Changes in Cerebral Blood Oxygenation and Hemodynamics After Endovascular Treatment of Vascular Malformation Measured by Time-Resolved Spectroscopy

Tatsuya Hoshino, Kaoru Sakatani, Noriaki Yokose, Takashi Awano, Sin Nakamura, Yoshihiro Murata, Tsun eo Kano, and Yoichi Katayama

Abstract Although endovascular treatment has a high success rate, it is not clear how endovascular treatment affects cerebral perfusion and hemodynamics during the perioperative period. We evaluated changes in cerebral blood oxygenation (CBO) repeatedly after endovascular treatment employing time-resolved spectroscopy (TRS). We investigated a patient (10 months old, female) who suffered cerebral arteriovenous fistula. Cerebral angiography demonstrated a pial arteriovenous fistula with three feeders (left PICA, SCA, and AICA). TRS demonstrated a decrease of oxyhemoglobin, total hemoglobin, and oxygen saturation associated with an increase of deoxyhemoglobin in all of the regions measured just after embolization, indicating that embolization improved hyperemia caused by the AV shunt. Interestingly, progressive improvement of hyperemia was observed 3 and 8 days after embolization of the feeders. The present study demonstrated that embolization of the feeders caused progressive changes in CBO and hemodynamics during the perioperative period. TRS may be a useful tool for monitoring cerebral blood perfusion changes after endovascular surgery.

1 Introduction

Intravascular surgery has been widely used for treatment of cerebrovascular was used to monitor hemodynamic changes in AVM after embolization [1]. However, it is difficult to evaluate the hemodynamic changes at various sites of the brain. A simple, non-invasive method for bed-side assessments of hemodynamic changes is required.

NIRS can measure concentration changes of oxyhemoglobin (oxy-Hb) and deoxyhemoglobin (deoxy-Hb) in the cortical vessels [2]. Various studies have shown the usefulness of NIRS for detecting cerebral ischemia during carotid endarterectomy [3]; however, it is difficult to apply NIRS to the diagnosis of vasospasm after SAH, since commercially available NIRS instruments, which employ continuous-wave light, do not provide quantitative values of the baseline Hb concentrations [4]. In contrast, time-resolved near-infrared spectroscopy (TRS) [5, 6] and frequency-domain NIRS [7] permit quantitative measurement of Hb concentrations in the resting condition. Recently, we have demonstrated the reliability of newly developed TRS by undertaking simultaneous TRS and PET measurements in normal adults [8]. In the present study, employing the TRS, we evaluated changes in cerebral blood oxygenation (CBO) and hemodynamics repeatedly after endovascular treatment.

2 Method

2.1 Case Presentation

The patient (10 months old, female) was admitted to Saitama Children

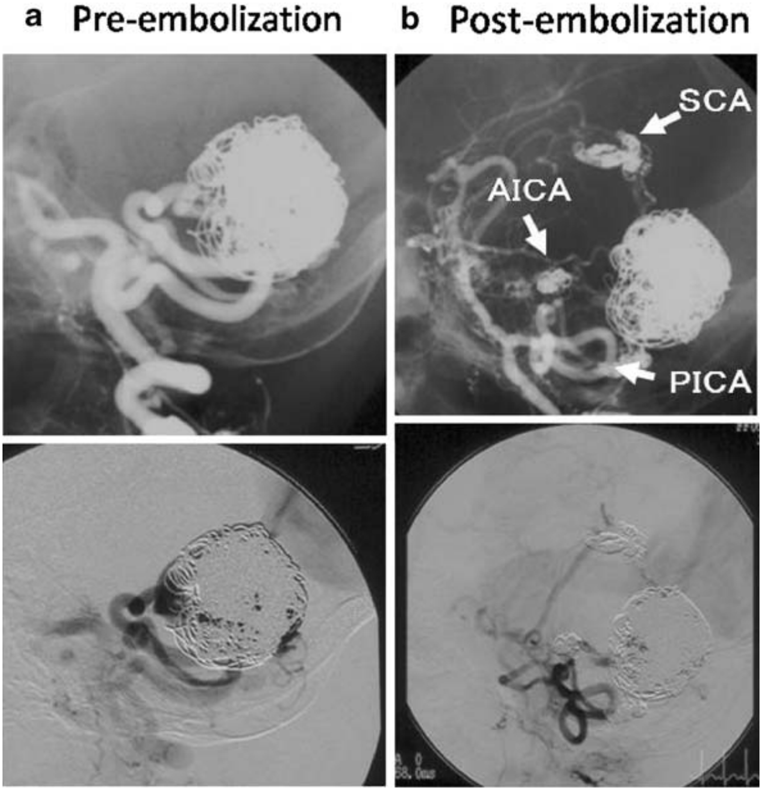

Fig. 1 Cerebral angiography before and after embolization

2.2 TRS

We measured Hb concentrations in the subject with a TRS-10 system (Hamamatsu Photonics K.K, Hamamatsu, Japan), which has been used in several studies [6, 8]. Details of this system have been described previously [6, 8]. Briefly, it consists of three pulsed laser diodes with different wavelengths (761 , 791 , and 836 nm; the pulse duration is 100 ps, with a repetition frequency of 5 Mhz), a photomultiplier tube (PMT; H6279-MOD, Hamamatsu Photonics K.K., Japan), and a circuit for time-resolved measurement based on the time-correlated single photon counting method. The observed temporal profiles were fitted to the photon diffusion equation using the non-linear least-squares fitting method. The reduced scattering (μ_s') and absorption coefficients (μ_a) for the three wavelengths were calculated. The concentrations of oxy-Hb, deoxy-Hb, total Hb (= oxy-Hb + deoxy-Hb; tHb) and oxygen saturation (StO_2) were then calculated using the least-squares method. The concentrations of Hb were expressed in μM. The distance between the emitter and receiver was 3 cm.

We measured pre- and postoperative concentration changes of hemoglobin in the second interventional surgery using the TRS. Measurements were performed before embolization, just after embolization, and at 3 and 8 days after embolization. The optodes were placed over the left frontal, temporal and occipital regions.

3 Results

Figure 2 shows the changes of oxy-Hb, deoxy-Hb, total-Hb concentrations, and StO_2 at the frontal, temporal and parietal regions on the left sides after embolization. Immediately after embolization, oxy-Hb decreased and deoxy-Hb increased, which caused reduction of StO_2, at all measurement areas.

Interestingly, the decreasing tendency of oxy-Hb and StO_2, associated with an increase of deoxy-Hb, was also observed at 3 and 8 days after embolization. In contrast, changes in t-Hb concentration were not remarkable compared with the changes in oxy-Hb and deoxy-Hb concentrations; only t-Hb on the left side, particularly at the occipital region, tended to decrease after embolization.

4 Discussion

The present study is the first demonstration of CBO changes in AVF after embolization using TRS. In contrast to standard neuroradiological techniques such as SPECT and DSA, TRS (a non-invasive optical technique) allows bed-side monitoring of CBO and hemodynamics. Employing TRS, we could evaluate the effect of embolization on CBO and hemodynamics repeatedly.

TRS yields a mixed arterial venous signal in the cortex; however, the contribution ratio of the vascular compartments is not yet clear [9]. Recently, we observed that the mean values of StO_2 in normal adults were similar to those of SjO_2 in patients with unruptured aneurysms [10], suggesting that TRS measures the blood oxygenation predominantly in the venous compartment. In addition, the Hb concentrations measured by TRS are the average concentrations within the illuminated area, including the extracranial and intracranial tissues. Simultaneous measurements of TRS and PET in normal adults suggested that the contribution ratios of the extracranial tissue were about 36.9 (830 nm), 33.2 (800 nm), and 60.3 % (760 nm) when the distance between the emitter and receiver was 3 cm [8].

In the present study, TRS demonstrated a decrease of StO_2 at all measurement areas after embolization; the reduction of StO_2 was caused by a decrease of oxy-Hb concentration and an increase of deoxy-Hb. These CBO changes indicate that embolization reduced AV shunt, since TRS measures Hb concentration mainly in venous compartments.

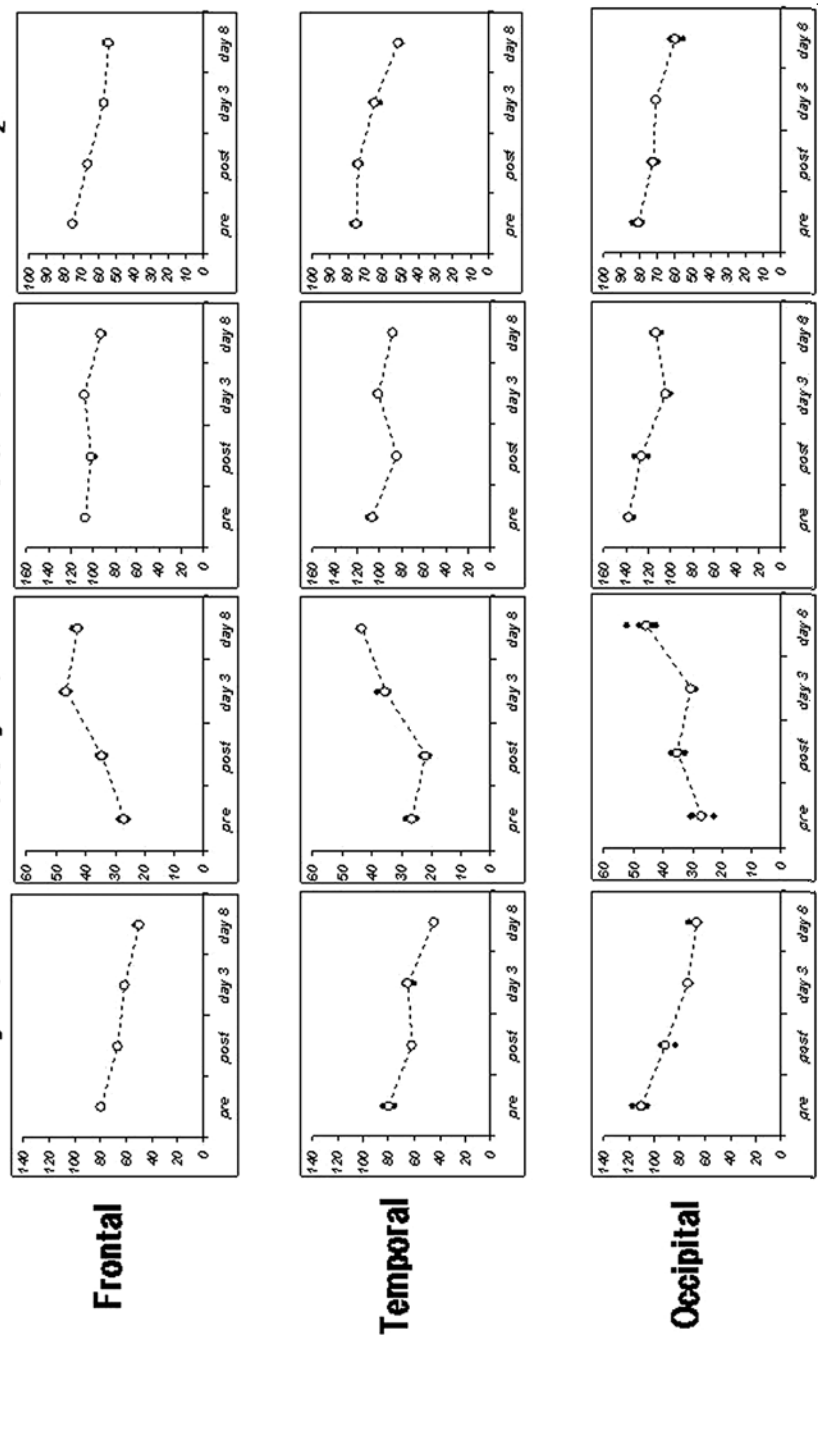

Fig. 2 Changes of oxy-Hb, deoxy-Hb, total-Hb concentrations, and StO_2 at the frontal, temporal and parietal regions on the *left sides* after embolization

In contrast to changes in oxy-Hb and deoxy-Hb, changes in total-Hb were not remarkable after embolization. In general, total-Hb, which is the sum of oxy-Hb and deoxy-Hb, reflects cerebral blood volume. Ijichi et al. measured the CBO of neonates (30–42 weeks) using TRS, and the calculated mean concentration of total-Hb was 64.7 ± 18.9 mM [6]. Thus, the concentration of total-Hb in the present case was relatively high, suggesting that venous congestion was caused by AV fistula. These results suggest that embolization did not improve venous congestion at the time of examination. In addition, improvements of venous congestion after embolization require more time compared with improvement of CBO.

5 Conclusion

TRS demonstrated that embolization of the feeders caused progressive changes in CBO and hemodynamics during the perioperative period in our patient. This indicates that the effect of embolization on the CBO and hemodynamics continued for some period after embolization. TRS, which allows repeated, non-invasive measurements of CBO, may be a useful tool for monitoring changes in CBO and hemodynamics after endovascular surgery.

References

1. Harders A, Bien S, Eggert HR et al. (1988) Haemodynamic changes in arteriovenous malformations induced by superselective embolization: transcranial Doppler evaluation. Neurol Res 10:239–245.
2. Jöbsis FF(1977) Noninvasive, infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. Science 198:1264–1267.
3. Al-Rawi P, Smielewski P, Kirkpatrick PJ (2001) Evaluation of a near infrared spectrometer (NIRO 300) for the detection of intracranial oxygenation changes in the adult head. Stroke 32:2492–2500.
4. Reynolds EO, Wyatt JS, Azzopardi D et al. (1988) New non-invasive methods for assessing brain oxygenation and hemodynamics. Br Med Bull 44:1052–1075.
5. Chance B, Leigh JS, Miyake H et al. (1988) Comparison of time-resolved and -unresolved measurements of deoxyhemoglobin in brain. Proc Natl Acad Sci USA85:4971–4975.
6. Ijichi S, Kusaka T, Isobe K et al. (2005) Developmental changes of optical properties in neonates determined by near-infrared time-resolved spectroscopy. Pediat Res 58:568–573.
7. Gatto R, Hoffman W, Mueller M, et al. (2006) Frequency domain near-infrared spectroscopy technique in the assessment of brain oxygenation: a validation study in live subjects and cadavers. J Neurosci Methods 157:274–277.
8. Ohmae E, Ouchi Y, Oda M et al. (2006) Cerebral hemodynamics evaluation by near-infrared time-resolved spectroscopy: correlation with simultaneous positron emission tomography measurements. NeuroImage 29:697–705.
9. McCormick PW, Stewart M, Goetting MG (1991) Noninvasive cerebral optical spectroscopy for monitoring cerebral oxygen delivery and hemodynamics. Crit Care Med 19:89–97.
10. Karibe H, Tominaga T, Sato K et al. (2001) Decrease in intraoperative brain surface temperature in patients with subarachnoid haemorrhage. Acta Neurochir (Wien) 143:9–14.