

Nobutaka Horie  
Naoki Kitagawa  
Minoru Morikawa  
Makio Kaminogo  
Izumi Nagata

## Monitoring of regional cerebral oxygenation by near-infrared spectroscopy in carotid arterial stenting: preliminary study

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N. Horie (✉) · N. Kitagawa  
M. Morikawa · M. Kaminogo · I. Nagata  
Department of Neurosurgery  
and Radiology, Nagasaki University  
School of Medicine, 1-7-1,  
Sakamoto-machi, Nagasaki-shi,  
Nagasaki 852-8501, Japan  
E-mail: nhorie-ns@umin.ac.jp  
Tel.: +81-958-497375  
Fax: +81-958-497378

**Abstract** In carotid arterial stenting (CAS), ischemic complications and cerebral hyperperfusion are recognized as devastating complications. To detect these complications in early stages, we assessed the feasibility for real-time measurement of regional oxygen saturation (rSO<sub>2</sub>) of the brain in 24 patients with symptomatic extracranial carotid artery stenosis in CAS. The rSO<sub>2</sub> changes were easy to evaluate and significantly correlated with the ischemic neurological symptoms as well as postoperative hyperperfusion detected by single-photon emission

computed tomography (SPECT). Moreover, the pattern of changes in rSO<sub>2</sub> was significantly correlated with the asymmetry index and the cerebral vasoreactivity examined by preoperative SPECT. Therefore, simultaneous monitoring of rSO<sub>2</sub> is feasible in detecting early hemodynamic complications in CAS.

**Keywords** Carotid arterial stenting · Regional oxygen saturation · Ischemia · Hyperperfusion

### Introduction

Percutaneous transluminal angioplasty and carotid arterial stenting (CAS) are less invasive than carotid endarterectomy (CEA) and are increasingly becoming the common treatment for high-grade symptomatic stenosis involving the extracranial carotid arteries [1]. As well as ischemic complications, cerebral hyperperfusion syndrome after CAS is recognized as a devastating complication [1, 2]. Large series of CAS have revealed the incidence of complications owing to hypoperfusion and hyperperfusion to be in the range 3.6%–7.9% [2]. Therefore, a real-time monitoring method for early detection of ischemic changes and prediction of postoperative hyperperfusion is warranted. Techniques used to monitoring for complications associated with CEA include electroencephalogram, transcranial Doppler, continuous recording of the brain stem auditory response, and motor and somatosensory evoked potentials [3], but each of these methods requires trained personnel, and interpretation of their results may not be

immediately available. This calls for innovation and employment of other non-invasive monitoring techniques that allow for fast interpretation during CAS.

During skull base surgery or CEA, monitoring of the regional oxygen saturation (rSO<sub>2</sub>) of the brain with transcranial near-infrared spectroscopy (NIRS) has proven to provide reliable information about changes in cerebral oxygenation [4, 5], but no studies have reported this technique in the setting of CAS. We previously reported that monitoring of rSO<sub>2</sub> with INVOS-3100 (Somanetics) could be a useful indicator in the evaluation of intracranial hemodynamic changes [6, 7]. In this study, we evaluated the feasibility of real-time measurement of rSO<sub>2</sub> as a monitoring device to detect early complications perioperatively in CAS.

### Materials and methods

Since 1998 our department has used INVOS-3100 in routine rSO<sub>2</sub> monitoring in CAS patients. Between

January 2000 and August 2004, 24 consecutive patients (22 male; mean age  $71.6 \pm 5.1$  years) underwent CAS at our institution. They all had high-grade ( $>70\%$ ) symptomatic stenoses involving extracranial carotid arteries with a high risk of CEA (age  $>75$  years, cardiac disease or chronic obstructive pulmonary disease). Twenty-two patients had unilateral lesions, and the remaining two had bilateral lesions. Two patients had contralateral occlusion of the internal carotid artery (ICA). Mean stenosis was  $91.5 \pm 1.3\%$  (range  $70\%$ – $95\%$ ) according to North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria [8].

### SPECT studies

All patients had pre- and post-diamox SPECT with the  $^{123}\text{I}$ -IMP (isopropyl iodoamphetamine) split-dose technique 7–10 days before CAS. In the preoperative SPECT, the degree of side-to-side asymmetry [asymmetry index (AI)] in the middle cerebral artery territory was obtained with the equation:  $\text{AI} = 200 \times (C_{\text{non}} - C_{\text{affect}}) / (C_{\text{non}} + C_{\text{affect}})$ , where  $C_{\text{non}}$  is the mean cerebral blood flow (CBF) on the non-affected side and  $C_{\text{affect}}$  is the mean CBF on the affected side.

Cerebral vasoreactivity (CVR) to an acetazolamide challenge (20 mg/kg) was calculated to evaluate the cerebral hemodynamic reserve as follows:

$$\text{CVR}(\%) = \frac{(\text{Acetazolamide challenge CBF} - \text{Resting CBF}) \times 100}{\text{Resting CBF}}$$

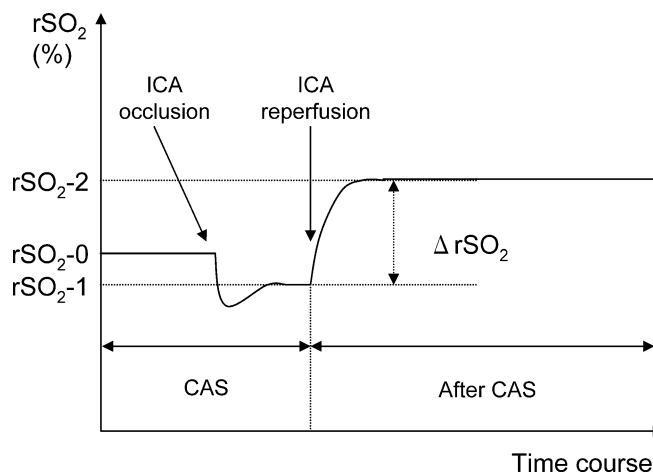
It is reported that the severe asymmetric pattern (higher AI) and poor vasoreactivity (lower CVR) detected by preoperative SPECT are significantly associated with postoperative hyperperfusion [9].

### Monitoring of $\text{rSO}_2$

The probe of the INVOS 3100 was placed on the affected side of the forehead and  $\text{rSO}_2$  was monitored continuously throughout the procedure, including 48 h postoperatively. We measured the baseline  $\text{rSO}_2$  ( $\text{rSO}_2-0$ ), the stable  $\text{rSO}_2$  ( $\text{rSO}_2-1$ ) maintained during temporary occlusion of the ICA, and the highest  $\text{rSO}_2$  ( $\text{rSO}_2-2$ ) after reperfusion (Fig. 1). Moreover, we measured  $\Delta\text{rSO}_2$  (the change from  $\text{rSO}_2-1$  to  $\text{rSO}_2-2$ ), which was the response of  $\text{rSO}_2$  after reperfusion. Results were compared with preoperative AI and CVR.

### Procedural techniques

All patients received supplemental oxygen via a nasal cannula at 2–5 l/min and maintained systemic oxygen



**Fig. 1** Time course of  $\text{rSO}_2$  monitoring by NIRS. We evaluated the baseline  $\text{rSO}_2$  ( $\text{rSO}_2-0$ ) before the procedure, the stable  $\text{rSO}_2$  ( $\text{rSO}_2-1$ ) throughout temporary occlusion of the ICA, and the highest  $\text{rSO}_2$  ( $\text{rSO}_2-2$ ) after reperfusion

saturation of 99%–100%; systolic blood pressure was maintained at 10%–20% higher than the baseline value during CAS to minimize drastic  $\text{rSO}_2$  changes during the procedure. In the operation, transfemoral catheterization was performed under local anesthesia with the patients fully awake. After selective catheterization of the target artery, a seven- to nine-French guide catheter was placed primarily proximal to the stenosis. Under distal protection with a Naviballoon (Kaneka) or Percusurge GuardWire System (Medtronic AVE), a 3.0–3.5-mm balloon catheter was used to cross and predilate the stenosis. Before the balloon inflation in the ICA, patients received 0.5–1.0 mg atropine to inhibit parasympathetic discharge, which could result in significant bradycardia. The stent device was then deployed across the lesion. An angioplasty balloon was used if necessary to post-dilate the stent, and the stent was embedded in the plaque to achieve more than 90% luminal diameter. An aspiration catheter was used to remove the debris from the treated vessel before the balloon was deflated and antegrade flow in the treated vessel was restored. Total ICA occlusion time was within 8–10 min, which is similar to that in a previous report [10].

### Statistical analysis

Data were analyzed by means of the computer software package StatView 5.0 (Abacus Concepts and Statistica 4.1; Statsoft). All parameters are shown as the mean  $\pm$  SD. The correlation between  $\Delta\text{rSO}_2$  and AI or CVR was assessed by linear regression analysis (statistical significance being set at the  $P < 0.05$  level).

## Results

The mean preoperative AI was  $10.3 \pm 1.9$  (range 0–33.3), and CVR was  $38.3 \pm 3.8\%$  (range 0%–80%). Technical success was achieved in all 26 lesions in 24 patients, reducing the initial stenosis of 70%–95% (mean  $91.5 \pm 1.3\%$ ) to 0%–20% (mean  $2.5 \pm 1.0\%$ ). The mean values for  $rSO_2-0$ ,  $rSO_2-1$ ,  $rSO_2-2$  and  $\Delta rSO_2$  were  $70.4 \pm 1.0\%$ ,  $67.4 \pm 1.1\%$ ,  $71.3 \pm 0.9\%$  and  $3.9 \pm 0.7\%$ , respectively. No patient showed symptomatic postoperative complications of much significance. In all the patients, CBF, demonstrated by postoperative SPECT, noticeably recovered after CAS.

### During temporary occlusion of the ICA

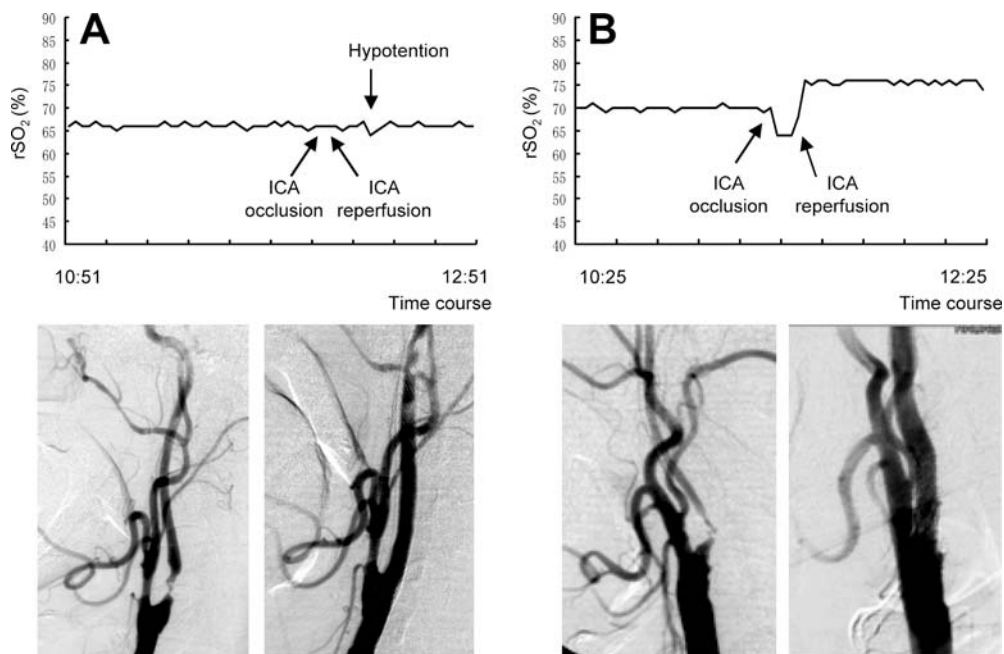
There were two patterns in the changes in  $rSO_2$  during temporary occlusion of the ICA. In 17 cases (71%), the

$rSO_2$  changed little with the ICA occlusion (pattern A; Fig. 2a). In pattern A, preoperative CVR was greater than 20% (mean 45.3%), but in the other seven cases (29%),  $rSO_2$  immediately dropped and did not recover throughout occlusion of the ICA (pattern B; Fig. 2b). In pattern B, preoperative CVR (mean 19.3%) was lower than that in pattern A. Moreover, four patients (including two patients with contralateral occlusions) showed falls in  $rSO_2$  of more than 5% throughout occlusion of the ICA. In these patients, symptoms (transient clouding of consciousness in two, and mild paresis of the contralateral arm in two) occurred 2–3 min after balloon inflation and were tolerated until completion of the procedure in 8–10 min. The symptoms immediately improved after reperfusion. These cases showed poor CVR and high AI on the preoperative SPECT. On the other hand, the rest of the patients with a fall in  $rSO_2$  of 5% within the baseline did not show any neurological symptoms, with CVR and AI readings in their SPECT study being within acceptable limits.

**Fig. 2 a** Continuous monitoring of  $rSO_2$  revealed little change throughout the temporal occlusion of the left ICA ( $rSO_2-1$ ) or after reperfusion ( $rSO_2-2$ ) from the baseline ( $rSO_2-0$ ). A Smart stent (Cordis) deployed at the stenotic portion of the left ICA achieved an increase in luminal caliber, from a pretreatment stenosis of 95% to a residual stenosis of 0%. After CAS, the patient developed transient hypotension due to parasympathetic discharge, which immediately improved. **b** Continuous monitoring of  $rSO_2$  revealed that  $rSO_2$  dropped from the baseline 70% ( $rSO_2-0$ ) to 64% ( $rSO_2-1$ ) immediately after the occlusion of the right ICA and stayed there, then increased to 76% ( $rSO_2-2$ ) after reperfusion. A Palmaz stent (Cordis) deployed at the stenotic portion of the right ICA achieved an increase in luminal caliber from a pretreatment stenosis of 95% to a residual stenosis of 0%

### Post-reperfusion after CAS

The  $rSO_2$  showed a tendency to increase to more than 5% of the baseline value and even throughout the entire 48 postoperative hours after reperfusion in three patients. These patients had also an abnormal CVR (below 20%) on the SPECT study. They were closely monitored and treated with continuous infusion of antihypertensive agents because of the possibility of hyperperfusion. Although no postoperative clinical symptoms were noted after CAS, two of them showed hyperperfusion on



postoperative SPECT (CBF increase of  $>100\%$ ). The rest of the patients did not show hyperperfusion.  $\Delta rSO_2$  was significantly correlated with the AI ( $r^2=0.522$ ,  $P=0.0001$ ) and the CVR ( $r^2=0.414$ ,  $P=0.0004$ ) (Fig. 3).

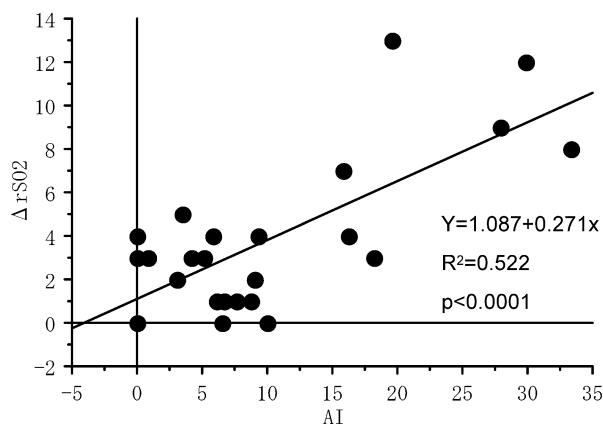
## Discussion

In this report we evaluated the feasibility of real-time measurement of  $rSO_2$  as a monitoring device in CAS. As a result, it is speculated that  $rSO_2$  monitoring would be a reliable method in the setting of CAS.

In our series, variable reduction in  $rSO_2$  was observed during temporary occlusion of the ICA, and all the four patients that showed falls in  $rSO_2$  of more than 5% developed neurological symptoms. It was confirmed that  $rSO_2$  monitoring was useful in detecting cerebral ischemia during CAS. Some authors reported that a fall of greater than 10% from the  $rSO_2$  baseline value was dangerous, but less than 10% was safe [4, 11]. In our series, the critical change in  $rSO_2$  was lower than that in previous reports. It is speculated that these cases are already hemodynamically compromised, and the threshold of  $rSO_2$  against ischemia is relatively low for these cases. Therefore, caution should be exercised, because the possibility of developing ischemic complications with a small decrease in  $rSO_2$  is high in patients with poor CVR. With the availability of filter systems for neuroprotection during CAS, this device may be useful in these cases [10].

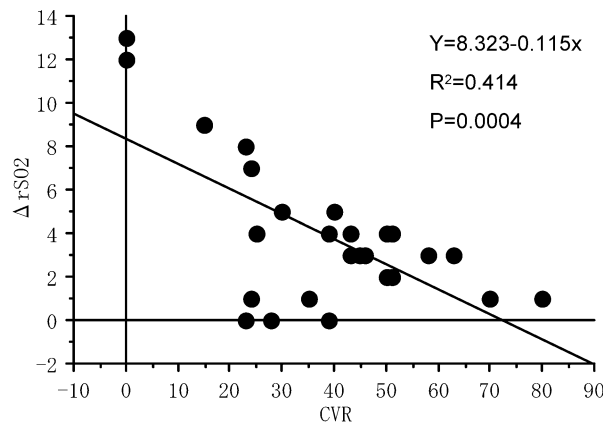
Hyperperfusion syndrome is also an important contributor to perioperative morbidity and mortality associated with CAS [1, 2, 12]. It is also reported that severely impaired cerebral vasoreactivity or a severe asymmetric pattern detected by SPECT is significantly associated with postoperative hyperperfusion [13].

**Fig. 3** Correlation between the  $\Delta rSO_2$  and AI or CVR evaluated by preoperative SPECT (statistical significance was set at the  $P < 0.01$  level)



Our previous study also indicated that the severity of ischemia during arterial occlusion significantly correlated with the magnitude of postischemic hyperperfusion [14]. In this study, CVR below 20% was associated with an overshoot in  $rSO_2$  after reperfusion, and postoperative hyperperfusion as documented by SPECT study. The asymmetrical CBF pattern was also associated with this  $rSO_2$  overshoot, which concurs with findings from studies elsewhere [9]. Based on this preliminary finding, we speculate that the change in  $rSO_2$  is an additional predictive value for the appearance of hyperperfusion. Ogasawara et al. reported that intraoperative  $rSO_2$  monitoring can reliably identify patients at risk for hyperperfusion after CEA [15]. The present study successfully addressed the feasibility of  $rSO_2$  as a new monitoring device in the setting of CAS. Owing to the small sample size in this preliminary study, the outcome of studies from large un-randomized series may give a clue. Nevertheless, our results in CAS were identical with the reports on CEA, and it is suggested that the large change in  $rSO_2$  has the potential to develop postoperative hyperperfusion in CAS [15].

The most significant advantage of cerebral hemodynamics measurement by NIRS is ease of use; placement of the sensor on the forehead is fast and easy, and continuous, real-time data reflecting changes in cerebrovascular hemoglobin saturation appear immediately, but this technique has some limitations. The major disadvantage of  $rSO_2$  is that it can measure only a small, limited area of the frontal cortex, which does not cover all the middle cerebral artery area evaluated by SPECT. Therefore, a discrepancy between the real-time  $rSO_2$  changes and the SPECT hemodynamics may occur in some patients. Given the low spatial resolution of the measurement system, placement over the parietal middle cerebral artery territory might lead to a better agreement between  $rSO_2$  monitoring and SPECT study. However this approach is hampered by the necessity of shaving an area of the patient's head the size of the sensor pad, which will probably not be acceptable to many of the patients undergoing the procedure for investigational



purposes. So understanding this limitation is important for routine utilization of this technique. At present, rSO<sub>2</sub> monitoring is not accepted as a replacement for SPECT in evaluating hemodynamics. However, this technique may prove useful in the evaluation of real-time hemodynamic changes in CAS patients.

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