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□ Clinical Research Article □

Assessment of cerebral oxygen supply-demand balance by near-infrared spectroscopy during induction of anesthesia in patients undergoing coronary artery bypass graft surgery: comparison of midazolam with propofol

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Background: Near-infrared spectroscopy (NIRS) continuously measures regional cerebral oxygen saturation (rSO_2) noninvasively and has been shown to detect even small changes in cerebral oxygen supply-demand balance. Although widely used, only the effect of midazolam on cerebral blood flow has been studied in humans and evidence is lacking about its effect on cerebral metabolic rate. We therefore evaluated the effect of midazolam on cerebral oxygen supply-demand balance with NIRS.

Methods: Sixty patients undergoing elective coronary artery bypass graft surgery were randomly allocated into either midazolam (n = 30) or propofol (n = 30) group. rSO_2 was recorded before induction while patients were breathing room air as baseline, after pre-oxygenation with 100% oxygen, after administration of either midazolam or propofol, after completion of administration of sufentanil and after tracheal intubation. Hemodynamic variables including cardiac index and mixed venous oxygen saturation were recorded at the same time points.

Results: rSO_2 and hemodynamic variables were similar between the groups throughout the study period. After pre-oxygenation, rSO_2 significantly increased compared to baseline in each group, and did not show any additional increase after administration of either midazolam or propofol and sufentanil in both groups.

Conclusions: Midazolam preserves cerebral blood flow-metabolism coupling to a similar degree to propofol as assessed by near infrared spectroscopy. **(Korean J Anesthesiol 2009; 57: 428～33)**

Key Words: Cerebral oxygen supply-demand balance, Coronary artery bypass graft surgery, Midazolam, Near-infrared spectroscopy, Propofol.

INTRODUCTION

During induction of general anesthesia, tracheal intubation can be far more stimulating than surgical incision requiring profound depth of anesthesia often at the expense of hypotension and bradycardia which may result in decreased cardiac output and myocardial ischemia [1,2]. Various induction agents and techniques have been introduced for patients with coronary artery occlusive disease. Among them, combination of either midazolam or propofol with sufentanil is being widely used with numerous studies reporting their hemodynamic stability [3-5].

In addition to their safety profile in hemodynamic stability, propofol and sufentanil have been well studied in human subjects in terms of cerebral oxygen supply-demand balance with both agents decreasing cerebral blood flow and metabolism to a similar degree [6-8]. Although widely used, only the effect of midazolam on cerebral blood flow has been studied in humans and evidence is lacking about its effect on cerebral metabolic rate [9,10].

Near-infrared spectroscopy (NIRS) continuously measures regional cerebral oxygen saturation (rSO_2) noninvasively and has

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been shown to detect even small changes in cerebral oxygen supply-demand balance elicited by etomidate [11-13]. rSO_2 scores are also affected by many factors including changes in hemodynamic status, which is more prone to occur during induction of general anesthesia in patients with ischemic heart disease [14,15]. By far, no comprehensive data exists regarding the influence of midazolam and hemodynamic changes on rSO_2 scores during the induction period.

We, therefore, evaluated the effect of midazolam on cerebral oxygen supply-demand balance by continuous monitoring of rSO_2 in a prospective, randomized and controlled trial with concomitant monitoring of hemodynamic variables including cardiac index (CI) and mixed venous oxygen saturation (SvO_2).

MATERIALS AND METHODS

This was a prospective, randomized and controlled study. After institutional review board approval and with written informed consent, 60 patients scheduled for isolated off-pump coronary artery bypass graft surgery (OPCAB) between August 2006 and March 2007 were studied. Patients undergoing emergent surgery and those with pre-existing neurologic disease, lung parenchymal disease, NYHA functional class ≥ 3, left ventricular ejection fraction $< 40\%$, unstable angina and recent myocardial infarction within 1 month were excluded. Patients who had significant luminal narrowing of either carotid and/or vertebral arteries on preoperative angiography were also excluded. All cardiovascular medications except diuretics were continued until the day of surgery.

Patients were randomly allocated into either midazolam (n = 30) or propofol (n = 30) group by a computerized randomization table. Only the anesthesiology nurse, who prepared the drugs, was aware of the randomization result and the syringes containing the drugs were wrapped with non-transparent black vinyl for blinding.

Upon arrival at the operating room, standard monitoring devices were applied and a radial artery catheter was inserted under local anaesthesia for continuous blood pressure monitoring. Also, a pulmonary artery catheter (Swan-Ganz CCOmbo® CCO/SvO_2, Edwards Lifesciences LLC, USA) was inserted via the right internal jugular vein under local anesthesia for continuous measurement of CI and SvO_2. Bispectral index (A-2000™, Aspect Medical Systems, Natwick, MA, USA) and rSO_2 (INVOS 5100™, Somanetics, Troy, MI, USA) were continuously monitored with both sensors applied to the forehead of the patients.

Hemodynamic variables, BIS and rSO_2 scores were recorded at the following time points; before induction while patients were breathing room air (T1, baseline), after pre-oxygenation with 100% oxygen for at least 3 min through tight-fitting anesthetic mask (T2), 3 min after administration of either midazolam 0.05 mg/kg or propofol 1 mg/kg according to randomization (T3), 3 min after completion of administration of sufentanil 1.5－2 ㎍/kg (T4) and 5 min after tracheal intubation (T5). The chosen doses of the drugs are conventionally used doses for induction of anesthesia in Korean patients undergoing OPCAB which provide sufficient depth of anesthesia without recall.

Arterial blood gas analyses were performed at T1 and T5. Venous blood gas analysis was performed only at T1 for calibration of SvO_2. End-tidal carbon dioxide tension ($Et\text{-}CO_2$) was monitored with side-stream capnography of the anesthesia machine (Primus, Dräger, Lübeck, Germany) and also recorded at T2, T3, T4 and T5. During T3 and T4, the patients' ventilation were manually assisted to obtain same level of $Et\text{-}CO_2$ as T2 at a peak airway pressure < 15 mmHg. Tracheal intubation was facilitated with rocuronium bromide 0.9 mg/kg which was administered either after the patients no longer obeyed to verbal command to open their eyes or BIS score was below 60. After tracheal intubation, the lungs were ventilated with a tidal volume of 8－10 ml/kg, at a rate of 8－12 breaths/min in 100% oxygen to obtain the same level of $Et\text{-}CO_2$ as T2 without positive end-expiratory pressure during the study period.

During induction of anesthesia, 6－8 ml/kg of isotonic crystalloid solution was infused in all patients. Phenylephrine 100 ㎍ was administered when the mean systemic arterial pressure (MAP) was decreased to below 60 mm Hg. Hemodynamic variables and rSO_2 scores before and after phenylephrine administration were also recorded.

Statistical analyses were performed using SPSS 12.0 (SPSS Inc., Chicago, IL, USA). Data were assessed for normal distribution of variance with Kolmogorov-Smirnov test. All data are expressed as number of patients or mean ± SD. We determined that 22 patients would be required in each group with 90% power to detect a 10% difference in rSO_2 score between the groups with a SD of 10% and alpha level of 0.05. Data between the groups were compared using Chi-square test, Fisher's exact test or independent t-test as appropriate. Changes between time points within the groups were compared using repeated-measures of ANOVA. A P value of less than 0.05

was considered as statistically significant.

RESULTS

Data from 60 patients were analyzed. Patients' characteristics were similar between the two groups (Table 1).

Changes in BIS and rSO_2 scores are shown in Table 2. BIS scores were significantly higher at T1, T2, T3 and lower at T4 in the midazolam group. At T3, after administration of either midazolam or propofol, 27 patients in the midazolam group and all patients in the propofol group did not respond to verbal command to open their eyes, despite BIS scores being over 60 in 25 and 14 patients in each group, respectively. BIS scores in all patients fell below 60 after administration of sufentanil at T4 and none of the patient had recall afterwards. The rSO_2 scores were similar between the groups throughout the study period. After pre-oxygenation at T2, rSO_2 scores were significantly increased compared to baseline scores at T1 in each group, and did not show any additional increase after administration of either midazolam or propofol and sufentanil in both groups. The rSO_2 scores at T5, 5 min after tracheal intubation bore no statistical significance compared to values of all other time points including baseline value in both groups.

Arterial oxygen saturations measured by pulse oximetry were similar between the groups and were significantly increased after pre-oxygenation and remained constant thereafter throughout the study period in each group (Table 2). Arterial oxygen tensions were 89 ± 16 mmHg, 391 ± 74 mmHg in the midazolam group and 86 ± 11 mmHg, 412 ± 70 mmHg in the propofol group at T1 and T5, respectively with both groups showing significant increase compared to baseline values at T1 of each group. Hematocrit concentrations were 37 ± 4%, 33 ± 4% in the midazolam group and 38 ± 4%, 35 ± 4% in the propofol group at T1 and T5, respectively with both groups showing significant decrease compared to baseline values at T1 of each group without any significant difference between the groups. Arterial carbon dioxide tensions were 38 ± 2 mmHg, 38 ± 4 mmHg in the midazolam group and 39 ± 3 mmHg, 38 ± 3 mmHg in the propofol group at T1 and T5, respectively without any significant differences between the groups. pH at T1 and T5 were all 7.45 ± 0.03 in both

Table 1. Patients' Characteristics

	Midazolam (n = 30)	Propofol (n = 30)	P value
Age (yr)	65 ± 6	63 ± 9	0.407
Gender (M/F)	20/10	20/10	1.000
Body surface area (m^2)	1.7 ± 0.2	1.7 ± 0.2	0.772
Diabetes (n)	14	9	0.117
Hypertension (n)	18	20	0.762
Preoperative medication (n)			
Nitrate	2	7	0.144
β-blockers	21	20	0.779
Calcium channel blockers	13	20	0.194
RAS antagonists	8	7	0.769
LVEF (%)	59 ± 12	63 ± 11	0.253

Values are mean ± SD or number of patients. No significant differences were observed between the groups. RAS: renin-angiotensin system, LVEF: left ventricular ejection fraction.

Table 2. Changes in Bispectral Index (BIS), Regional Cerebral Oxygen Saturation (rSO_2), Arterial Oxygen Saturation (SaO_2) and End Tidal Carbon Dioxide Tension ($Et\text{-}CO_2$)

	Group	T1	T2	T3	T4	T5
BIS	Midazolam	95 ± 3*	94 ± 5*	71 ± 10*,†,‡	41 ± 6*,†,‡	41 ± 9†
	Propofol	93 ± 4	91 ± 6	58 ± 15†,‡	45 ± 7†,‡	43 ± 8†
rSO_2L (%)	Midazolam	65 ± 9	72 ± 9†	74 ± 9†	72 ± 9†	70 ± 9
	Propofol	66 ± 7	74 ± 8†	74 ± 8†	73 ± 9†	70 ± 9
rSO_2R (%)	Midazolam	64 ± 10	71 ± 9†	73 ± 9†	71 ± 9†	68 ± 9
	Propofol	66 ± 7	74 ± 8†	74 ± 8†	73 ± 10†	70 ± 10
SaO_2 (%)	Midazolam	95.9 ± 2.2	99.7 ± 0.5†	99.8 ± 0.4†	99.0 ± 0.4†	99.5 ± 0.3†
	Propofol	95.8 ± 3.4	99.7 ± 0.9†	99.9 ± 0.2†	99.9 ± 0.2†	99.9 ± 0.3†
$Et\text{-}CO_2$ (mmHg)	Midazolam		35 ± 4	35 ± 5	34 ± 4	34 ± 3
	Propofol		35 ± 2	35 ± 3	34 ± 3	34 ± 3

Values are mean ± SD. L: left, R: right, T1: while patients were breathing room air, T2: 3 min after breathing 100% oxygen through tight-fitting anesthetic mask, T3: 5 min after administration of either midazolam 0.05 mg/kg or propofol mg/kg, T4: 3 min after completion of administration of sufentanil 1.5−2 mg/kg, T5: 5 min after tracheal intubation. *$P < 0.05$ compared to propofol group, †$P < 0.05$ vs T1, ‡$P < 0.05$ compared to value of the previous time point.

Table 3. Changes in Hemodynamic Variables

	Group	T1	T2	T3	T4	T5
CI (L/min/m^2)	Midazolam	3.0 ± 0.6	3.1 ± 0.6	3.2 ± 0.6	3.2 ± 0.6	3.1 ± 0.6
	Propofol	3.0 ± 0.5	3.0 ± 0.4	3.0 ± 0.5	3.1 ± 0.4	3.2 ± 0.6
SvO_2 (%)	Midazolam	74 ± 3	82 ± 5*	85 ± 6*	82 ± 6*	82 ± 9*
	Propofol	76 ± 3	82 ± 5*	84 ± 5*	83 ± 6*	82 ± 6*
MAP (mmHg)	Midazolam	97 ± 14	99 ± 14	84 ± 15*,†	70 ± 11*,†	75 ± 16*
	Propofol	101 ± 20	103 ± 12	84 ± 12*,†	70 ± 9*,†	79 ± 11*
CVP (mmHg)	Midazolam	7 ± 3	6 ± 3	7 ± 3	7 ± 3	7 ± 3
	Propofol	7 ± 3	7 ± 3	8 ± 2	7 ± 2	7 ± 2

Values are mean ± SD. T1: while patients were breathing room air, T2: 3 min after breathing 100% oxygen through tight-fitting anesthetic mask, T3: 5 min after administration of either midazolam 0.05 mg/kg or propofol mg/kg, T4: 3 min after completion of administration of sufentanil 1.5−2 mg/kg, T5: 5 min after tracheal intubation, CI: cardiac index, SvO_2: mixed venous oxygen saturation, MAP: mean systemic arterial pressure, CVP: central venous pressure. *P < 0.05 vs T1, †P< 0.05 compared to value of the previous time point.

Table 4. Changes in Regional Cerebral Oxygen Saturation (rSO_2) Scores and Hemodynamic Variables of the 23 Patients Who Required Phenylephrine Administration

	T3	Before phenylephrine	After phenylephrine
rSO_2L (%)	76 ± 7	75 ± 7	75 ± 8
rSO_2R (%)	76 ± 7	75 ± 7	75 ± 8
CI (L/min/m^2)	3.0 ± 0.6	3.0 ± 0.6	3.0 ± 0.5
SvO_2 (%)	83 ± 4	83 ± 4	82 ± 6
MAP (mmHg)	79 ± 11	56 ± 4*	74 ± 10†
CVP (mmHg)	7 ± 2	7 ± 2	7 ± 3

Values are mean (SD). T3: 5 min after administration of either midazolam 0.05 mg/kg or propofol 1 mg/kg, L: left, R: right, CI: cardiac index, SvO_2: mixed venous oxygen saturation, MAP: mean systemic arterial pressure, CVP: central venous pressure. *P < 0.05 vs T3, †P < 0.05 vs before phenylephrine.

groups. Et-CO_2 from T2 to T5 were similar between the groups with no significant differences between each time points within group (Table 2).

Changes in hemodynamic variables are shown in Table 3. CI and central venous pressure (CVP) were similar between the groups throughout the study period with no significant differences between each time points within group. SvO_2 and MAP were also similar between the groups throughout the study period. SvO_2 was increased in both groups at T2, T3, T4 and T5 compared to baseline values of each group. MAP was decreased in both groups at T3, T4 and T5 compared to baseline values of each group.

Phenylephrine bolus to maintain MAP at predefined level was administered to 12 and 11 patients in the midazolam and propofol group, respectively. All phenylephrine boluses were required during or after sufentanil administration. In the 23 patients, MAP was decreased to a range of 51−60 mmHg and significantly increased after phenylephrine administration with no significant changes in rSO_2 scores (Table 4).

None of the patients developed ECG changes indicative of ischemia during the study period.

DISCUSSION

In this study, we could observe that midazolam preserves cerebral blood flow-metabolism coupling to a similar degree to propofol as assessed by NIRS. We could also observe that pre-oxygenation alone causes significant increase in rSO^2 scores and that neither midazolam nor propofol with sufentanil exerted additional increase on rSO_2 scores. Transient decrease in MAP after sufentanil administration to a range of 51−60 mm Hg and subsequent increase with phenylephrine bolus was not associated with significant changes in rSO_2 scores.

NIRS noninvasively provides continuous, real-time rSO_2 and is being increasingly used to detect disturbances in cerebral oxygen supply-demand balance, especially in carotid endarterectomy and cardiac surgeries [16,17]. It also has been validated to detect even small changes in cerebral oxygen supply-demand balance elicited by administration of etomidate during propofol anesthesia [13]. However, to evaluate subtle changes in cerebral oxygen supply-demand balance with NIRS after administration of a certain drug, other factors affecting rSO_2 scores such as hemodynamic variables and hematocrit concentration should also be assessed and taken into consideration [18-21]. In addition, to avoid confounding effects of other anesthetic drugs, which are known to affect cerebral

blood flow and/or metabolic rate, the drug which is to be evaluated should be administered exclusively. In accordance, we have assessed the effects of midazolam on cerebral oxygen supply-demand balance by NIRS, with strict control of arterial pH by maintaining Et-CO_2 constant at its pre-induction value and concomitant monitoring of beat to beat hemodynamic changes including CI and SvO_2. The reason we concomitantly monitored SvO_2 was that, in case of constant cardiac output, any changes in SvO_2 may reflect significant changes in the oxygen extraction ratio of major organs including the brain, which implies changes in oxygen supply-demand balance [22,23]. We also administered midazolam exclusively before any other anesthetics and used propofol as active control. Propofol already has been well studied in terms of preserving cerebral oxygen supply-demand balance in human subjects by reducing both cerebral blood flow and metabolic rate to a similar degree [7,24].

As our results indicate, arterial oxygen saturation, Et-CO_2 and SvO_2 remained constant after pre-oxygenation within each group and were also similar between the groups at all time points. CI, MAP and CVP were similar between the groups throughout the study period. CI and CVP also remained constant in both groups compared to baseline values of each group throughout the study period. Although MAP significantly decreased in both groups after administration of either midazolam or propofol compared to values of T1 and T2 of each group, it was well within the range of cerebral autoregulation. Midazolam, propofol and sufentanil are all known to preserve cerebral autoregulation [7,8,10]. The independence of MAP and rSO_2 scores, shown when MAP was further decreased to below 60 mmHg after administration of sufentanil and subsequently increased with phenylephrine in the 23 patients, indicate preserved cerebral autoregulation and that MAP is an unlikely contributing confounder to the observed rSO_2 scores [25]. Under the above mentioned conditions, the observed rSO_2 scores assessed by NIRS indicate that midazolam preserves cerebral oxygen supply-demand balance to a similar degree as propofol.

Interestingly, Stoneham and Martin have reported reversing signs of neurological deficit following cross clamping of carotid artery by administration of 100% oxygen probably due to increase of the mitochondrial oxygen tension above the critical level to restart oxidative phosphorylation in ischemic cerebral neurones [26]. In accordance, Baraka et al [27] have reported significant increase of rSO_2 scores assessed by NIRS after administration of 100% oxygen in 6 awake patients. They also reported that induction of general anesthesia resulted in further increase in rSO_2 scores suggesting that monitoring of enhanced cerebral oxygen supply-demand balance by NIRS while applying high inspired oxygen fraction and induction of general anesthesia may decrease the need for shunting of the carotid artery. We could also observe similar results with high inspired oxygen fraction and rSO_2 scores in all 60 patients supporting their suggestion. However, we could not observe additional significant increase in rSO_2 scores after induction of general anesthesia. This observation may be in part attributed to decrease in hematocrit concentration as a result of hemodilution induced by administration of 6－8 ml/kg of isotonic crystalloid solution during the induction period [28].

The limitations of our study are as follows. First, the rSO_2 probes in this study were attached in the forehead measuring rSO_2 of the watershed territory corresponding to the junction of anterior and middle cerebral artery [11]. Thus, our results may not accurately reflect changes of global cerebral oxygen supply-demand balance, although we have excluded patients with significant luminal narrowing of the carotid and vertebral arteries.

In conclusion, in addition to its' safety profile regarding hemodynamic stability, midazolam preserves cerebral oxygen supply-demand balance to a similar degree to propofol as assessed by NIRS during induction of anesthesia. The balance was maintained even when MAP was decreased to 51 mmHg, with intact cerebral autoregulation observed as independence of rSO_2 scores and changes in MAP. The finding that pre-oxygenation alone caused significant increase in rSO_2, merits further studies to evaluate its potentially beneficial effect on reversing neurological deficits and the role of NIRS as the monitoring device.

REFERENCES

1. Vuyk J, Lim T, Engbers FH, Burm AG, Vletter AA, Bovill JG. The pharmacodynamic interaction of propofol and alfentanil during lower abdominal surgery in women. Anesthesiology 1995; 83: 8-22.
2. Zbinden AM, Maggiorini M, Petersen-Felix S, Lauber R, Thomson DA, Minder CE. Anesthetic depth defined using multiple noxious stimuli during isoflurane/oxygen anesthesia. I. Motor reactions. Anesthesiology 1994; 80: 253-60.
3. Lehmann A, Zeitler C, Thaler E, Isgro F, Boldt J. Comparison of two different anesthesia regimens in patients undergoing aorto-coronary bypass grafting surgery: sufentanil-midazolam versus re-

mifentanil-propofol. J Cardiothorac Vasc Anesth 2000; 14: 416-20.
4. Kleinschmidt S, Grundmann U, Janneck U, Kreienmeyer J, Kulosa R, Larsen R. Total intravenous anaesthesia using propofol, gamma-hydroxybutyrate or midazolam in combination with sufentanil for patients undergoing coronary artery bypass surgery. Eur J Anaesthesiol 1997; 14: 590-9.
5. van der Maaten JM, Epema AH, Huet RC, Hennis PJ. The effect of midazolam at two plasma concentrations of hemodynamics and sufentanil requirement in coronary artery surgery. J Cardiothorac Vasc Anesth 1996; 10: 356-63.
6. Oshima T, Karasawa F, Satoh T. Effects of propofol on cerebral blood flow and the metabolic rate of oxygen in humans. Acta Anaesthesiol Scand 2002; 46: 831-5.
7. Vandesteene A, Trempont V, Engelman E, Deloof T, Focroul M, Schoutens A, et al. Effect of propofol on cerebral blood flow and metabolism in man. Anaesthesia 1988; 43(Suppl): 42-3.
8. Stephan H, Groger P, Weyland A, Hoeft A, Sonntag H. The effect of sufentanil on cerebral blood flow, cerebral metabolism and the CO_2 reactivity of the cerebral vessels in man. Anaesthesist 1991; 40: 153-60.
9. Veselis RA, Reinsel RA, Beattie BJ, Mawlawi OR, Feshchenko VA, DiResta GR, et al. Midazolam changes cerebral blood flow in discrete brain regions: an $H_2{}^{(15)}O$ positron emission tomography study. Anesthesiology 1997; 87: 1106-17.
10. Forster A, Juge O, Morel D. Effects of midazolam on cerebral blood flow in human volunteers. Anesthesiology 1982; 56: 453-5.
11. Taillefer MC, Denault AY. Cerebral near-infrared spectroscopy in adult heart surgery: systematic review of its clinical efficacy. Can J Anaesth 2005; 52: 79-87.
12. Owen-Reece H, Smith M, Elwell CE, Goldstone JC. Near infrared spectroscopy. Br J Anaesth 1999; 82: 418-26.
13. Lovell AT, Owen-Reece H, Elwell CE, Smith M, Goldstone JC. Continuous measurement of cerebral oxygenation by near infrared spectroscopy during induction of anesthesia. Anesth Analg 1999; 88: 554-8.
14. Hung YC, Huang CJ, Kuok CH, Chen CC, Hsu YW. The effect of hemodynamic changes induced by propofol induction on cerebral oxygenation in young and elderly patients. J Clin Anesth 2005; 17: 353-7.
15. Madsen PL, Secher NH. Near-infrared oximetry of the brain. Prog Neurobiol 1999; 58: 541-60.
16. Cuadra SA, Zwerling JS, Feuerman M, Gasparis AP, Hines GL. Cerebral oximetry monitoring during carotid endarterectomy: effect of carotid clamping and shunting. Vasc Endovascular Surg 2003; 37: 407-13.
17. Yao FS, Tseng CC, Ho CY, Levin SK, Illner P. Cerebral oxygen desaturation is associated with early postoperative neuropsychological dysfunction in patients undergoing cardiac surgery. J Cardiothorac Vasc Anesth 2004; 18: 552-8.
18. Yoshitani K, Kawaguchi M, Iwata M, Sasaoka N, Inoue S, Kurumatani N, et al. Comparison of changes in jugular venous bulb oxygen saturation and cerebral oxygen saturation during variations of haemoglobin concentration under propofol and sevoflurane anaesthesia. Br J Anaesth 2005; 94: 341-6.
19. Akca O, Liem E, Suleman MI, Doufas AG, Galandiuk S, Sessler DI. Effect of intra-operative end-tidal carbon dioxide partial pressure on tissue oxygenation. Anaesthesia 2003; 58: 536-42.
20. Torella F, Haynes SL, McCollum CN. Cerebral and peripheral oxygen saturation during red cell transfusion. J Surg Res 2003; 110: 217-21.
21. Torella F, Cowley RD, Thorniley MS, McCollum CN. Regional tissue oxygenation during hemorrhage: can near infrared spectroscopy be used to monitor blood loss? Shock 2002; 18: 440-4.
22. Cariou A, Monchi M, Dhainaut JF. Continuous cardiac output and mixed venous oxygen saturation monitoring. J Crit Care 1998; 13: 198-213.
23. Reinhart K, Kuhn HJ, Hartog C, Bredle DL. Continuous central venous and pulmonary artery oxygen saturation monitoring in the critically ill. Intensive Care Med 2004; 30: 1572-8.
24. Stephan H, Sonntag H, Schenk HD, Kohlhausen S. Effect of Disoprivan (propofol) on the circulation and oxygen consumption of the brain and CO_2 reactivity of brain vessels in the human. Anaesthesist 1987; 36: 60-5.
25. Jalowiecki P, Pioro A, Dziurdzik P, Karawczyk L, Karpel E, Dyaczynska-Herman A. Regional cerebral oxygenation monitoring in children undergoing elective scoliosis surgery with controlled urapidil induced hypotension. Med Sci Monit 1998; 4: 987-92.
26. Stoneham MD, Martin T. Increased oxygen administration during awake carotid surgery can reverse neurological deficit following carotid cross-clamping. Br J Anaesth 2005; 94: 582-5.
27. Baraka AS, Nawfal M, El-Khatib M, Haroun-Bizri S. Regional cerebral oximetry after oxygen administration. Br J Anaesth 2005; 95: 720.
28. Han SH, Ham BM, Oh YS, Bahk JH, Ro YJ, Do SH, et al. The effect of acute normovolemic haemodilution on cerebral oxygenation. Int J Clin Pract 2004; 58: 903-6.