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Cerebral oxygenation is better during mild hypothermic than normothermic cardiopulmonary bypass

Purpose: Normothermic cardiopulmonary bypass (CPB) has been recently used in cardiac surgery. However, there is a controversy whether there is a difference in incidence of neurological disorder after coronary artery bypass graft (CABG) surgery between normothermic CPB and mild hypothermic CPB. In this study, we assessed the effects of normothermia and mild hypothermia (32°C) during CPB on jugular oxygen saturation (SjvO₂).

Methods: Twenty patients scheduled for elective CABG surgery were divided into two groups. Group 1 (n=10) underwent normothermic (>35°C) CPB, and Group 2 (n=10) underwent mild hypothermic (32°C) CPB. Alpha-stat blood gas regulation was applied. After inducing anesthesia, a 4.0 French fibre optic oximetry oxygen saturation catheter was inserted into the right jugular bulb to monitor SjvO₂ continuously throughout anesthesia and surgery.

Results: The SjvO₂ in the normothermic group was decreased at 20 (41.5 ± 2.4%) and 40 min (43.8 ± 2.8%) after the onset of CPB compared with control (53.9 ± 5.4%, $P < 0.05$). However, there was no change in SjvO₂ in the mild hypothermic group during the study. No changes in jugular venous-arterial differences of lactate or creatine phosphokinase isoenzyme BB were observed in two groups during the study.

Conclusions: Cerebral oxygenation, as assessed by SjvO₂, was increased during mild hypothermic CPB than during normothermic CPB.

Objectif : La circulation extracorporelle (CEC) normothermique a été récemment utilisée en chirurgie cardiaque. Mais, il y a controverse sur une différence possible d'incidence de troubles neurologiques après un pontage aortocoronarien selon qu'on utilise la CEC normothermique ou légèrement hypothermique. Nous évaluons ici les effets de la normothermie et d'une légère hypothermie (32 °C) pendant la CEC sur la saturation en oxygène de la veine jugulaire (SO_{2vj}).

Méthode : Vingt patients admis pour un pontage aortocoronarien électif ont été répartis en deux groupes. Ceux du Groupe 1 (n = 10) ont reçu une CEC normothermique (>35 °C) et ceux du Groupe 2 (n = 10) une CEC légèrement hypothermique (32 °C). La régulation alpha-stat des gaz du sang a été utilisée. Après l'induction de l'anesthésie, un cathéter fibroscopique d'oxymétrie de calibre 4 French, pour déterminer la saturation en oxygène, a été inséré dans le golfe de la jugulaire droite pour une surveillance continue de la SO_{2vj} pendant l'anesthésie et l'opération.

Résultats : Dans le groupe normothermique, la SO_{2vj} a diminué à 20 (41,5 ± 2,4 %) et à 40 min (43,8 ± 2,8 %) après le début de la CEC comparée au groupe témoin (53,9 ± 5,4 %, $P < 0,05$). Il n'y a pas eu de changement de SO_{2vj} dans le groupe légèrement hypothermique pendant la durée de l'étude. De même, on n'a pas observé de modifications intergroupes des différences veineuses-artérielles de la quantité de lactate ou d'isoenzyme BB de la créatine-phosphokinase.

Conclusion : L'oxygénation cérébrale, évaluée par la SO_{2vj}, était plus élevée pendant la CEC légèrement hypothermique que pendant la CEC normothermique.

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NORMOTHERMIC CPB has recently been used in cardiac surgery¹. However, there is controversy whether there is a difference in the incidence of neurological complications after surgery between normothermic and hypothermic CPB.¹ Martin *et al.* reported a three-fold greater stroke rate and a considerably higher incidence of perioperative neurological dysfunction in patients who underwent normothermic surgery.² In contrast, Warm Heart Investigations (WHI) reported no difference in the incidence of strokes.³

A recent study reported that the incidence of neurophysiological dysfunction after CABG surgery in hypothermic conditions (28°C) did not differ from that in mild hypothermia (32°C).⁴ This report indicated that the neuroprotective effect of mild hypothermia (32°C) was equivalent to that of traditional hypothermic conditions (28-30°C). McLean *et al.* showed that mild hypothermia markedly reduced the increase in extracellular glutamate observed during ischemia.¹ Since small differences in brain temperature are known to have great impact on neurological protection,¹ it is important to assess the effect of mild hypothermia on the state of brain oxygenation in human.

In a previous study, we reported that cerebral desaturation during CPB was more often observed in normothermic (>35°C) than in hypothermic conditions (30°C).⁵ However, until now, there has been no comparative study assessing the effect of normothermia and mild hypothermia (32°C) on jugular oxygen saturation (SjvO₂) during CPB.

The aim of this study was to determine whether SjvO₂ during normothermic CPB was different from that during mild hypothermic (32°C) CPB.

Patients and methods

After obtaining approval of the ethics committee of our institution and informed consent, 20 consecutive patients who undergoing elective coronary artery bypass graft surgery were studied. The patients were randomly divided into two groups: Group 1 (n=10) underwent normothermic CPB (>35°C), and group 2 (n=10) underwent mild hypothermic CPB (32°C). None of the patients had pulmonary, renal, hepatic disease, diabetes mellitus or clinical or laboratory evidence of cerebral vascular disease.

All patients received 10 mg diazepam *po* one hour before anesthesia. The left radial artery was cannulated with a 22-gauge indwelling catheter to monitor arterial blood pressure. Anesthesia was induced with 25 µg·kg⁻¹ fentanyl and 0.2 mg·kg⁻¹ midazolam and tracheal intubation was facilitated with 0.2 mg·kg⁻¹

vecuronium. After the induction of anesthesia, a pulmonary arterial catheter (Vigilance®, Swan-Ganz CCO Thermodilution Catheter, Baxter, Co. U.S.A.) was inserted through the right internal jugular vein. For continuous monitoring of jugular oxygen saturation (SjvO₂), a 4.0 French fiberoptic oximetry oxygen saturation catheter (Dual-lumen oximetry catheter®, Baxter, Co.) was inserted into the right jugular bulb using a modified Seldinger technique. This catheter was connected to an Explorer™ system (Baxter, Co.) and calibrated *in vivo* by drawing a blood sample from the catheter. The position of the jugular bulb catheter was verified by X-ray. The SjvO₂ values were collected and processed in a monitor-computer interfere, and displayed and stored every five seconds in an Apple Macintosh computer (Apple Macintosh Computer Co, Ltd, Cupertino, CA).

The partial pressures of the arterial and jugular venous blood gases were analyzed using a Stat Profile Ultima® (NOVA Biomedical Co. Boston, MA). In all patients, the lungs were ventilated with oxygen 50% and N₂ 50%, and P_{ET}CO₂ was monitored (Ultima®, Datex, Helsinki, Finland) and maintained between 35-40 mmHg. Following anesthesia induction, 4 mg·kg⁻¹·hr⁻¹ propofol was infused using a syringe pump and continued until the patients arrived in the intensive care unit. Muscular relaxation was maintained by intermittent administration of vecuronium. No volatile anesthetic was administered. Rectal and nasopharyngeal temperatures were continuously monitored (Hewlett Packard, Andover, MA). The tympanic membrane temperature was also continuously monitored by Mon-a-Therm® (Mallinckrodt Co, St. Louis, MO).

The CPB was primed with a crystalloid, non-glucose containing solution, and a nonpulsatile pump flow rate of 2.2 to 2.5 L·min⁻¹·m⁻² was maintained. A membrane oxygenator and a 40 µm arterial line filter

TABLE I Demographic data.

	Group 1	Group 2
Age (yr)	59 ± 4	56 ± 3
Height (cm)	161 ± 5	159 ± 3
Weight (kg)	58 ± 4	58 ± 5
LVEF (%)	60 ± 4	58 ± 6
Phenylephrine dosage (mg)	5.3 ± 1.5	3.3 ± 1.2
Catecholamine dosage		
Dopamine µg·kg ⁻¹ ·min ⁻¹)	4.4 ± 0.4	6.0 ± 1.2
Dobutamine µg·kg ⁻¹ ·min ⁻¹)	4.4 ± 0.4	5.6 ± 1.2
Total CPB time (min)	141 ± 14	151 ± 14
Aortic clamping time (min)	116 ± 15	125 ± 11

Values are means ± SEM. No statistical differences between groups.

TABLE II Variable parameters in normothermic and hypothermic groups during perioperative period

<i>(a) Normothermia</i>							
Measurement time	(1)	(2)	(3)	(4)	(5)	(6)	(7)
C.I (l·min ⁻¹ ·m ⁻²)	2.2 ± 0.4	2.4 ± 0.1	2.5 ± 0.1	2.5 ± 0.1	2.5 ± 0.1	2.7 ± 0.3	3.0 ± 0.4
MAP (mmHg)	80 ± 5	81 ± 10	66 ± 7*	69 ± 8	73 ± 5	76 ± 5	75 ± 5
IJP (mmHg)	8 ± 2	9 ± 2	5 ± 3	6 ± 2	7 ± 3	9 ± 3	10 ± 2
PaCO ₂ (mmHg)	38 ± 2	37 ± 3	37 ± 2	37 ± 2	38 ± 2	39 ± 3	38 ± 2
Hb (g·dl ⁻¹)	12.8 ± 0.8	8.2 ± 0.4	6.8 ± 0.7*	7.0 ± 0.7*	7.1 ± 0.6	7.3 ± 0.5	8.5 ± 0.6
SjvO ₂ (%)	55.9 ± 5.4	54.5 ± 3.6	41.5 ± 2.4*	43.8 ± 2.8	48.1 ± 2.8	51.3 ± 2.1	56.1 ± 3.3
Ca-jvo ₂ (ml·dL ⁻¹)	8.4 ± 2.2	6.4 ± 2.8	6.0 ± 1.7*	6.1 ± 1.9*	6.2 ± 2.6*	6.4 ± 3.2*	6.4 ± 2.6
OER (%)	46 ± 8	48 ± 8	60 ± 7*	58 ± 6*	54 ± 7	51 ± 6	46 ± 8
TT (°C)	35.7 ± 0.3	34.7 ± 0.3*	35.5 ± 0.4	35.6 ± 0.4	35.6 ± 0.4	35.7 ± 0.5	35.8 ± 0.3

Values are means ± SEM * $P < 0.05$ compared with (1)

(1) after induction of anesthesia and before the start of surgery, (2) at the onset of CPB, (3) 20 min after the onset of CPB, (4) 40 min after the onset of CPB, (5) 60 min after the onset of CPB, (6) at the cessation of CPB, (7) at the end of the operation.

<i>(b) Moderate hypothermia</i>							
Measurement time	(1)	(2)	(3)	(4)	(5)	(6)	(7)
C.I (l·min ⁻¹ ·m ⁻²)	2.4 ± 0.3	2.5 ± 0.1	2.5 ± 0.1	2.5 ± 0.1	2.4 ± 0.1	2.9 ± 0.32	2.8 ± 0.4
MAP (mmHg)	87 ± 6	77 ± 8	66 ± 6*	77 ± 6	73 ± 46	74 ± 6	79 ± 9
IJP (mmHg)	10 ± 2	9 ± 3	6 ± 3	6 ± 3	7 ± 2	8 ± 2	8 ± 1
PaCO ₂ (mmHg)	37 ± 2	38 ± 3	38 ± 3	36 ± 2	37 ± 2	37 ± 2	37 ± 3
Hb (g·dl ⁻¹)	12.8 ± 0.8	7.7 ± 0.9	7.4 ± 0.8	7.1 ± 0.5	7.2 ± 0.6	7.4 ± 0.6	7.9 ± 0.9
SjvO ₂ (%)	62.2 ± 5	55.1 ± 3.3	63.9 ± 4.3	64.9 ± 5.2	61.2 ± 2.8	57.8 ± 3.6	63.8 ± 4.1
Ca-jvo ₂ (ml·dL ⁻¹)	7.3 ± 2.2	5.5 ± 2.4	4.3 ± 2.2	4.1 ± 2.7*	4.5 ± 2.5	4.9 ± 2.3	5.1 ± 2.6
OER (%)	40 ± 7	48 ± 7	40 ± 5	39 ± 6	42 ± 6	45 ± 6	40 ± 5
TT (°C)	36.3 ± 0.2	35.1 ± 0.4*	32*	32.1 ± 0.2*	36	35.8 ± 0.2	36.1 ± 0.3

Values are means ± SEM * $P < 0.05$ compared with (1)

(1) after induction of anesthesia and before the start of surgery, (2) at the onset of CPB, (3) just after the cooling to 32°C, (4) during stable hypothermia at 32°C, (5) just after the rewarming to 36°C, (6) at the cessation of CPB, (7) at the end of the operation.

C.I: cardiac index, MAP: mean arterial pressure, IJP: internal jugular vein pressure, Hb: hemoglobin, TT: tympanic temperature, SjvO₂: jugular venous oxygen saturation, Ca-jvo₂: arterio-venous oxygen content difference, OER: oxygen extraction ratio

were used, and PaCO₂ uncorrected for temperature was adjusted to normocapnic levels (35 to 40 mmHg) by varying fresh gas flow to the membrane oxygenator (alpha-stat regulation).

The target nasopharyngeal temperatures were 32°C and >35°C for the mild hypothermic and normothermic groups, respectively.

Hematocrit was maintained at >0.20 during CPB, with the addition of blood as necessary. Phenylephrine infusions were used during CPB to maintain mean arterial pressures (MAP) of 50-90 mmHg.

Intermittently, antegrade blood cardioplegia was administered at 37°C for the normothermic group and at 5°C for the mild hypothermic group. Distal coronary anastomoses and proximal anastomoses were performed during a single aortic cross-clamp.

Hemodynamic variables, arterial and jugular venous blood gases were measured as follows.

Normothermic group: (1) after induction of anesthesia and before the start of surgery, (2) at the onset

of CPB, (3) 20 min after the CPB, (4) 40 min after the CPB, (5) 60 min after the CPB, (6) at the cessation of CPB, and (7) at the end of the operation.

Mild hypothermic group: (1) after the induction of anesthesia and before the start of surgery, (2) at the onset of CPB, (3) just after the cooling to 32°C, (4) during stable hypothermia at 32°C, (5) just after the rewarming to 36°C, (6) at the cessation of CPB, and (7) at the end of the operation.

Intraoperative epiaortic ultrasonography confirmed that none of the patients had moderate or severe atherosclerotic lesions in the ascending aorta.

Cerebral desaturation was defined as a SjvO₂ < 50%, as described by Cook.⁶

Statistical analysis

All data are expressed as means ± SEM. After confirmation of equal variance among the groups by the Bartlett test, changes in mean values were compared with the baseline values using two-way repeated mea-

tures analysis of variance. The parameters obtained from the normothermic and the mild hypothermic groups were compared using an unpaired t test. Statistical significance was set at $P < 0.05$.

To identify the determinant factor to reduced $SjvO_2$ value at pre- and post CPB and during CPB, multiple linear regression analysis was performed using the measured parameters such as hemoglobin concentration (Hb), tympanic temperature, $PaCO_2$, cerebral perfusion pressure.

Cerebral perfusion pressure was defined as mean arterial pressure minus internal jugular venous pressure.

All calculations were performed on a Macintosh computer with SPSS (SPSS, Inc, Chicago, III) and Stat View 4.5 software packages (Abacus Concepts, Inc, Berkeley, CA).

Results

There were no differences in age, height, weight, LV ejection fraction, phenylephrine dosage, aortic clamping time, total CPB time and catecholamine dosage between the two groups. Mean arterial pressure (MAP) and hemoglobin (Hb) concentration were decreased during the CPB period in both groups. There were no differences in MAP, cardiac index, internal jugular vein pressure, $PaCO_2$ or Hb between two groups during the study (Table).

The $SjvO_2$ in the normothermic group was decreased at 20 and 40 min after the onset of CPB compared with the value at period (1) ($SjvO_2$ value at period (1); $53.9 \pm 5.4\%$, $SjvO_2$ value at 20 min after the onset of CPB; $41.5 \pm 2.4\%$, $SjvO_2$ value at 40 min after the onset of CPB; $43.8 \pm 2.8\%$, $P < 0.05$) (Figure 1). However, in the mild hypothermic group there was no changes in $SjvO_2$ throughout the study (Figure 2).

No changes in V-A differences of lactate or CPK-BB were observed in either group during the study (Figures 1 and 2).

Temperature and hemoglobin are determinant factors of $SjvO_2$ during the CPB period and, there is no determinant factor to $SjvO_2$ during pre- and post-CPB period (data not shown).

Discussion

The present study showed that cerebral oxygenation, estimated by $SjvO_2$, was well maintained throughout mild hypothermic CPB, but decreased during normothermic CPB. There is a controversy whether the incidence of postoperative neurophysiological dysfunction after normothermic CPB differs from that after hypothermic CPB.^{1,7} Plourde *et al.* reported that there was no difference in postoperative cognitive function between normothermic and hypothermic

FIGURE 1 Time course of changes in $SjvO_2$ and veno (jugular venous)-arterial (V-A) differences in lactate and creatine phosphokinase isoenzyme BB (CPK-BB) in normothermic group.

* $P < 0.05$ compared with period (1)

V-A : veno (jugular venous)-arterial difference

groups.⁸ In contrast, Mora *et al.* reported that postoperative neurophysiological dysfunction was more often observed in normothermia than in hypothermia.⁹ Regragui *et al.* reported similar results.⁴ They examined postoperative neurophysiological dysfunction after CPB at 28°C, 32°C and 37°C, and found that there was a difference in postoperative cognitive function between normothermic (37°C) and hypothermic (28°C) groups, but not between mild hypothermic (32°C) and hypothermic (28°C) groups. Previously, we examined the effects of normothermia (37°C) and hypothermia (30°C) on $SjvO_2$ during CPB,⁵ which indicates the global balance of cerebral blood flow and the cerebral metabolic rate and is used to estimate the adequacy of flow / metabolism coupling in the brain. In this study we found the difference between two groups in the number of patients whose $SjvO_2$ value was $< 50\%$. According to the present and previous studies, $SjvO_2$ was decreased during

FIGURE 2 Time course of changes in S_{svO₂} and veno (jugular venous) -arterial (V-A) differences in lactate and creatine phosphokinase isoenzyme BB (CPK-BB) in hypothermic group. V-A : veno (jugular venous)-arterial difference

normothermic CPB, but not during hypothermic (30°C) or mild hypothermic (32°C) CPB. This finding is compatible with other reports. Cook *et al.* demonstrated the cerebral desaturation during CPB in 54% of patients in a normothermic group and 12% of those in a hypothermic group (27°C).⁶ If cerebral desaturation is related to postoperative neurological disorders, as suggested by Croughwell *et al.*,¹⁰ mild hypothermia is superior to normothermia in preventing postoperative neurological disorders.

No changes in V-A difference of lactate or CPK BB concentrations were observed during this study. This differs from Sapire *et al.*,¹¹ who reported an increase in V-A lactate difference during the rewarming period in hypothermic CPB (15°C-33°C). This increase in V-A lactate difference was related to the decrease of S_{svO₂}. They suggested that the increase in V-A lactate difference observed during rewarming was an indication of cerebral anaerobic metabolism. However, van den Hinden *et al.* reported that the increase in V-A

lactate difference was not observed in low-flow perfusion, but in circulatory arrest.¹² Aren *et al.* reported similar results.¹³ These reports suggest that lactate is released from the brain to a limited degree, but that the amount is small and clinically unimportant. The difference between our results and that of Sapire may be explained by differences in other CPB conditions, such as duration and temperature management.

Study limitations

There is controversy concerning the correlation between S_{svO₂} reduction during CPB and postoperative neurological disorders. Recent reports from Duke University demonstrated that a reduction in S_{svO₂} value had only a minor effect on neuropsychologic outcome.¹⁵ However, Goto *et al.* reported that a reduction in S_{svO₂} in patients with preexisting neurological disorder may have great influence on neurologic outcome.¹⁶ We did not examine neurological outcome in patients treated by normothermic CPB. Since our patients had no preexisting neurological disorder, extensive examination might have been able to detect the temporary neurological disorders, as observed in Mora's report.⁹

We did not examine the changes in lactate and CPK-BB in cerebrospinal fluids (CSF). Significant changes in lactate and CPK BB concentrations might be observed in CSF in patients treated by normothermic CPB.

In this study, there is a small, but not significant difference in S_{svO₂} between groups at period (1). Many factors, such as, age, species, anesthetic drugs, temperature, PaCO₂, PaO₂ and blood viscosity, might influence the S_{svO₂}.

In conclusion, cerebral oxygenation during mild hypothermic CPB was well maintained in uncomplicated CABG patients.

References

- 1 McLean RF, Wong BI. Normothermic versus hypothermic cardiopulmonary bypass: central nervous system outcomes. *J Cardiothorac Vasc Anesth* 1996; 10: 45-53.
- 2 Martin TD, Craver JM, Gott JP, *et al.* Prospective, randomized trial of retrograde warm blood cardioplegia: myocardial benefit and neurologic threat. *Ann Thorac Surg* 1994; 57: 298-304.
- 3 The Warm Heart Investigators. Randomized trial of normothermic versus hypothermic coronary bypass surgery. *Lancet* 1994; 343: 559-63.
- 4 Regragui I, Birdi I, Izzat MB, *et al.* The effects of cardiopulmonary bypass temperature on neuropsychologic outcome after coronary artery operations: a prospective

- randomized trial. *J Thorac Cardiovasc Surg* 1996; 112: 1036–45.
- 5 Kadoi Y, Kawahara F, Saito S, *et al.* Effects of hypothermic and normothermic cardiopulmonary bypass on brain oxygenation. *Ann Thorac Surg* 1999; 68: 34–9.
 - 6 Cook DJ, Oliver WC Jr, Orszulak TA, Daly RC. A prospective, randomized comparison of cerebral venous oxygen saturation during normothermic and hypothermic cardiopulmonary bypass. *J Thorac Cardiovasc Surg* 1994; 107: 1020–9.
 - 7 Murkin JM. Hypothermic cardiopulmonary bypass time for a more temperate approach? (Editorial) *Can J Anaesth* 1995; 42: 663–8.
 - 8 Plourde G, Leduc AS, Morin JE, *et al.* Temperature during cardiopulmonary bypass for coronary artery operations does not influence postoperative cognitive function: a prospective, randomized trial. *J Thorac Cardiovasc Surg* 1997; 114: 123–8.
 - 9 Mora CT, Henson MB, Weintraub WS, *et al.* The effect of temperature management during cardiopulmonary bypass on neurologic and neuropsychologic outcomes in patients undergoing coronary revascularization. *J Thorac Cardiovasc Surg* 1996; 112: 514–22.
 - 10 Croughwell ND, Newman MF, Blumenthal JA, *et al.* Jugular bulb saturation and cognitive dysfunction after cardiopulmonary bypass. *Ann Thorac Surg* 1994; 58: 1702–8.
 - 11 Sapire KJ, Gopinath SP, Farhat G, *et al.* Cerebral oxygenation during warming after cardiopulmonary bypass. *Crit Care Med* 1997; 25: 1655–62.
 - 12 van der Linden J, Astudillo R, Ekroth R, Scallan M, Lincoln C. Cerebral lactate release after circulatory arrest but not after low flow in pediatric heart operations. *Ann Thorac Surg* 1993; 56: 1485–9.
 - 13 Arén C, Badr G, Feddersen K, Rådegran K. Somatosensory evoked potentials and cerebral metabolism during cardiopulmonary bypass with special reference to hypotension induced by prostacyclin infusion. *J Thorac Cardiovasc Surg* 1985; 90: 73–9.
 - 14 Johnsson P. Markers of cerebral ischemia after cardiac surgery. *J Cardiothorac Vasc Anesth* 1996; 10: 120–6.
 - 15 Newman MF, Kramer D, Croughwell ND, *et al.* Differential age effects of mean arterial pressure and rewarming on cognitive dysfunction after cardiac surgery. *Anesth Analg* 1995; 81: 236–42.
 - 16 Goto T, Yoshitake A, Baba T, Shibata Y, Sakata R, Uozumi H. Cerebral ischemic disorders and cerebral oxygen balance during cardiopulmonary bypass surgery: preoperative evaluation using magnetic resonance imaging and angiography. *Anesth Analg* 1997; 84: 5–11.