Changes in jugular bulb oxygen saturation during off-pump coronary artery bypass graft surgery

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ABSTRACT

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Background: The effect of hemodynamic derangement during coronary artery anastomosis in off pump coronary artery bypass surgery (OPCAB) on cerebral blood flow (CBF) has not been elucidated. Jugular bulb oxygen saturation ($SjvO_2$) is a useful indicator of CBF provided that cerebral metabolic rate is constant. This study was designed to evaluate the changes in $SjvO_2$ during OPCAB.

Methods: With IRB approval, 48 patients were included. After anesthesia, an 18 G catheter was introduced into the jugular bulb. Hemodynamic variables and oxygen profiles from gas analysis of jugular bulb blood and arterial blood were obtained: after sternotomy(baseline); at 5 min after the beginning of the anastomosis of the left anterior descending artery (LAD), obtuse marginal artery (OM), and posterior descending artery (PDA); and after sternal closure.

Results: Cardiac index and mixed venous oxygen saturation decreased significantly during the anastomosis of the LAD, OM and PDA compared to the baseline value. Although the changes in $SjvO_2$ during the anastomosis of the LAD, OM and PDA were statistically significant compared to its baseline value, $SjvO_2$ remained within normal limit throughout the study.

Conclusions: $SjvO_{2,}$ which represents the global cerebral oxygenation, was well maintained during the anastomosis of all coronary arteries despite significant hemodynamic changes during OPCAB.

Key Words: surgery, off-pump coronary artery bypass; monitoring, jugular bulb oxygen saturation

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I. INTRODUCTION

Cerebral injury is a major complication following coronary artery surgery.[1,2] Off pump coronary artery bypass (OPCAB) surgery has become popular over the past decade since cardiopulmonary bypass (CPB) is known to be associated with neurologic dysfunction.[3,4] Although there are several reports of favorable cerebral outcome following OPCAB,[5,6] the beneficial effects of OPCAB on cerebral function is still controversial.[7,8] During OPCAB, manipulation of the heart to expose the graft site induces hemodynamic instability, which might compromise cerebral perfusion.[7,9]

Jugular bulb oxygen saturation ($SjvO_2$) is a useful indicator of cerebral blood flow (CBF) provided that cerebral metabolic rate (CMR) is constant since it theoretically reflects the relationship between global cerebral oxygen supply and global cerebral oxygen demand.[10]

The aim of this study was to evaluate the changes in CBF occurring during OPCAB using $SjvO_2$.

II. METHODS

With institutional review board approval, 48 patients undergoing OPCAB surgery were included after having obtained written informed consent.

All patients were premedicated with intramuscular injection of morphine 0.05-0.1 mg/kg. In the operating theatre, 5 ECG leads were attached and leads II and V_5 were continuously monitored. A 20-G radial artery catheter was inserted to measure arterial blood pressure and arterial blood gas. A thermodilutional pulmonary artery catheter (Swan-Ganz CCOmbo/SvO_2 Model 744HF75, Baxter Healthcare Corp., Irvine, CA, USA) for continuous cardiac output (CO) and mixed venous oxygen saturation (SvO_2) monitoring was inserted in the right internal jugular vein via a 9.0-Fr introducer (AVA HF, Baxter Healthcare Corp., Irvine, CA, USA). Anesthesia was induced with midazolam 2.0-3.0 mg, sufentanil 1.0-1.5 μg/kg, and rocuronium 50 mg. Anesthesia was maintained with continuous infusion of sufentanil (0.2-0.3 μg/kg/ h), rocuronium (20-30 mg/h) and isoflurane (under 0.5 %) in oxygen (50%) with air. For $SjvO_2$ measurement, an 18-G central venous catheter was inserted into the left internal jugular vein in the cephalad direction via modified Sheldinger technique until resistance was sensed at the jugular bulb. The catheter was withdrawn about 3-5 mm from the resistant position. The positioning of the jugular bulb catheter tip was verified by radiograph. The correctly positioned catheter tip should lie cranial to a line extending from the atlanto-occipital joint space and caudal to the lower margin of the orbit. Samples of jugular bulb blood were drawn at a rate of 1 ml/min. After the induction of anesthesia, mechanical ventilation was controlled to maintain normocarbia according to end tidal carbon dioxide ($ETCO_2$) concentration of 33-35mmHg. Arterial oxygen saturation (SaO_2), end-expiratory isoflurane concentration (ET-Isof), nasopharyngeal temperature (NT) and rectal temperature (RT) were monitored continuously. The depth of anesthesia was monitored with bispectral index score (BIS) monitor (A-200 BIS monitor, Aspect Medical System Inc., Newton, MA, USA). Transesophageal echocardiography was used to monitor left ventricular function, using the transgastric short-axis view at the mid-papillary level. The two, four, and five-chamber view were monitored when the images were difficult to obtain while the heart was displaced for anastomoses. In order to maintain normothermia, the temperature in the operation theatre was kept above 21°C, intravenous fluid was warmed, and a humidifier was attached to the inspiratory limb of the ventilator. Forced-air warming was applied after the veins had been harvested.

Heparin 1.0 mg/kg was given after dissection of the internal mammary artery, and an activated clotting time over 250 sec was maintained during coronary anastomoses. A pericardial suture was placed between the left and right pulmonary veins in the posterior aspect of the pericardial reflection, and a 2-cm-wide tape was attached to elevate the apex of the heart in order to expose the lateral wall. To expose individual coronary arteries, the heart was stabilized with a tissue stabilizer (Octopus Tissue Stabilization System, Medtronic, Minneapolis, MN, USA).

The same surgeon performed all the operations. Norepinephrine 0.03-0.05 μg/kg/min was given as required if mean arterial pressure (MAP) fell below 60 mm Hg. Coronary anastomoses were performed on confirmation of hemodynamic stability, and a coronary artery shunt (Guidant Axius Coronary Shunt, Guidant co., Santa Clara, CA, USA) was inserted during the anastomosis of the left anterior descending artery (LAD) and posterior descending artery (PDA). CPB was started under the following conditions: MAP below 50 mm Hg unresponsive to volume loading and drug therapy; ventricular fibrillation unresponsive to cardioversion; progressive ST segment change or elevation of mean pulmonary artery pressure (MPAP) during positioning and stabilization of the heart; and severe abnormal ventricular wall motion suggestive of myocardial ischaemia.

Physiologic variables were measured after the sternotomy (baseline), at 5 min after the application of the tissue stabilizer on the LAD (n=47), obtuse marginal artery (OM, n=43), and PDA (n=37), and after the sternal closure. Partial pressure of oxygen and carbon dioxide (PaO_2 and $PaCO_2$, respectively) of arterial blood as well as partial pressure of oxygen and oxygen saturation of jugular venous blood were analyzed using Stat Profile Ultima

(NOVA Biomedical Co., Boston, Massachusetts, USA). Using above oxygen profile, arterial oxygen content (CaO_2), jugular venous oxygen content ($CjvO_2$), the difference in oxygen content between arterial and jugular venous blood ($AjvDO_2$), and cerebral oxygen extraction ratio (OER) were calculated according to standard formulae. At the same time, hemoglobin (Hb), ET-Isof, BIS, NT, RT and the hemodynamic variables such as CO, SvO_2, heart rate (HR), MAP, MPAP, and central venous pressure (CVP) were recorded. Using above hemodynamic variables, cerebral perfusion pressure (CPP), cardiac index (CI), systemic and pulmonary vascular resistance indices (SVRI and PVRI, respectively) and stroke volume index (SVI) were calculated according to standard formulae.

Data were analyzed with SPSS (version 10.0, SPSS Inc., Chicago, IL, USA) and expressed as mean (standard deviation). Fisher's exact test was used to compare the percentage of the patient with low $SjvO_2$ (< 55%) at each measuring time. Repeated measures of ANOVA were used to determine if differences exist between values at baseline and values at each coronary artery anastomosis. Unpaired t-test was used to compare the cerebral oxygenation profile between patients with and without history of hypertension and diabetes mellitus. A P value of less than 0.05 was considered statistically significant.

III. RESULTS

The patient characteristics are summarized in Table 1. About 50% of the patients had either diabetes mellitus and/or hypertension. Twenty percent of the patients had cerebrovascular disease or peripheral vascular disease. All patients were discharged from intensive care unit without any neurobehavioral complication. The mean length of the catheter from the skin to the jugular bulb was 15.2 (range, 13.0-18.0) cm.

Table 1. Patient characteristics

	Mean (SD) or number (%)	Range
Age (Year)	60.8 (8.6)	41-78
Sex (male/female)	39/9	
Body surface area (m^2)	1.74 (0.16)	1.38-2.13
Diabetes mellitus (n)	22 (46)	
Hypertension (n)	25 (52)	
Stroke history (n)	5 (10)	
Vascular disease (n)	5 (10)	
Left ventricular ejection fraction (%)	57.02 (14.5)	25-80

The hemodynamic variables during the anastomosis of the coronary arteries are summarized in Table 2. MAP and mean PAP were maintained constant during the anastomosis. During the anastomosis of LAD, OM, and PDA, decrease in CI (all P <0.001) and SvO_2 (all P <0.001) were significant compared to the baseline value.

Table 2. Hemodynamic variables during five periods

	Sternotomy	Coronary artery anastomosis			Sternal closure
		LAD	OM	PDA	
SvO_2 (%)	85.9 (3.2)	78.5 (5.3)[a]	72.9 (7.2)[a]	73.2 (7.3)[a]	82.3 (4.4)[a]
CI (L/min/m^2)	3.4 (0.7)	2.7 (0.6)[a]	2.3 (0.6)[a]	2.5 (0.6)[a]	3.3 (0.7)
HR (beats/min)	68.5 (10.8)	69.5 (12.1)	68.2 (12.8)	71.4 (12.1)[b]	75.8 (12.4)[a]
CVP (mmHg)	8.1 (2.5)	11.2 (2.9)[a]	9.8 (4.1)[c]	13.5 (3.0)[a]	9.8 (2.6)[a]
MAP (mmHg)	76.9 (8.5)	79.2 (8.0)	77.1 (7.3)	76.3 (8.5)	82.7 (12.3)[c]
MPAP (mmHg)	21.1 (5.9)	23.4 (6.6)[c]	19.8 (5.5)	22.6 (5.5)	20.7 (4.6)
SVRI (dyns·sec·cm^{-5}·m^2)	1678 (394)	2110 (509)[a]	2526 (704)[a]	2150 (549)[a]	1869 (602)[c]

Values are expressed as mean (standard deviation). [a]$P < 0.001$, [b]$P < 0.01$, [c]$P < 0.05$ compared with Y-graft.

The cerebral oxygen profiles and related factors are listed in Table 3. $PaCO_2$ and body temperature were maintained in normal range throughout the study period. Although the change in $SjvO_2$ was statistically significant compared to that of baseline value during the anastomosis of LAD, OM, and PDA (all P <0.001), values of $SjvO_2$ were within normal range during all coronary anastomosis. The difference in the number of the patients with $SjvO_2$ less than 55% in each period was not significant (n = 6, 3, and 2 at LAD, OM, and PDA anastomosis, respectively). $AjvDO_2$ was maintained within normal range and their changes during the anastomosis of all three coronary arteries were not statistically significant.

The differences in cerebral oxygenation profile between the patients with and without diabetes mellitus, and between with and without hypertension were not statistically significant. In 10 patients with cerebrovascular disease history or vascular disease, 3 of them (30%) had decreased $SjvO_2$ below 55% where only 6 out of 38 patients (16%) without the history had decreased $SjvO_2$ below 55%.

Table 3. Cerebral oxygen profiles and related factors during five periods

	Sternotomy	Coronary artery anastomosis			Sternal closure
		LAD	OM	PDA	
$SjvO_2$ (%)	66.0 (6.9)	63.0 (6.7)[a]	63.3 (6.7)[a]	62.6 (5.6)[a]	65.8 (6.8)
CaO_2 (ml/dl)	15.1 (2.4)	14.8 (2.2)	14.6 (2.1)[c]	14.5 (2.3)	14.1 (1.7)[b]
$CjvO_2$ (ml/dl)	9.5 (1.6)	9.3 (1.8)[c]	9.2 (1.7)[c]	9.0 (1.8)[c]	9.0 (1.6)[c]
$AjvDO_2$ (ml/dl)	5.4 (1.5)	5.8 (1.2)	5.8 (1.6)	5.7 (1.2)	5.1 (1.3)
OER (%)	33.9 (7.7)	35.4 (7.1)[b]	35.4 (8.2)[c]	36.0 (5.6)[b]	32.3 (9.2)
$PaCO_2$ (mmHg)	35.2 (2.8)	34.8 (2.5)	34.8 (2.4)	34.5 (2.2)	35.7 (3.1)
CPP (mmHg)	69.1 (8.6)	68.5 (8.5)	67.6 (8.7)	63.0 (7.9)[a]	73.3 (12.6)
Hb (g/dl)	10.3 (1.5)	10.1 (1.6)	10.0 (1.5)[c]	9.9 (1.6)	9.6 (1.2)[b]
NT (^{o}C)	35.8 (0.6)	35.8 (0.6)	35.8 (0.6)	35.9 (0.7)[c]	36.1 (0.7)[a]

Values are expressed as mean (standard deviation). [a]$P < 0.001$, [b]$P < 0.01$, [c]$P < 0.05$ compared with Y-graft.

IV. DISCUSSION

When $SjvO_2$ was monitored during OPCAB with intermittent blood gas analysis, $SjvO_2$ was maintained within normal range regardless of the changes in hemodynamic variables during OPCAB, even though the changes in $SjvO_2$ during the anastomosis was statistically significant compared to the baseline value. $SjvO_2$ remained over 60% during all coronary artery anastomosis in most patients, which reflects the adequacy of the cerebral perfusion. In several patients, $SjvO_2$ decreased at one or two measuring time but no definite neurologic complication was found after the surgery.

OPCAB has become a popular method of coronary revascularization in these days since it is reported to have less morbidity including cerebral dysfunction compared to coronary artery bypass surgery under CPB.[5,6] But the effect of hemodynamic derangement occurring during positioning of the heart to expose anastomosis site on cerebral perfusion is not known. For example, steep trendelenburg position to expose the posterior side of the heat elevates the jugular venous pressure, compromising CBF independent of whether an otherwise acceptable MAP is maintained.[7] And also, significant decrease in CO, whether due to arrhythmias, dislocation of the heart, subclinical ischemia, or some combination of these, may significantly compromise blood flow to the brain.[7,9]

In recent studies on cardiac surgery, $SjvO_2$ was used to assess cerebral oxygenation in anesthetized patients.[10-12] Since $SjvO_2$ theoretically reflects the relationship between global cerebral oxygen supply and demand, it is a useful indicator of CBF provided that CMR is constant.[13,14] Although there is debate as to what the normal range of $SjvO_2$ is, most authorities assume 50-54% to be the lower limit of normal and 75% the upper normal.[13-15] In this study, $SjvO_2$ in 1 patient was below 50% (49.5%) during the anastomosis of OM, which represents mild cerebral hypoxia, but no neurological complication has developed after the surgery. $AjvDO_2$ represents the balance between $CMRO_2$ and CBF more accurately. Normally, $AjvDO_2$ is stable at 4-8 ml O_2 /100 ml blood and if $CMRO_2$ remains constant, it also should reflect changes in CBF.[15,16] In this study, $AjvDO_2$ was maintained within normal range and the change during the anastomosis was not statistically significant. However, since $SjvO_2$ was not continuously monitored in this study it is possible that the incidence of patients with low $SjvO_2$ less than 55% was higher during the anastomosis.

There are several studies about the factors affecting $SjvO_2$ and cerebral autoregulation during CPB.[11,13,16-18] They conclude that Hb, temperature, pH, and $PaCO_2$ are the factors correlated with $SjvO_2$ during CPB. Above factors were controlled in this study. Others have mentioned on the influence of MAP or CPP in $SjvO_2$ but they concluded that the increase in $SjvO_2$ following the increase in MAP or CPP was probably due to impaired autoregulation during CPB.[19,20] Three patients, 1 during OM anastomosis and 2 patients during PDA anastomosis, in this study showed CPP below 50 mm Hg but $SjvO_2$ was maintained above 55% in those patients. Anesthesia can affect cerebral metabolism as well as the caliber of the cerebral vasculature. In this study, a large dose of sufentanil was combined with isoflurane less than 0.4% to maintain anesthesia and BIS values were kept between 50 and 60 during the surgery. Although BIS does not surrogate cerebral metabolism rate, it indicates a moderate degree of anesthetic depth. High dose of sufentanil has been known to preserve the coupling between CBF and CMR, and maintain the cerebrovascular response to CO_2.[21] In addition, since isoflurane anesthesia is reported to cause no significant changes in CBF less than 1.5 minimum alveolar concentration (MAC) in animal studies,[22] the effect of anesthetics used in this study on the coupling of CBF and CMR is probably low. It has been known that the flow-pressure autoregulatory curve of CBF is shifted rightward in hypertensive patients and normal coupling of CBF and $CMRO_2$ is disrupted in patients with diabetes mellitus, especially during CPB.[23,24] Therefore, it is possible that both factors have affected the changes in $SjvO_2$ during the anastomosis of coronary arteries. However, there was no significant difference in $SjvO_2$ between patients with and without hypertension or diabetes mellitus. The number of patients with $SjvO_2$ less than 55% during anastomosis between patients with and without hypertension or diabetes mellitus was not significantly different either. During OPCAB, hypertension or diabetes mellitus did not alter cerebral autoregulation significantly. In contrast, although the number of patients with cerebrovascualr disease history or vascular disease was small, the incidence of patients with $SjvO_2$ less than 55% during the anastomosis was twice in patients with history compared to that in patients without the history. Cautious monitoring of cerebral oxygenation and management of hemodynamics associated with cerebral oxygen profile is needed during OPCAB especially in patients with history of vascular disease.

The lack of association between SvO_2 and $SjvO_2$ has been validated with limited studies.[25,26] Likewise, the decrease in SvO_2 and CI during the anastomosis of coronary arteries was not related to the change in $SjvO_2$ in this study. This result implies that the balance between oxygen supply and $CMRO_2$ was maintained regardless of the decrease in CI and SvO_2 during OPCAB. However, it should be emphasized that $SjvO_2$ is a measure of global cerebral oxygenation It is not particularly sensitive to small areas of focal ischemia and a normal saturation does not guarantee the adequacy of the cerebral perfusion.[10 15] Nevertheless, a low saturation does indicate cerebral hypoperfusion but whether or not $SjvO_2$ influences neurological outcome after cardiac surgery remains unclear.[18] Kadoi and colleagues[27] performed a battery of neurologic and neuropsychological tests on the day before the operation, at 7 days and 6 months after the operation. They reported that reduced $SjvO_2$ was associated with short-term cognitive dysfunction in elderly patients undergoing CPB. Although 6, 3, and 2 patients in this study developed low $SjvO_2$ (< 55%) during LAD, OM, and PDA anastomosis respectively, no short-term neurological disorder was detected using routine postoperative neurological assessment. The possibility exists, however, that an extensive assessment of neurological and cognitive function might have detected minor neurological abnormalities.[2]

There are several technical limitations in monitoring $SjvO_2$. They are the site of sampling, catheter migration, and extracranial contamination. Generally, right internal jugular vein is used for jugular bulb catheterization, as right side is more likely to be the dominant anatomical side.[28] The left jugular bulb was used to sample the blood in this study because the pulmonary artery catheter had to be inserted through the right internal jugular vein. Shenkin, Harmel and Ketty[29] demonstrated that blood in each internal jugular vein is fairly representative of the drainage from all the histologic components of the brain, and blood entering the brain via each internal carotid artery is distributed almost wholly to the ipsilateral hemisphere and drained predominantly by the internal jugular vein on the corresponding side. Therefore the site of sampling would not have affected the result of this study. Since $SjvO_2$ did not fluctuate during the study period, the migration of the catheter or extracranial contamination was not considered in the measurement of $SjvO_2$. Since $SjvO_2$ was measured directly, but not monitored continuously, $SjvO_2$ and the incidence of cerebral hypoperfusion during coronary anastomosis could be underestimated in this study.

V. CONCLUSION

Global cerebral oxygenation measured with $SjvO_2$ was reduced compared to baseline values but constantly maintained within normal range in OPCAB regardless of the changes in hemodynamic variables in most patients. However, since $SjvO_2$ decreased below critical level in several patients during coronary artery anastomosis, cautious monitoring of cerebral oxygenation is needed during OPCAB.

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ABSTRACT (IN KOREAN)

심폐회로를 이용하지 않는 관상동맥우회술 중 혈역학적 변화에 따른 경정맥구 산소포화도의 변화

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김 지 영

심폐회로를 이용하지 않는 관상동맥우회술(off-pump coronary artery bypass graft surgery, OPCAB)은 심장의 위치변화에 따라 심한 혈역학적 변화가 야기될 수 있다는 단점이 있으나 이러한 혈역학적 변화가 뇌혈류에 미치는 영향에 관해 연구된 바는 없다. 이에 본 연구는 뇌대사량이 동일하다고 가정할 때 뇌혈류의 변화를 반영한다고 알려진 경정맥구 산소포화도(jugular venous oxygen saturation, $SjvO_2$)를 이용하여 OPCAB 중 생기는 뇌혈류의 변화를 알아보았다.

OPCAB 이 예정된 48 명의 환자를 대상으로 마취후 경정맥구에 도관을 삽관한 후 이를 통한 혈액체취와 동시에 혈역학적 변수들을 기록하였다. 흉골절개후 기록한 수치들을 대조치로 정하고 좌전하행동맥 (left anterior descending artery, LAD), 둔각모서리동맥 (obtuse marginal branches; OM), 후하행동맥 (posterior descending artery, PDA) 각각의 관상동맥 문합을 위해 Octopus 심장 고정기를 부착후 5 분 경과 후, 관상동맥 문합이

끝나고 심장 고정기를 제거한 후 변수들을 기록하고 동맥혈과 경정맥구 정맥혈 채취 및 혈액가스분석을 시행하여 동맥혈 산소포화도와 산소함유량 및 이산화탄소분압을 측정하였다.

심박출지수와 혼합정맥혈 산소포화도는 각각의 관상동맥 문합시 대조치에 비하여 통계학적으로 유의하게 감소하였다. 수술중 $SjvO_2$ 변화 역시 통계학적으로는 대초치에 비하여 유의하게 감소였으나 그 수치들은 정상범위로 유지되었다.

결론적으로 OPCAB 시행중 뇌의 산소화를 나타내는 지표인 $SjvO_2$ 는 혈역학적 변화에도 불구하고 정상범위로 유지되었다.

핵심되는 말 : 심폐회로를 이용하지 않는 관상동맥우회술, 경정맥구 산소포화도