INTRODUCTION

The tissue oxygenation represents the balance between the local oxygen delivery and consumption, which relates to both the organ’s metabolic activity and its blood flow (1). Near-infrared radiation is capable of transmitting through the body tissues due to the property which is scarcely absorbed by water and hemoglobin, and the scatter of the radiation is less than that of ultraviolet or visible radiation (2). The analysis of the near-infrared spectrum, i.e. near-infrared spectroscopy (NIRS), therefore, allows clinicians to evaluate the oxygenation in human brain tissues, which have some distance from the scalp (2). Similar to transcranial Doppler sonography or stump pressure measurements, NIRS accurately reflects changes in cerebral blood flow, indicating that the methodology is a clinically meaningful, non-invasive monitoring method in the population, which is potentially suffered from cerebral ischemia (3). However, whether the NIRS technology can correctly detect the changes in oxygenation related to ischemia and reperfusion of organs and tissues other than brain remains unclear.

The changes in both temperature and blood flow of the surface skin are known to modify the value of cerebral regional saturation of oxygen (rSO2), which is determined by the NIRS employing the Beer-Lambert law (4). On the other hand, the tissue oxygenation index (TOI) defined by the NIRS using the spatially resolved spectroscopy appears more reliable than rSO2 in the evaluation of cerebral oxygenation because the tissue hemoglobin concentration, situation of cutaneous circulation, skull thickness, and the area of the cerebrospinal fluid layer affect rSO2, but not TOI, at least in the brain (5, 6). However, whether the tissue oxygenation parameters derived from different NIRS technologies similarly reflect the changes in forearm blood flow (FBF) caused by the brief ischemia and the subsequent reperfusion remains unknown.

The present study was designed to examine how different tissue oxygenation parameters derived from different NIRS technologies move in parallel with the medial and lateral sides of FBF. Thirteen volunteers underwent the prospective observational study. The tissue oxygenation index (TOI), regional saturation of oxygen (rSO2), skin tissue oxygenation (StO2), and FBF values were evaluated in the forearm. Medial rSO2 values at 1 to 3 minutes after the termination of brief ischemia were higher than lateral rSO2 and respective TOI values. FBF and StO2 values quickly increased according to the cessation of brief ischemia, whereas the medial and lateral values did not differ during and after the brief ischemia. TOI and StO2, but not rSO2, reflected changes in FBF of both medial and lateral sides simultaneously in response to the reperfusion after brief ischemia. The muscle tissue oxygenation during reperfusion favors the use of TOI and StO2, but not rSO2, as the surrogate parameter. J. Med. Invest. 64 : 228-232, August, 2017

Keywords : Forearm blood flow ; near-infrared spectroscopy ; regional saturation of oxygen ; tissue oxygenation index

METHODS

After institutional approval from Aichi Medical University School of Medicine (the approved no. 13-134), this study was registered in the UMIN Clinical Trial Registry (UMIN000026435). The informed consent was obtained from healthy enrolled volunteers (n=13, 24-35 years of age). The work described has been carried out under Declaration of Helsinki. Subjects with the history of redness or rash on their forearm were excluded from this study.

Equipment for measurements

NIRO-200NXTM (Hamamatsu Photonics, Hamamatsu, Japan), INVOS 5100CCTM (Covidien, Tokyo, Japan), C9183TM (Hamamatsu...
continuous TOI (%), rSO2 (%), StO2 (%) and FBF (arbitrary perfusion unit, Axminster, Devon, UK) was employed to determine the continuous TOI (%), rSO2 (%), StO2 (%) and FBF (arbitrary perfusion unit, Axminster, Devon, UK) was employed to determine the continuous TOI (%), rSO2 (%), StO2 (%) and FBF (arbitrary perfusion unit, Axminster, Devon, UK) was employed to determine the continuous TOI (%), rSO2 (%), StO2 (%) and FBF (arbitrary perfusion unit, Axminster, Devon, UK) was employed to determine the continuous TOI (%), rSO2 (%), StO2 (%) and FBF (arbitrary perfusion unit, Axminster, Devon, UK) was employed to determine the continuous TOI (%), rSO2 (%), StO2 (%) and FBF values by the MoorFLPI-2TM (Moor Instruments, Axminster, Devon, UK). The laser-speckle imaging monitor MoorFLPI-2TM that is equipped with the class 1 near-infrared laser source with the wavelength of 730 to 810 nm (4). 

Qualitative measurement of rSO2 change of 11% at a significance level of 0.05 (SD = 9.7). Statistical analysis using PASW Statistics 18TM (IBM Japan Inc., Tokyo, Japan) was performed by the repeated-measures analysis of variance followed by Scheffe’s test. Differences were considered to be statistically significant when P is < 0.05.

RESULTS

Medial rSO2 values at 1 to 3 minutes after the termination of brief ischemia were higher than lateral rSO2 and respective TOI values (Figure 1). SO2 and FBF values quickly decreased or increased according to brief ischemia and the termination, whereas the values did not differ between medial and lateral sides at any measurement period (Figures 2 and 3). TOI, rSO2, StO2 and FBF values demonstrated restoration at 10 minutes to the levels at the commencement of measurements according to reperfusion of the forearm (Figures 1, 2 and 3).

Mean blood pressure and heart rate did not change in response to brief ischemia and the termination in both the trials 1 and 2 and the values were within the normal range (Figure 4). No volunteer claimed health problems including redness or rash on the forearm related to this study.

DISCUSSION

Medial rSO2 values at the initial phase of the forearm reperfusion were higher than lateral rSO2, and respective TOI values whereas FBF values did not differ between the both medial and lateral sides during the measurements. These results suggest that the medial rSO2 values are modified by the forearm reperfusion after brief ischemia. The changes in skin oxygenation related to hyperthermia as well as vasoconstriction alter the value of cerebral rSO2 from the Beer-Lambert NIRS, but not TOI evaluated by the spatially resolved methodology (4-6). However, the different skin perfusion in the medial and lateral sides of the forearm does not appear the cause of the NIRS value modification because StO2 values between the both sides did not differ throughout the measurements. Previous studies proved that TOI is more reliable than rSO2 measured by the Beer-Lambert Principle in cerebral NIRS parameters since the tissue hemoglobin concentration, skull thickness, and the area of the cerebrospinal fluid layer do not affect TOI (5, 6). The current results probably add an answer to the question why an oxygenation monitor, which is adopted the spatially resolved methodology, has long been used to determine the human skeletal muscle oxygenation in the physiological studies (10). However, the reason for the difference between TOI and rSO2 in the current study remains unclear as the algorism of the NIRS technology employed in INVOS 5100CTM has not been opened to the public.

Some surrogate parameters should be essential to evaluate FBF when secure recanalization and reperfusion have to be non-invasively monitored in the clinical conditions including those after vascular bypass surgery and the use of the tourniquet in the extremities. Also, the noninvasive NIRS monitoring of skeletal muscle oxygenation is increasingly critical as a surrogate parameter to determine the cardiovascular and respiratory conditions of patients in the clinical practice, including the estimation of heart failure, the performance of ventilation, and successful remote preconditioning (11-13). Therefore, whether the NIRS monitor employs the Beer-Lambert or spatially resolved methodology is probably a significant determinant that one can achieve the accurate non-invasive evaluation of FBF using the technology. However, further studies are required to determine whether such a difference is clinically meaningful.
Figure 1  Changes in medial and lateral TOI (%) as well as rSO2 (%) values in the trials 1 and 2 (n = 13 each) from the before brief ischemia to 10 minutes after the reperfusion. * : P < 0.05 vs. lateral rSO2 and respective TOI values.

Figure 2  Changes in medial and lateral StO2 (%) values (n = 13) from the before brief ischemia to 10 minutes after the reperfusion.
Figure 3  Changes in medial and lateral FBF (Arbitrary Perfusion Unit) values (n = 13) from the before brief ischemia to 10 minutes after the reperfusion.

Figure 4  Levels of mean blood pressure (left) and heart rate (right) during the study including the trials of 1 and 2 (n = 13).
CONCLUSIONS

In healthy volunteers, TOI and StO$_2$, but not rSO$_2$, reflected changes in FBF of both medial and lateral sides simultaneously in response to the reperfusion after brief ischemia. These results indicate that the muscle tissue oxygenation during reperfusion favors the use of TOI and StO$_2$, but not rSO$_2$ and that the NIRS monitor using the spatially resolved methodology have to be selected when physicians need to evaluate FBF non-invasively in the clinical conditions.

CONFLICT OF INTEREST

The authors have no conflict of interest.

ACKNOWLEDGEMENTS

This work was presented in part at the annual meeting of the International Anesthesia Research Society, Honolulu, HI, USA, March 21–24, 2015, and that of the American Society of Anesthesiologists, San Diego, CA, USA, October 24–28, 2015. The authors thank Hamamatsu Photonics (Hamamatsu, Japan) for the kind support offering the use of C9183TM to us.

STATEMENTS OF FUNDING

This work was supported by departmental sources.

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