Monitoring brain oxygen saturation during awake off-pump coronary artery bypass

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Abstract

Objective: To evaluate the changes in cerebral blood flow during awake off-pump coronary artery bypass grafting and compare with the changes during off-pump coronary artery bypass grafting under general anesthesia, using continuous monitoring of regional cerebral oxygen saturation.

Methods: The study population comprised 3 groups of patients who had undergone off-pump coronary artery bypass grafting with thoracic epidural anesthesia, general anesthesia, or a combination of the two. Regional brain oxygen saturation, determined with a near-infrared oxygen monitor, and mean arterial pressure during surgery were calculated and compared among the 3 groups.

Results: Patients who had undergone awake off-pump coronary artery bypass grafting with thoracic epidural anesthesia had a significantly higher cerebrovascular impairment ratio, and the EuroSCORE was high. No significant differences were observed among the 3 groups in terms of the relationship between mean arterial pressure during surgery and regional brain oxygen saturation. It is suggested that there were no differences in cerebral blood flow and mean arterial pressure changes among the 3 groups.

Conclusions: Awake off-pump coronary artery bypass grafting is a safe surgical technique for patients with history of cerebral infarction or impaired cerebral blood flow. Awake off-pump coronary artery bypass grafting is a less invasive procedure that allows efficient management of intraoperative cerebral blood flow, and can be equally effective as a percutaneous coronary intervention.

Keywords

Anesthesia, epidural, cerebrovascular circulation, coronary artery bypass, monitoring, intraoperative, wakefulness

Introduction

Cerebral infarction is one of the serious complications that develop after coronary-bypass graft surgery (CABG). Off-pump coronary artery bypass grafting (OPCAB) is associated with fewer post-surgical cerebral infarctions than conventional CABG.[1-4] This difference is likely because conventional CABG results in thrombi, air embolism, or intraoperative decrease in cerebral blood flow due to cardiopulmonary bypass. The incidence of postoperative cerebral infarction was 0.8-2.4% in OPCAB patients.[1-4] Age and cerebrovascular disease have been associated with the increased risk for postoperative cerebral infarction.[3] Our aim is to further reduce such incidences of postoperative cerebral infarction.

Awake off-pump coronary artery bypass grafting (AOCAB) is a novel intraoperative or perioperative management technique introduced by Karagoz, et al. in 2000.[5] We have also performed AOCAB under thoracic epidural anesthesia (TEA) in such high-risk patients with a history of cerebral infarction or impaired cerebral blood flow or severe pulmonary dysfunction since 2003.[6] In AOCAB, general anesthesia or tracheal intubation are unnecessary because spontaneous breathing can be maintained by high TEA alone. Thus cerebrovascular data can be collected from conscious patients that enables effective monitoring.[7] Hence, it has been anticipated that AOCAB can be performed in high-risk patients with a history of cerebral infarction, impaired cerebral blood flow detected during preoperative examination, or lower respiratory function. However, there has been no report on data of cerebral blood flow during AOCAB with comparison between AOCAB and OPCAB.

In the present study, we evaluated the changes in cerebral blood flow during AOCAB in comparison with the changes during OPCAB using continuous monitoring of the regional cerebral oxygen saturation (rSO_2).

Patients and Methods

This study was approved by the Kanazawa University Hospital Research Ethics Committee, and informed consent was obtained from all patients. Twenty-one patients were enrolled in this prospective, nonrandomized study. The patients were divided into the following 3 groups: 7 patients who underwent AOCAB under epidural anesthesia alone (Group A), 7 patients who underwent OPCAB with a combination of general and epidural anesthesia (Group B), and 7 patients who underwent OPCAB under general anesthesia alone (Group C). Group A is a high-risk group, which comprised of patients who had history of cerebral infarction or impaired cerebral blood flow determined during preoperative examination. All patients underwent a color Doppler ultrasound study of the carotid arteries prior to surgery. If the patient had a history of carotid stenosis of 50% or more, they were divided into Group A. The patients of Group B and Group C do not have a history of cerebral infarction or impaired cerebral blood flow determined during preoperative examination. The patients of Group A and Group B did not receive preoperative anticoagulants and antiplatelets therapy (<1 week). The patients in Group C had required anticoagulant therapy before the surgery for unstable angina pectoris.

Anesthesia

On the day before the surgery, a thoracic epidural catheter was inserted at the T1-2 or T2-3 level in Group A and B patients by anesthesiologists in the operating room. We performed peridurography to confirm that the catheter was inserted in the epidural space. Continuous infusion of a mixture of 2% lidocaine (40 ml) and fentanyl (250 μg) was initiated in the operating room on the day of surgery. For Group A patients, we began the AOCAB procedure after they had paralysis of the intercostal muscles, and after confirming the loss of cold/pain sensation in the appropriate areas and abdominal breathing. Group B patients were administered 1–1.5% sevoflurane and continuously infused with a mixture of 2% lidocaine (40 ml) and fentanyl (250 μg) via the epidural catheter. An epidural catheter was not inserted in Group C patients because they had received anticoagulants; the patients inhaled 1.5–2% sevoflurane and received intravenous fentanyl during OPCAB.

Evaluation of patients' background

Table 1 shows patients' characteristics to compare the background of the patients. We used Euro SCORE (European System for Cardiac Operative Risk Evaluation) II for a predictive index of the operation risk of the patients. Euro SCORE II is a risk model which allows the calculation of the risk of death after a heart operation. The model asks for 17 items of information about the patient, the state of the heart and the proposed operation, and uses logistic regression to calculate the risk of death.[8]

Cerebral saturation monitoring measurement

During surgery, we monitored cerebral blood flow with a near-infrared oxygen monitor (NIRO-300; Hamamatsu Photonics KK, Hamamatsu, Japan) and determined the rSO_2. This device transcranially measures tissue oxygenation index by using a near-infrared spectrometer. This index is evaluated by the ratio of oxygenated hemoglobin to the total hemoglobin in the tissue and is expressed as a percentage. This value was measured every 5 seconds before inducing anesthesia and until the completion of the surgery by attaching a probe to the patient's forehead. The mean tissue oxygenation was calculated and compared among the 3 groups at the following points: before anesthesia; after anesthesia; and at the time of anastomosis to the left anterior descending artery, left circumflex artery, or right coronary artery.

Evaluation of serous S-100β

S-100β is released into the cerebrospinal fluid upon damage to the cranial nerve system or into the blood stream upon disruption of blood-brain barrier; therefore, S-100β has been reported to be a possible indicator of cranial nerve impairment.[9] We measured serous S-100β levels by enzyme-linked immunosorbent assay (ELISA) (YK150 Human S-100β ELISA kit, Fujinomiya, JAPAN) before surgery, in the ward immediately after surgery, and 1 and 3 days after surgery, and compared the levels among the 3 groups.

Hemodynamic assessment

We measured the heart rate (HR) and mean arterial pressure (MAP) during surgery by inserting a catheter into the radial artery, determined pulmonary artery pressure and the central venous pressure (CVP) by inserting a pulmonary artery catheter through the right internal jugular vein. HR and MAP, pulmonary artery pressure, CVP were also calculated and compared among the 3 groups before anesthesia; after anesthesia; and at the time of anastomosis to the left anterior descending artery, left circumflex artery, or right circumflex artery. Intravenous methoxamine hydrochloride was mainly administered in patients with decreased blood pressure during the surgery to keep MAP at least over 50 mmHg.

Statistical analysis

Data are expressed as mean ± standard deviation. Statistical analysis was performed with the Statistical Package for the Social Sciences software (SPSS, Chicago, IL, USA). Multiple comparisons were made by using Fisher's exact test and the Steel-Dwass test. The level of significance was $p < 0.05$.

Results

The patient characteristics and operative data are shown in Table 2. In Group A, the ratio of the

cerebrovascular impairment and Euro SCORE II were significantly high, therefore Group A is a significant high-risk group. No statistically significant differences were noted among the groups with mean age, gender, weight, body surface area, hypertention, diabetes, myocardial infarction, or ejection fraction. None of the patients developed a new cerebral infarction or died in the perioperative stage. No patient in Group A was converted to general anesthesia. Because patients became verbose, irritable, or their level of consciousness decreased when MAP decreased to 50mmHg or less, we administered vasopressor at real time and maintained normalized consciousness. There were no significant differences in terms of the amount of methoxamine hydrochloride used among 3 groups.

In Table 3, HR, MAP, pulmonary artery pressure, CVP, and rSO_2 before and after anesthesia and according to the anastomosis location are shown. Preanesthetic HR was significantly higher in Group C than in other groups, but there were no significant differences in any other parameters. There were no significant differences in hemodynamics during surgery among the 3 groups.

The correlation between rSO_2 and MAP among the 3 groups is shown in scattergrams (Figures 1, 2). At MAP 60 mmHg and above, rSO_2 was approximately constant regardless of MAP and no significant relationship was observed between MAP and rSO_2 during surgery in all 3 groups (Figure 1). Thus at MAP 60 mmHg and above, autoregulation was similarly maintained in all 3 groups (Figure 2).

At MAP less than 60mmHg, rSO_2 had an approximately direct proportional relation with MAP, and no significant differences in relationship were observed between MAP and rSO_2 during surgery among all 3 groups.

Although serous levels of S-100β were evaluated, no significant differences among the groups were observed (Table 4).

Discussion

In the present study, it was possible to prove the relationship between MAP and cerebral blood flow during AOCAB by evaluating intra-operative cerebral blood flow using rSO_2 as an index. In AOCAB, cerebral blood flow is maintained by autoregulation at MAP≥60mmHg. However, symptoms due to decreased level of cerebral blood flow were observed at MAP≤50mmHg. Comparing OPCAB with AOCAB, though patients of Group B and C had no history of impaired cerebral blood flow, cerebral blood flow was maintained by autoregulation at MAP≥60mmHg but autoregulation was lost at MAP<60mmHg, and as with AOCAB, the level of cerebral blood flow decreased as MAP decreased. When MAP decreased during AOCAB, considering also the necessity to maintain consciousness, by using a vasopressor we were able to successfully perform the surgery without converting to general anesthesia.

Cerebral autoregulation can maintain normal cerebral blood flow at an average pressure of 60-150mmHg.[10] Once out of that range, autoregulation does not function, and cerebral blood flow cannot be maintained. It has been suggested that an overly decreased level of cerebral blood flow can trigger cerebral infarction. According to our data, whether patients underwent surgery with epidural anesthesia, general anesthesia employing sevoflurane, which is said to increase cerebral blood flow [11], or a combination of the two, the level of cerebral blood flow decreased as MAP decreased. Even in OPCAB which is performed without using cardiopulmonary bypass, MAP remains under 50mmHg, causing the level of cerebral blood flow to remain low. This condition may be one of the reasons for incidences of cerebral infarction associated with OPCAB. Measuring cerebral blood flow using a near-infrared oxygen monitor is easy and quick. In AOCAB, by measuring cerebral blood flow and

being aware of the patient's level of consciousness, impaired cerebral blood flow can be immediately detected and treated. AOCAB is a useful method for lowering incidences of cerebral infarction and maintaining patient QOL. It is also a promising ultra-minimally invasive method for high-risk patients with impaired cerebral blood flow.

Recently, several major thoracic procedures performed in awake patients have been reported.[5-7] In order to reduce the adverse effects of general anesthesia and the cost, TEA has been employed to perform such awake thoracic surgery procedures. AOCAB is a novel intraoperative or perioperative management technique. This surgical method opens the door to surgical treatment for high-risk patients with serious diseases in whom general anesthesia is difficult, as well as allowing patients who opt for early recovery to return to normal living shortly after surgery with markedly improved QOL. AOCAB has other advantages compared to OPCAB. We have reported that the hypercoagulable state at 5 days after the operation was suggested in the OPCAB group, but not in those in the AOCAB group.[12] We also demonstrated [13] that AOCAB reduces incidences of postoperative atrial fibrillation due to its inhibition of sympathetic activity without inhibiting vagal activity which causes antiarrythmic effects. This study suggests that reduced incidences of postoperative atrial fibrillation in AOCAB are due to the effect of TEA. However, in the present study, the changes in the cerebral blood flow were almost equivalent among the 3 groups; suggesting that TEA had hardly any influence.

Continuous monitoring of rSO_2 is possible by attaching a probe to the patient's forehead. Near-infrared spectrometry and bispectral index are non-invasive methods to evaluate cerebral blood flow.[14] This method that we used is simple, non-invasive, and can be achieved at real-time; therefore,

rSO_2 is measured during open heart surgery.[15,16] In the present study, rSO_2 changed quickly with mean blood pressure, especially when the heart was displaced. During anastomosis of the left circumflex artery, both the mean blood pressure and rSO_2 decreased. However, since the rSO_2 probe can only be attached to the forehead, the area that can be monitored is limited to that perfused by the anterior cerebral artery. Therefore, it is necessary to develop a probe that allows monitoring of other areas.

S-100 protein is a neural specific protein that can bind calcium. The S-100 protein consists of 2 subunits: α and β chains. The β-chain subunit is present in the glial cells or Schwann cells. S-100β can be a good indicator of cerebrovascular impairment because the blood level of S-100β increases after a cerebral event.[17,18] However, in our study, no patients experienced cerebrovascular impairment after surgery, and most likely due to this result, there were no significant differences in the S-100β levels among the 3 groups.

This trial had several limitations to compare AOCAB and OPCAB. First of all, the background of the three groups highly differ. All patients with impaired cerebral blood flow were enrolled in Group A. It is necessary to conduct a study of matching patients, however, this limitation is a result of our view that, when it is possible to apply epidural anesthesia, it is more effective to perform AOCAB for patients with impaired cerebral blood flow. Also, the size of the groups must be increased for a more refined study. In the future, a randomized study should be conducted with larger groups of matching patients.

Conclusion

We evaluated cerebral blood flow by using near-infrared oxygen monitor during AOCAB. Though Group A included extremely high-risk patients, there were no significant differences in cerebral blood flow compared to the other 2 groups. AOCAB was a safe surgical technique for the patients with a history of cerebral infarction or impaired cerebral blood flow. AOCAB is a less invasive operative procedure that allows efficient management of intraoperative cerebral blood flow and can be equally effective as percutaneous coronary intervention.

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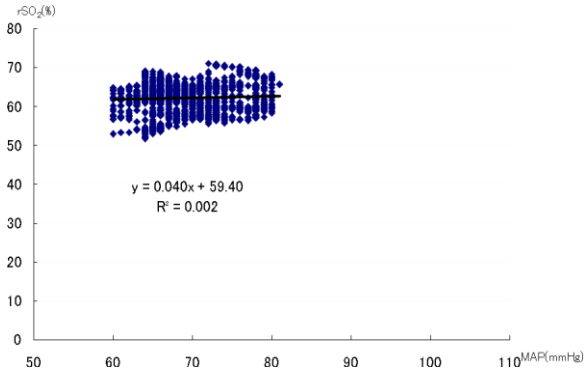

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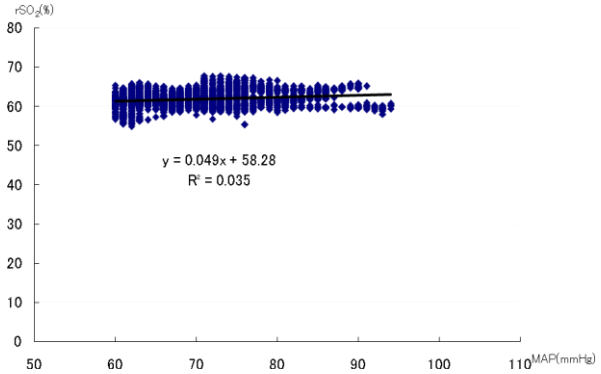

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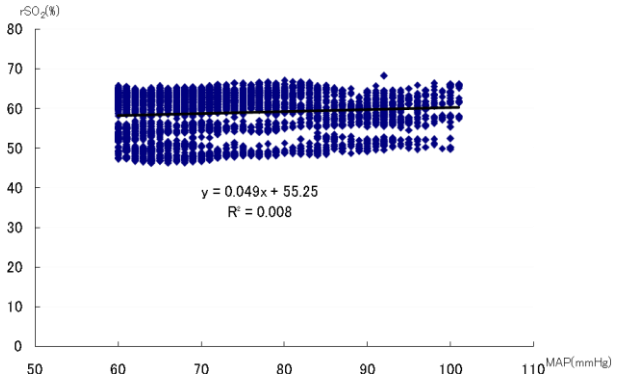
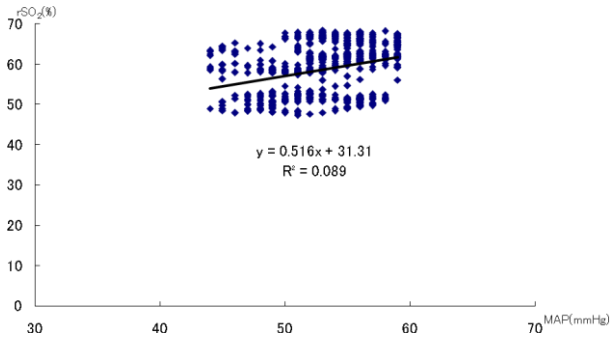


c)

FIGURE 1. Relationship between rSO_2 and MAP 60 mmHg and above, a) in Group A, b) in Group B, c) in Group C

MAP: mean arterial pressure, rSO_2: regional brain oxygen saturation



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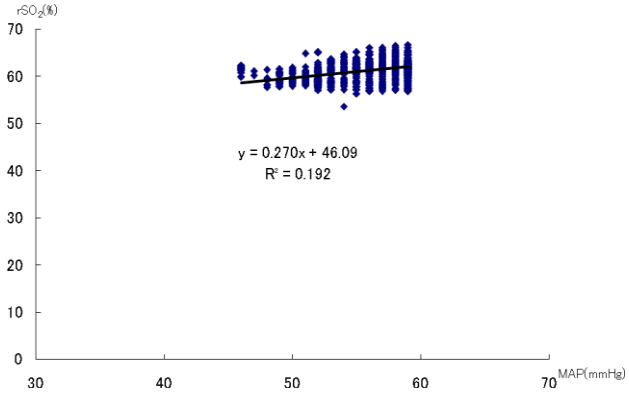

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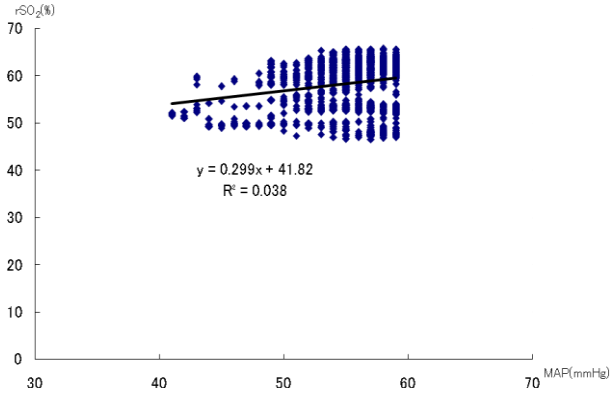

c)

FIGURE 2. Relationship between rSO_2 and MAP less than 60 mmHg, a) in Group A, b) in Group B,

c) in Group C

MAP: mean arterial pressure, rSO_2: regional brain oxygen saturation

TABLE 1. Patient characteristics and operative data

	Group A (n = 7)	Group B (n = 7)	Group C (n = 7)	p Value
Age (y)	66.4 ± 8.4	68.0 ± 13.7	63.0 ± 7.9	0.62
Male	6	6	6	1
Weight (kg)	57.5 ± 11.1	57.6 ± 7.8	55.9 ± 8.9	0.87
Body surface area (m^2)	1.58 ± 0.1	1.59 ± 0.1	1.53 ± 0.1	0.61
Cerebral infarction or Cerebrovascular impairment	7	0	0	<0.01
Hypertension	3	4	3	0.82
Diabetes	7	5	4	0.29
Hyperlipidemia	1	4	1	0.26
Myocardial infarction	3	2	3	0.81
Ejection fraction (%)	61.0 ± 16	60.6 ± 14.6	50.3 ± 6.6	0.55
Euro SCORE II (%)	1.33±0.49	0.83±0.41	0.63±0.10	<0.01

TABLE 2. Operative data

	Group A	Group B	Group C	p Value
Operation time (min)	195.5 ± 72.2	245 ± 55.3	232.1 ± 745.5	0.53
Number of distal anastomosis	2.2 ± 1.1	2.8 ± 0.6	2.6 ± 0.7	0.33
Methoxamine hydrochloride (mg)	2.8 ± 2.8	9.0 ± 7.1	4.0 ± 3.0	0.25
Operation end - extubates time (min)	0	25.7±6.71	22.8±2.7	<0.01
New cerebral infarction	0	0	0	1
Perioperative death	0	0	0	1

TABLE 3. Mean values of patient parameters pre- and post-anesthesia and at each anastomosis region

		Group A	Group B	Group C	p Value
	Pre-anesthesia	65.7 ± 6.6	73.8 ± 1.5	80.2 ± 7.2	0.04
	Post-anesthesia	68.4 ± 3.9	58.7 ± 6.4	68.7 ± 14.4	0.30
Heart rate (/min)	LAD	67.8 ± 5.1	63.5 ± 8.2	66.5 ± 10.5	0.53
	LCX	58.6 ± 4.9	66.4 ± 5.6	73.6 ± 14.4	0.17
	RCA	68.3 ± 8.9	72.2 ± 4.9	58.8 ± 5.0	0.11
	Pre-anesthesia	82.7 ± 17	114 ± 14	80.7 ± 15	0.27
	Post-anesthesia	71.1 ± 15	69.4 ± 12.9	78.5 ± 16.9	0.50
MAP (mmHg)	LAD	60.6 ± 7.2	61.6 ± 7.0	63.7 ± 6.0	0.58
	LCX	54.4 ± 2.1	60.2 ± 9.0	57.6 ± 4.9	0.26
	RCA	61.1 ± 12.4	61.5 ± 9.3	56.5 ± 4.6	0.51
	Pre-anesthesia	19.5 ± 4.4	18.6 ± 1.9	22.8 ± 9.2	0.43
	Post-anesthesia	19.7 ± 3.3	17.2 ± 3.1	23.7 ± 7.9	0.16
MPAP (mmHg)	LAD	21 ± 4.7	19.5 ± 3.6	20.5 ± 4.4	0.66
	LCX	16.2 ± 0.8	21.3 ± 4.3	21.5 ± 2.7	0.61
	RCA	22.9 ± 6.2	21.7 ± 4.2	17.3 ± 0.9	0.25
	Pre-anesthesia	6 ± 2.9	5.4 ± 1.1	4.3 ± 3.4	0.46
	Post-anesthesia	8.4 ± 4.1	8.5 ± 0.8	8.7 ± 2.7	0.89
CVP (mmHg)	LAD	7.7 ± 6.1	10.4 ± 3.7	6.9 ± 2.2	0.36
	LCX	9.9 ± 0.4	10.3 ± 3.4	13.1 ± 3.7	0.33
	RCA	8.2 ± 3.6	13.1 ± 3.2	11.5 ± 0.1	0.17
	Pre-anesthesia	63.2 ± 3.1	65.1 ± 4.1	61.6 ± 2.8	0.25
	Post-anesthesia	63.9 ± 4.3	64.2 ± 4.3	62.3 ± 4.7	0.34
rSO_2 (%)	LAD	62.8 ± 6.4	63.5 ± 4.3	59.3 ± 5.0	0.40
	LCX	61.8 ± 0.4	62.1 ± 3.7	59.0 ± 4.0	0.37
	RCA	62.9 ± 2.6	63.0 ± 4.3	58.9 ± 2.6	0.34

LAD: left anterior descending artery, LCX: left circumflex artery, MAP: mean arterial pressure, MPAP: mean pulmonary artery pressure, RCA: right coronary artery

TABLE 4. Changes in the serous levels of S-100β (ng/ml)

	Group A	Group B	Group C	p Value
Before surgery	0.15 ± 0.03	0.15± 0.05	0.14 ±0.02	0.73
Immediately after surgery	1.13 ± 0.13	1.39 ± 0.13	1.40 ± 0.15	0.38
1 day after the operation	0.65 ± 0.12	0.48 ± 0.14	0.51 ± 0.14	0.45
3 days after the operation	0.22 ± 0.08	0.24 ± 0.05	0.23 ± 0.08	0.70