction

Near-infrared spectroscopy (NIR) can give continuous, direct information about cerebral oxygen metabolism not only in infants but also in adults by providing signals from oxyhemoglobin (oxy-Hb), deoxyhemoglobin (deoxy-Hb), and the redox state of cytochrome aa$_3$ (Cyt). Using NIR, we examined the cerebral oxygen metabolism of normal adults and patients with moyamoya disease.

Methods

We studied ten patients with moyamoya disease and nine normal adult volunteers using NIR. Table 1 summarizes the patients studied. The disease was diagnosed in all patients by angiography, which demonstrated stenosis or occlusion of bilateral internal carotid arteries with moyamoya vessels. Besides angiography, computed tomography (CT) scan or magnetic resonance imaging (MRI) were performed in all patients, and single photon emission CT was performed in seven patients. Extracranial-intracranial (EC-IC) bypass, such as superficial temporal artery–middle cerebral artery (STA–MCA) anastomosis, were performed in seven of ten patients.

We measured the relative changes in the concentrations of oxy-Hb, deoxy-Hb, and the redox state of Cyt using an NIR instrument (NIRO-500, Hamamatsu Photonics, Hamamatsu, Japan). For measurement of these parameters, the transmitting fiberoptic bundle pulsed six consecutive wavelengths of NIR light (780, 808, 828, 850, 870, and 904 nm), and reflected

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light was collected in the receiving fiberoptic bundle and transmitted to a photomultiplier tube. We used the differential path length fraction of adult heads (5.93 ± 0.42, mean ± SD), which was determined by time-of-flight measurement of an ultrashort optical pulse through the tissues [1]. Using an algorithm developed by Wray et al. [2], concentrations of oxy-Hb, deoxy-Hb, and Cyt were continuously analyzed by means of a computer incorporated into the apparatus. The change in cerebral blood volume (CBV) was considered to be that of total hemoglobin (oxy-Hb + deoxy-Hb) [3].

Results

**Effects of Hyperventilation**

Hyperventilation decreased PaCO$_2$ and increased PaO$_2$ with respiratory alkalosis in both control and moyamoya groups. In both groups, hyperventilation caused a decrease of oxy-Hb with only a mild increase in deoxy-Hb, resulting in a decrease of total Hb (Fig. 1). These changes recovered to the control levels after hyperventilation.

**Effects of CO$_2$ Inhalation**

Inhalation of CO$_2$ increased PaCO$_2$ and PaO$_2$ with respiratory acidosis in both groups. In both normal adults and the patients with moyamoya disease, CO$_2$ inhalation caused an increase of oxy-Hb with a mild decrease in deoxy-Hb, resulting in an increase of total Hb. However, these changes were smaller in the moyamoya group than those in the control group. Figure 2 compares the changes of the NIR parameters taken before, during, and after CO$_2$ inhalation in normal adult and a patient with moyamoya diseases. Note that oxy-Hb rapidly increased with a mild decrease of deoxy-Hb in the normal adult immediately after the start of CO$_2$ inhalation, but these same changes were smaller in the patients with moyamoya disease than those in the normal adults.

**Comparison of CO$_2$ Responses in Normal Adults and Patients with Moyamoya Disease**

Figure 3 shows the correlation between the changes of arterial PCO$_2$ and oxy-Hb. In both normal adults and the patients with moyamoya disease, oxy-Hb increases linearly with increase of arterial PCO$_2$. However, these changes in moyamoya disease patients are slightly smaller than those in the normal adult. To clearly see the difference in CO$_2$ responses of control and moyamoya groups, we calculated the CO$_2$ response index as the changes in oxy-Hb, deoxy-Hb, and total Hb, while eliminating the effects of arterial PCO$_2$ change (Table 2). We excluded the cases without EC-IC bypass surgery. There is no significant difference in the CO$_2$ response index between