Anesthesiology
2000; 92:1324–9

Jugular Venous Bulb Oxygen Saturation in Patients with Preexisting Diabetes Mellitus or Stroke during Normothermic Cardiopulmonary Bypass

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Background: **The authors hypothesized that patients with cerebrovascular abnormalities or metabolic disorders may experience abnormality in cerebral circulation more frequently than patients without these risks. The current study attempted to assess jugular venous bulb oxygen saturation (Sjv_{O_2}) in patients with preexisting diabetes mellitus or stroke undergoing normothermic cardiopulmonary bypass.**

Methods: **Thirty-nine patients undergoing elective coronary artery bypass graft surgery were studied, including 19 age-matched control patients, 10 diabetic patients, and 9 patients with preexisting stroke A 4.0-French fiberoptic oximetry oxygen saturation catheter was inserted into the right jugular bulb to continuously monitor internal Sjv_{O_2}. Hemodynamic parameters and arterial and jugular venous blood gases were measured at seven time points: (1) after the induction of anesthesia and before the start of surgery, (2) just after the beginning of cardiopulmonary bypass, (3) 20 min after the beginning of bypass, (4) 40 min after the beginning of bypass, (5) 60 min after the beginning of bypass, (6) just after the cessation of bypass, and (7) at the end of the operation.**

Results: **No significant differences were seen in mean arterial pressure, arterial carbon dioxide tension (Pa_{CO_2}), or hemoglobin concentration among the three groups during the study. The Sjv_{O_2} value did not differ among the three groups after anesthesia induction and before surgery, just after the beginning of cardiopulmonary bypass, 60 min after the beginning of bypass, just after the end of bypass, or at the end of the operation. Significant differences between the control group and the diabetic and stroke groups were observed, however, at 20 min and 40 min after the beginning of bypass (at 20 min: control group 62.2 ± 6.8%, diabetes group 48.4 ± 5.1%, stroke group 45.9 ± 6.3%; at 40 min: control group 62.6 ± 5.2%, diabetes group 47.1 ± 5.2%, stroke group 48.8 ± 4.1% [values expressed as the mean ± SD]; $P < 0.05$). Also, values in the diabetes and stroke groups were decreased at 20 min and 40 min after the beginning of bypass compared with before the start of surgery.**

Conclusions: **A reduced Sjv_{O_2} value was observed more frequently in patients with preexisting diabetes mellitus or stroke during normothermic cardiopulmonary bypass. It is possible that cerebral circulation during normothermic bypass is altered in patients with risk factors for cerebrovascular disorder. (Key words: Cerebral ischemia; extracorporeal circulation; metabolic disorder; neurologic complication.)**

CENTRAL nervous system complications continue to be a major cause of injury and death after cardiac surgery.[1] Neuropsychologic dysfunction after cardiopulmonary bypass (CPB) has been reported in as many as 79% of patients during the early postoperative period.[2]

Patients undergoing elective coronary artery bypass graft surgery often have diabetes mellitus (DM) and cerebrovascular disease,[1] each of which presents risk factors for cerebral circulatory disturbance. In addition, patients with DM or preexisting stroke undergoing coronary artery bypass graft surgery may be at risk for cerebral ischemia, especially during normothermic CPB. Goto *et al.*[3] reported that patients with preexisting cerebral neurologic disorders showed a greater degree of jugular venous desaturation than did patients without neurologic disorders during hypothermic CPB. Similarly, Croughwell *et al.*[4] reported that patients with DM showed abnormal cerebral autoregulation during CPB.

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Received from the Department of Anesthesiology and Reanimatology, Gunma University, School of Medicine, Gunma, Japan; and the Department of Anesthesiology, Saitama Prefectural Cardiovascular and Pulmonary Center, Saitama, Japan. Submitted for publication June 3, 1999. Accepted for publication December 10, 1999. Supported in part by a grant-in-aid for scientific research (no. 10770741 to Dr. Kadoi) from the Japanese Ministry of Education, Culture, and Science, Tokyo, Japan.

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Table 1. Demographic Data for the Three Groups

	Normal Group	Diabetic Group	Stroke Group
LVEF (%)	60 ± 7 (52–71)	59 ± 10 (47–75)	57 ± 9 (49–72)
Total CPB time (min)	172 ± 37 (109–211)	144 ± 34 (111–195)	135 ± 29 (89–174)
Aortic clamping time (min)	122 ± 28 (91–167)	114 ± 24 (77–166)	107 ± 20 (74–148)

Values are mean ± SD (range). No statistical differences among the three groups.
LVEF = left ventricular ejection fraction; CPB = cardiopulmonary bypass.

These reports led us to consider the question of whether there is a difference in the incidence of jugular venous oxygen desaturation during normothermic CPB between patients with and those without such complications.

Materials and Methods

After obtaining the approval of the ethical committee of our institution and written informed consent from the patients, 19 age-, weight-, and height-matched control patients (control group), 10 diabetic patients (DM group), and 9 patients with preexisting stroke (stroke group) undergoing elective coronary artery bypass graft surgery were studied. The clinical data of DM and stroke groups are shown in tables 1–3. The stroke group had no diabetic disease. None of the patients had pulmonary, renal, or hepatic disease.

All patients received 10 mg oral diazepam 1 h before administration of anesthesia. A cannula was inserted in the left radial artery to monitor arterial blood pressure. Anesthesia was induced with 25 μg/kg intravenous fentanyl, 0.2 mg/kg midazolam, and 0.2 mg/kg vecuronium, and the trachea then was intubated. After induction of anesthesia, the pulmonary arterial catheter (Vigilance Swan–Ganz CCO Thermodilution Catheter; Baxter, Irvine, CA) was inserted through the right internal jugular vein. For continuous monitoring of jugular vein oxygen saturation (Sjv_{O_2}), a 4.0-French fiberoptic oximetry catheter (Dual-lumen Oximetry Catheter; Baxter) was passed to the right jugular bulb retrogradely from the internal jugular vein using a modified Seldinger technique. Proper position of the top of the catheter was verified by radiograph. This catheter was connected to an analysis system (Explorer; Baxter) and calibrated *in vivo* by drawing a blood sample from the catheter. The arterial and jugular venous blood gases were analyzed (Stat Profile Ultima; NOVA Biomedical, Boston, MA). All patients were ventilated with 50% oxygen and 50% nitrogen. End-tidal carbon dioxide concentration was monitored (Ultima; Datex, Helsinki, Finland) and maintained between 35 and 45 mmHg. After induction of anesthesia, 4 $mg \cdot kg^{-1} \cdot h^{-1}$ propofol was infused using a syringe pump and continued until the patients were placed in the intensive care unit. Relaxation was maintained with an intermittent administration of vecuronium. No volatile anesthetics were administrated. The tympanic membrane temperature also was monitored continuously (Mon-a-Therm; Mallinckrodt, St. Louis, MO) as an indicator of brain temperature.

Cardiopulmonary bypass was primed with a crystalloid, non–glucose-containing lactate Ringer's solution, and a nonpulsatile pump flow rate of 2.2–2.5 $l \cdot min^{-1} \cdot m^{-2}$ was maintained. A membrane oxygenator and a 40-μm

Table 2. Clinical Data of Diabetic Patients

Patient Number	Fasting Blood Glucose (mg/dl)	HbA1c (%)	Therapy	Diabetic Complications
1	187	8.1	Glibenclamide	Retinopathy + nephropathy
2	107	5.1	Diet	(−)
3	222	7.4	Insulin	(−)
4	154		Glibenclamide	Nephropathy
5	198	8.1	Insulin	Retinopathy
6	217		Glibenclamide	(−)
7	149	5.4	Glibenclamide	Retinopathy
8	147	6.4	Glibenclamide	(−)
9	165	6.6	Insulin	(−)
10	111	7.2	Glibenclamide	(−)

HbA1c = glycosylated hemoglobin (normal value 4.3–5.8%).

Table 3. Clinical Data of Stroke Patients

Patient Number	Brain CT Examinations
1	Multiple lacunar infarction
2	Small cerebral infarction
3	Multiple lacunar stroke
4	Small cerebral infarction
5	Multiple lacunar infarction
6	Broad infarction
7	Small cerebral infarction
8	Small cerebral infarction
9	Multiple lacunar stroke

CT = computerized tomography.

arterial line filter were used, and arterial oxygen tension (Pa_{CO_2}) uncorrected for temperature was adjusted to normocapnic levels (35–45 mmHg) by varying fresh gas flow to the membrane oxygenator. The target tympanic temperature was 35°C.

Hematocrit was maintained at more than 20% during CPB, with the addition of blood as needed. Phenylephrine infusions were used during CPB to maintain mean arterial pressure of 50–90 mmHg.

Cerebral perfusion pressure (CPP) was defined as mean arterial pressure minus internal jugular venous pressure. Internal jugular pressure was measured by monitoring pressure at the distal end of the Sjv_{O_2} catheter. All hemodynamic transducers were referenced to atmospheric pressure at the level of the external auditory meatus.

After the end of CPB, catecholamines, such as dopamine and dobutamine, were infused to maintain the cardiac index above 2.2 $l \cdot min^{-1} \cdot m^{-2}$. No patients needed infusion of epinephrine or norepinephrine to maintain the cardiac index above 2.2 $l \cdot min^{-1} \cdot m^{-2}$.

Antegrade blood cardioplegia was administrated intermittently from the aortic root at 37°C. Distal coronary and proximal anastomoses were performed during a single aortic cross-clamping.

Hemodynamic parameters, arterial and jugular venous blood gases, and internal jugular venous pressure were measured (1) after the induction of anesthesia and before the start of surgery, (2) just after the beginning of CPB, (3) 20 min after the beginning of CPB, (4) 40 min after the beginning of CPB, (5) 60 min after the beginning of CPB, (6) just after 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.

Statistical Analysis

All data were expressed as the mean ± SD. After the study was completed, we evaluated the sample size. The sample size calculation was based on the hypothesis that the Sjv_{O_2} value in diabetic or stroke patients would be decreased by 10% compared with that in control patients. The sample size provides 80% power to detect a 20% difference between groups with a 5% probability of an a-type error. Changes in mean values were compared with the baseline values using an analysis of covariance. Contrast was used to compare the differences among the three groups at each time point. Statistical significance was set at $P < 0.05$.

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

Results

Postoperative neurologic dysfunction did not develop in any patient. There was no significant difference in preoperative blood pressure among the three groups (data not shown). Table 4 shows the time course for changes in variable parameters among three groups. Mean arterial pressure, cardiac index, hemoglobin, q]Pa_{CO2}, internal jugular pressure, and CPP among the three groups did not differ significantly at any time.

Figure 1 shows the time course for changes in Sjv_{O_2} among the three groups. Sjv_{O_2} did not differ among the three groups after anesthesia induction and before surgery, just after the beginning of CPB, 60 min after the beginning of CPB, just after the end of CPB, or at the end of the operation. Significant differences between the control group and the diabetic and stroke groups were observed, however, at 20 min and 40 min after the beginning of CPB (at 20 min: control group 62.2 ± 6.8%, diabetes group 48.4 ± 5.1%, stroke group 45.9 ± 6.3%; at 40 min: control group 62.6 ± 5.2%, diabetes group 47.1 ± 5.2%, stroke group 48.8 ± 4.1% [values expressed as the mean ± SD]; $P < 0.05$). Also, Sjv_{O_2} values in diabetic and stroke groups were decreased at 20 min and 40 min after onset of CPB compared with before the start of surgery. There was no significant difference in Sjv_{O_2} values between the diabetic group and the stroke group during at any point of the study.

Discussion

The principal findings of this study are that (1) patients with preexisting DM or stroke had a reduced Sjv_{O_2} com-

Table 4. Variable Parameters among the Three Groups during Perioperative Period

Measurement Time		1	2	3	4	5	6	7
CI ($l \cdot min^{-1} \cdot m^{-2}$)	Control group	2.6 ± 1.3	2.4 ± 0.2	2.5 ± 0.2	2.5 ± 0.2	2.5 ± 0.2	3.0 ± 0.7	3.2 ± 0.8
	DM group	2.7 ± 1.0	2.4 ± 0.3	2.5 ± 0.2	2.5 ± 0.2	2.5 ± 0.2	3.0 ± 0.7	3.3 ± 0.3
	Stroke group	2.6 ± 1.1	2.4 ± 0.2	2.5 ± 0.2	2.5 ± 0.2	2.5 ± 0.2	2.8 ± 0.9	3.3 ± 0.9
MAP (mmHg)	Control group	103 ± 19	76 ± 14*	69 ± 13*	63 ± 12*	74 ± 10*	89 ± 13	88 ± 12
	DM group	104 ± 17	67 ± 11*	63 ± 9*	63 ± 6*	63 ± 9*	74 ± 12*	76 ± 15
	Stroke group	97 ± 12	65 ± 14*	64 ± 11*	67 ± 9*	62 ± 7*	74 ± 8*	77 ± 13
IJP (mmHg)	Control group	10 ± 3	10 ± 3	7 ± 2	7 ± 2	7 ± 2	10 ± 3	11 ± 3
	DM group	9 ± 4	6 ± 3	5 ± 4	4 ± 2*	5 ± 3	7 ± 4	8 ± 3
	Stroke group	7 ± 4	7 ± 4	5 ± 3	4 ± 4	5 ± 4	8 ± 3	8 ± 4
CPP (mmHg)	Control group	89 ± 12	63 ± 12*	61 ± 9*	53 ± 9*	65 ± 8*	80 ± 11	76 ± 13
	DM group	92 ± 14	59 ± 9*	55 ± 8*	57 ± 5*	56 ± 7*	65 ± 11*	67 ± 14
	Stroke group	88 ± 14	57 ± 10*	57 ± 7*	59 ± 8*	57 ± 7*	66 ± 12*	67 ± 14
Pa_{CO_2} (torr)	Control group	40 ± 5	37 ± 4	40 ± 2	40 ± 3	41 ± 2	37 ± 4	37 ± 5
	DM group	39 ± 2	40 ± 2	39 ± 3	39 ± 3	39 ± 3	39 ± 4	36 ± 4
	Stroke group	40 ± 1	39 ± 3	39 ± 3	38 ± 4	39 ± 4	37 ± 4	39 ± 2
Pa_{O_2} (torr)	Control group	260 ± 68	392 ± 54*	377 ± 69	364 ± 58	378 ± 24*	353 ± 61	316 ± 43
	DM group	244 ± 37	440 ± 39*	364 ± 61*	380 ± 77*	376 ± 56*	422 ± 68*	313 ± 59
	Stroke group	362 ± 59	415 ± 58	453 ± 63	369 ± 25	406 ± 51	438 ± 43	405 ± 84
Hb (g/dl)	Control group	12.1 ± 0.9	7.4 ± 0.9*	7.4 ± 1.1*	7.0 ± 1.1*	7.5 ± 0.9*	7.7 ± 0.4*	8.5 ± 0.5
	DM group	10.5 ± 0.8	7.0 ± 0.6*	7.0 ± 0.8*	7.3 ± 1.0*	7.3 ± 1.1*	7.0 ± 0.6*	8.4 ± 0.6
	Stroke group	11.1 ± 1.2	7.2 ± 0.8*	6.6 ± 1.0*	6.7 ± 1.2*	7.1 ± 0.8*	8.2 ± 0.6	9.2 ± 0.5
TT (°C)	Control group	35.5 ± 0.4	35.3 ± 0.4	35.1 ± 0.8	35.3 ± 0.4	35.5 ± 0.9	35.6 ± 0.6	35.6 ± 0.3
	DM group	35.7 ± 0.6	35.0 ± 0.8	35.2 ± 1.0	35.3 ± 0.6	35.8 ± 0.5	35.6 ± 0.4	35.4 ± 0.4
	Stroke group	35.7 ± 0.8	34.9 ± 0.9	35.0 ± 1.1	35.3 ± 0.5	35.4 ± 0.8	35.2 ± 0.8	35.0 ± 0.9

Values are mean ± SD.

* $P < 0.05$ compared to period 1.

(1) after the induction of anesthesia and before the start of surgery, (2) just after 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) just after the cessation of CPB, (7) at the end of the operation.

CI = cardiac index; MAP = mean arterial pressure; IJP = internal jugular venous pressure; CPP = cerebral perfusion pressure (defined as MAP minus IJP); TT = tympanic temperature.

pared with those in the control group during normothermic CPB, and (2) the reduced Sjv_{O_2} was not attributable to either the mean arterial pressure or Pa_{CO_2} but rather to the preexisting DM or stroke.

Many studies have attempted to determine preoperative factors that may be used to predict major perioperative neurologic events in patients undergoing coronary artery bypass graft surgery. In addition to age, history of preexisting symptomatic neurologic disease and history of DM were considered to be concurrent risk factors in many studies.[5,6] To date, few clinical studies have examined patients with DM or preexisting stroke. One of the many possible causes of postoperative stroke in patients with DM or preexisting stroke is the impaired cerebrovascular circulatory and vasodilatory reserve. Dandona *et al.*[7] reported that 56% of awake diabetic patients failed to increase cerebral blood flow (CBF) after a 5% CO_2 inhalation challenge. Maeda *et al.*[8] reported that the CBF reactivity to CO_2 measured by transcranial Doppler ultrasonography in patients with asymptomatic small infarctions was significantly lower than that of control subjects. Cook *et al.*[9] reported that low Sjv_{O_2}, which indicates lower CBF in relation to cerebral metabolic rate, was observed more often in normothermic CPB than in hypothermic CPB in patients without preexisting DM or stroke. Thus, we considered whether patients who had risk factors for cerebral circulatory disturbances such as DM or stroke might have reduced Sjv_{O_2} more often than patients without these risk factors during normothermic CPB.

Some studies have described the alterations in cerebral circulation in patients with DM or preexisting stroke during hypothermic CPB.[3,4] Croughwell *et al.*[4] reported that the CBF of their diabetic group was constant despite an increase in temperature from 27 to 37°C, in contrast to an 83% increase in CBF in the control group. This was contradictory to the fact that the cerebral metabolic rate of oxygen consumption in both groups increased in parallel with rewarming. Goto *et al.*[3] found that patients with preexisting small cerebral infarctions had reduced Sjv_{O_2} compared with controls during CPB, especially during the rewarming period. They speculated that the

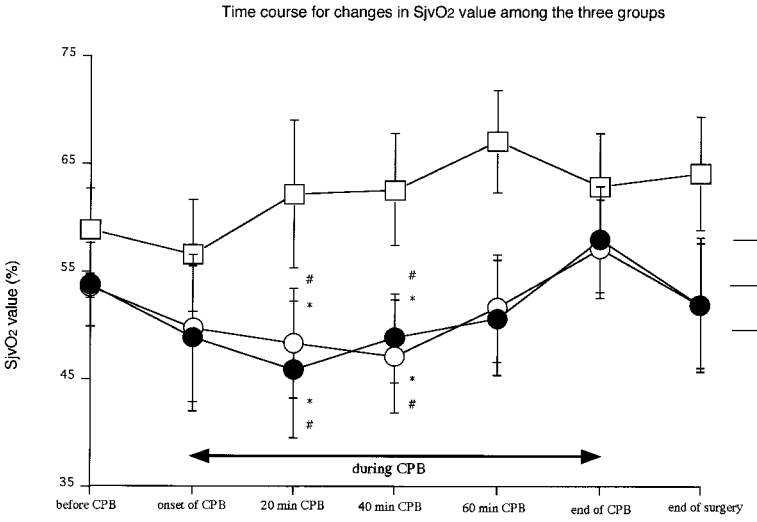

Fig. 1. The time course for changes in jugular venous bulb oxygen saturation (Sjv_{O_2}) among the three groups in the current study. Sjv_{O_2} did not differ among the three groups after anesthesia induction and before surgery, just after the beginning of cardiopulmonay bypass, 60 min after the beginning of bypass, just after the end of bypass, or at the end of the operation. Significant differences between the control group and the diabetic and stroke groups were observed, however, at 20 min and 40 min after the beginning of cardiopulmonary bypass (#$P < 0.05$ compared with control group). Also, Sjv_{O_2} in the diabetic and stroke groups was decreased at 20 min and 40 min after the beginning of cardiopulmonary bypass, compared with before the start of surgery (*$P < 0.05$). There was no significant difference in Sjv_{O_2} between the diabetic group and the stroke group at any point of the study. Values are expressed as the mean ± SD.

imbalance in CBF and cerebral metabolic rate of oxygen consumption might have resulted from impaired cerebral circulatory disturbance in patients with preexisting stroke, and they considered the fact that patients with risk factors for cerebral circulatory disturbance were unable to preserve effective CBF if systemic hypoperfusion occurred. From the results of our study, we also concluded that patients with DM or stoke may be at a much higher risk of cerebral oxygenation abnormality than otherwise normal patients.

In the current study, multiple linear regression analysis indicated that either DM or preexisting stroke was a single determining factor of Sjv_{O_2} value during normothermic CPB. CPP, Pa_{CO_2}, and arterial oxygen tension did not differ among groups. Sjv_{O_2} did not correlate with CPP during normothermic CPB in the control group. There have been some reports describing the correlation between CPP and Sjv_{O_2} during CPB. Grubhofer *et al.*[10] reported that an increase in CPP in response to administering phenylephrine (from 47 to 93 mmHg) induced increases in Sjv_{O_2} by 4.9% during hypothermic CPB. Furthermore, they considered this finding to suggest impaired cerebral autoregulation, and they recommended administration of phenylephrine to increase CPP in patients with lower Sjv_{O_2} during CPB. In contrast, Hessel[11] commented that the poor correlation between slopes obtained during the rise versus the decline in arterial pressure ($r = 0.10$) in the report of Grubhofer *et al.*[10] was disturbing. We suspect that the differences between our study and the one by Grubhofer *et al.*[10] could be a result of the different species studied, anesthetic conditions, management of CPB, preoperative baseline mean arterial pressure, or mean arterial pressure during CPB.

The finding that control patients with normothermic CPB did not show any reduction in Sjv_{O_2} is inconsistent with findings both of Cook *et al.*[9] and of our previous studies.[12,13] It is possible that many factors such as age, species, anesthetic drugs, Pa_{CO_2}, arterial oxygen tension, and blood viscosity influence Sjv_{O_2} during normothermic CPB. Sjv_{O_2} in our control group had tended to increase over time during CPB. Cook *et al.*[9] reported that the increase in Sjv_{O_2} appeared to be adapting to CPB flow conditions with time.

Croughwell *et al.*[14] reported that reduced Sjv_{O_2} during CPB was a risk factor for cerebral ischemia. There has been some controversy, however, regarding interpretation of Sjv_{O_2} during CPB.[15,16] Dexter and Hindman[16] recently reported that a high Sjv_{O_2} value during hypothermic CPB indicated impaired oxygen transfer from hemoglobin to the brain. They also found that during normothermia, increased oxygen extraction reduced Sjv_{O_2}, but that this reduction does not indicate an imbalance in either CBF or metabolism. In contrast, Hanel *et al.*[17] reported that maximal reduction in the Sjv_{O_2} value did not occur when blood–brain temperature gradients were at their maximum but rather occurred when the temperature gradients were small. To date, it is not clear whether reduced Sjv_{O_2} during hypothermic or normothermic CPB indicates an imbalance in CBF and metabolism.

Whether Sjv_{O_2} influences neurologic outcome after cardiac surgery remains unclear.[18] Murkin *et al.*[19] suggested that neurologic outcome may be poorer in patients with higher Sjv_{O_2} during CPB. Patients with risk factors for cerebral circulatory disturbance, however, have not been studied extensively in terms of whether the state of cerebral oxygenation as measured by the Sjv_{O_2} value has some effect on their neurologic outcome. Using a routine postoperative neurologic assessment, we did not detect any neurologic disorders in any of the patients. The possibility exists, however, that an extensive assessment of neurologic and cognitive function might have detected minor neurologic abnormalities. Further studies are needed to determine if any correlation exists between Sjv_{O_2} reduction and neurologic disorders.

In conclusion, reduced Sjv_{O_2} was observed more frequently in patients with preexisting DM or stroke during normothermic CPB. It is possible that cerebral circulation during normothermic CPB is altered in patients with risk factors for cerebrovascular disorder.

References

1. Roach GW, Kanchuger M, Mangano CM, Newman M, Nussmeier N, Wolman R, Aggarwal A, Marschall K, Graham SH, Ley C: Adverse cerebral outcomes after coronary bypass surgery. N Engl J Med 1996; 335:1857–63

2. McLean RF, Wong B: Normothermic versus hypothermic cardiopulmonary bypass: Central nervous system outcomes. J Cardiothorac Vasc Anesth 1996; 10:45–53

3. 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

4. Croughwell N, Lyth M, Quill TJ, Newman M, Greeley WJ, Smith R, Reves JG: Diabetic patients have abnormal cerebral autoregulation during cardiopulmonary bypass. Circulation 1990; 82(suppl):407–12

5. Mckhann GM, Goldsborough MA, Borowicz LM, Mellits ED, Brookmeyer R, Quaskey SA, Baumgartner WA, Cameron DE, Stuart RS, Gardner TJ: Predictors of stroke risk in coronary artery bypass patients. Ann Thorac Surg 1997; 63:516–21

6. Newman MF, Wolman R, Kanchuger M, Marschall K, Mangano CM, Roach G, Smith LR, Aggarwal A, Nussmeier N, Herskowitz A, Mangano DT: Multicenter preoperative stroke risk index for patients undergoing coronary artery bypass graft surgery. Circulation 1996; 94(suppl):II74–80

7. Dandona P, James IM, Newbury PA, Woollard ML, Beckett AG: Cerebral blood flow in diabetes mellitus: Evidence of abnormal cerebrovascular reactivity. BMJ 1978; 29:325–6

8. Maeda H, Matsumoto M, Handa N, Hougaku H, Ogawa S, Itoh T, Tsukamoto Y, Kamada T: Reactivity of cerebral blood flow to carbon dioxide in various types of ischemic cerebrovascular disease: Evaluation by the transcranial Doppler method. Stroke 1993; 24:670–5

9. 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

10. Grubhofer G, Lassnigg AM, Schneider B, Rajek MA, Pernerstorfer T, Hiesmayr MJ: Jugular venous bulb oxygen saturation depends on blood pressure during cardiopulmonary bypass. Ann Thorac Surg 1998; 65:653–8

11. Hessel EA: Jugular venous bulb oxygen saturation depends on blood pressure during cardiopulmonary bypass [invited commentary]. Ann Thorac Surg 1998; 65:658

12. Kadoi Y, Kawahara F, Saito S, Morita T, Kunimoto F, Goto F, Fujita N: Effects of hypothermic and normothermic cardiopulmonary bypass on brain oxygenation. Ann Thorac Surg 1999; 68:34–9

13. Kawahara F, Kadoi Y, Saito S, Yoshikawa D, Goto F, Fujita N: Balloon pump induced pulsatile perfusion during cardiopulmonary bypass does not improve brain oxygenation. J Thorac Cardiovasc Surg 1999; 118:361–6

14. Croughwell ND, Newman MF, Blumenthal JA, White WD, Lewis JB, Frasco PE, Smith LR, Thyrum EA, Hurwitz BJ, Leone BJ, Schell RM, Reves JG: Jugular bulb saturation and cognitive dysfunction after cardiopulmonary bypass. Ann Thorac Surg 1994; 58:1702–8

15. Dexter F, Hindman BJ: Theoretical analysis of cerebral venous blood hemoglobin oxygen saturation as an index of cerebral oxygenation during hypothermic cardiopulmonary bypass. ANESTHESIOLOGY 1995; 83:405–12

16. Hindman BJ: Jugular venous hemoglobin desaturation during rewarming on cardiopulmonary bypass. ANESTHESIOLOGY 1998; 89:19–23

17. Hanel F, Knobelsdorff G, Werner C, Esch JS: Hypercapnia prevents jugular bulb desaturation during rewarming from hypothermic cardiopulmonary bypass. ANESTHESIOLOGY 1998; 89:19–23

18. Newman MF, Kramer D, Croughwell ND, Sanderson I, Blumenthal JA, White WD, Smith LR, Towner EA, Reves JG: Differential age effects of mean arterial pressure and rewarming on cognitive dysfunction after cardiac surgery. Anesth Analg 1995; 81:236–42

19. Murkin JM, Martzke JS, Bauchan AM, Bentley RN, Wong CJ: A randomized study of the influence of perfusion technique and pH management strategy in 316 patients undergoing coronary artery bypass surgery. J Thorac Cardiovasc Surg 1995; 110:349–62