Original Article

Relationship Between Cerebral Oximetry Monitoring and Mixed Venous Oxygen Saturation During Cardiopulmonary Bypass and Postoperative Cognitive Impairment

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ABSTRACT

Background: We assessed the relationship between postoperative cognitive impairment and cerebral oximetry (INVOS) and mixed venous oxygen saturation (SvO_2) during cardiopulmonary bypass (CPB).

Methods: This observational cohort study enrolled 110 patients and divided them into 2 groups of 55 subjects. After the exclusion of 5 patients in the SvO_2 group and 3 in the INVOS group, the final analysis was conducted on 50 and 52 patients in the former and latter groups, respectively. The Mini-Mental State Examination (MMSE) score was used to assess cognitive impairment in the patients on the second and third postoperative days. SPSS software, version 24, was used for statistical analysis.

Results: On the second postoperative day, the frequency of cognitive dysfunction was 4% in the SvO_2 group and 3.8% in the INVOS group (P = 0.73). Three days after surgery, the incidence of cognitive dysfunction in the SvO_2 and INVOS groups was 2% and 1.9% (P = 0.49), respectively. No statistically significant difference was observed between the 2 groups concerning the incidence of cognitive dysfunction after surgery with CPB.

Conclusions: Our results indicated that cerebral tissue perfusion monitoring by INVOS could be replaced with the SvO_2 approach without increasing the incidence of cognitive dysfunction compared with INVOS in adult cardiac surgery using CPB. ***(Iranian Heart Journal 2024; 25(1): 66-73)***

KEYWORDS: Cardiopulmonary bypass, Cognitive disorders, Tissue perfusion, Cerebral oxygen saturation, Mixed venous oxygen saturation

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Cardiopulmonary bypass (CPB) was first introduced by Gibbons in 1953.[1, 2] The approach enables surgical teams to enhance the survival and life quality of patients suffering from cardiovascular disease.[3, 4]

CPB is a common technique used during cardiac surgery to support the circulation of the patient. In this process, a heart-lung machine takes over the function of the lungs and heart.[5] However, CPB might result in some complications,[6, 7] such as impairment of neuropsychological cognition, mental abilities, concentration, and short- and long-term memory.[8-10] Several patients suffer from complications related to the central nervous system after heart surgery.[11-14] These complications are not limited to the central nervous system and may include excessive bleeding, systemic inflammation, and cardiac, pulmonary, renal, and cognitive dysfunction.[15, 16]

Cognitive impairment can help identify cerebral ischemia. Peripheral inflammatory markers result in postoperative cognitive dysfunction, a prevalent complication of cardiac and noncardiac operations.[17, 18] After CPB, cognitive dysfunction involves various types of impairment in orientation, timing, memory,[19-24] writing, and reading.[25-29] To identify contributing factors, an objective neurological assessment requires a practical device.[18]

Tissue perfusion parameters should be measured easily, swiftly, and noninvasively without needing advanced skills.[12, 30] Global tissue perfusion is indicated by some popular biomarkers of tissue perfusion, including central venous oxygen saturation and serum lactate.[31] INVOS has been used to continuously monitor cerebral saturation besides monitoring vital signs, such as respiratory rate, heart rate, and blood pressure.[32] Near-infrared spectroscopies can measure the brain's regional hemoglobin O_2 saturation under the probe by INVOS. INVOS is also employed in other tissues for monitoring their adequacy of perfusion.[33] A noninvasive, reliable, and easy-to-use monitor of global oxygen balance could be beneficial for a wider group of patients at risk for surgery and anesthesia.[34] Monitoring venous saturation, as an indirect procedure of systemic perfusion, could benefit pediatric patients after cardiac surgery for assessing oxygen delivery.[35]

Patients undergoing cardiac surgery whose regional cerebral O_2 saturation (rSO_2) is noticeably reduced compared with baseline values are more prone to overall major organ dysfunction, lengthened intensive care unit (ICU) and hospital stays, delirium, and postoperative cognitive decline.[36] Schmidt et al[37] investigated the influence of systemic oxygenation on cerebral O_2 saturation. During extubated cardiac surgery, they investigated whether there was a difference in the correlation between rSO_2 measured with ForeSight Elite cerebral oximeters and INVOS with SvO_2 by altering systemic oxygenation in patients. Different reactions to the relationship between SvO_2 and variations in systemic oxygenation have been observed in cerebral oximeters. The results cast doubt over the interchangeable use of these devices.

Garcia et al[38] hypothesized that rSO_2 could guide red blood cell transfusion in high-risk cardiac surgery.

In the present study, we compared the frequency of cognitive disorders on the second and third postoperative days between 2 groups monitored by mixed venous O_2 saturation (SvO_2) and cerebral O_2 saturation (INVOS) measured by tissue perfusion monitoring during CPB.

METHODS

The study protocol of this prospective observational cohort study was approved by our institutional ethics committee. Patients were enrolled after they provided written informed consent. The sample size was considered at a significance level of 0.05 and a test power of 80% with the assumption that the occurrence of cognitive disorders through interventions based on tissue perfusion monitoring by measuring the oxygen saturation of the venous mixture compared with the measurement of the oxygen saturation of the brain tissue did not exceed 24%. To be considered statistically significant, according to the following formula, the sample size in each group was determined to be 49:

$$n = \frac{(z_{1-\alpha} + z_{1-\beta})^2 (p_1 q_1 + p_2 q_2)}{d^2}$$

$$p_1 = 0.28 \quad p_2 = 0.52$$

Considering probable loss to follow-up, 55 patients were assigned to each group (the SvO_2 and INVOS groups). After the exclusion of 5 patients in the SvO_2 group and 3 patients in the INVOS group, we finally analyzed 50 and 52 patients in the former and latter arms, respectively.

The data for the study were collected in the operating rooms of a university hospital after the approval of the ethics committee of the hospital. The patients' age ranged from 18 to 60 years. Inclusion criteria were ejection fractions above 25%, nonpulsating flow pumps, 20-40 μm arterial filters in CPB, and blood gas controls. No known heart arrhythmia, no cognitive impairment diagnosed based on the Mini-Mental State Examination (MMSE) before surgery, no kidney failure, no carotid artery stenosis, no diabetes, no metabolic syndrome, and no pregnancy. Exclusion criteria were reduced hemoglobin (> 7 g/dL), increased body temperature (> 37.5 °C), decreased hypothermia (< 32 °C), pump time between 20 minutes and 120 minutes, diminished mean arterial pressure (< 60 mm Hg), no extubation within 2 days after surgery, decreased venous blood saturation (< 60%), decreased arterial blood saturation (< 90%), and diminished arterial CO_2 pressure (< 30 mm Hg).

No cognitive dysfunction or neurological problems were found in the patients in the preoperative phase. Similar clinical conditions were considered for both groups. To evaluate the accuracy of the results obtained by INVOS, we used arterial blood gas (ABG). The same anesthesia protocol was employed for the study population. Heparinization was established and followed by mild hypothermic CPB at 32 °C with 2–2.5 l/min flow rates. CO_2 partial pressure was maintained between 35 mm Hg and 45 mm Hg, mean arterial pressure above 60 mm Hg, and hematocrit at 22%. The single-clamp method was generally utilized. Rewarming occurred in approximately half an hour at a low rate during CPB to avoid hyperthermia.

The results of the cognitive evaluation were recorded on the second and third days after surgery. The patients were monitored during CPB using either cerebral oximetry or SVO_2 with standardized monitoring. Two and 3 days after surgery, the MMSE questionnaire was completed in the ICU. The questionnaire, designed and compiled in 1975, is a screening tool with 30 questions measuring the severity of cognitive impairment and cognitive changes in 6 fields quantitatively. These areas include orientation time and place, recording 3 words, paying attention and calculating, remembering 3 words, language and its skills, and visual structural skills. The maximum score of the test is 30, with lower scores indicating more severe cognitive problems. Scores of 0 to 10 denote severe cognitive impairment, 11 to 20 moderate cognitive impairment, 21 to 26 mild cognitive impairment, and 27 to 30 normal cognition. [25] Additionally, sex, age, body surface area, and body mass index were recorded and compared between the groups. MMSE was used to examine the patients, and the results of the 2 groups were compared using the questionnaire.

Statistical Analysis

The collected data were entered into IBM SPSS Statistics for Windows, version 22.0 (IBM Corp, Armonk, NY, USA). The Kolmogorov-Smirnov test was used to evaluate normal distribution of the data. The χ^2 test was also conducted. The independent samples *t* test was used to compare the mean values of continuous variables between the study groups. Confounding factors were managed as much as possible through the selection of homogenous patients in both groups by considering rigorous inclusion and exclusion criteria. The criteria were explained in the METHODS. Thus, the need for a multivariate analysis was obviated. A *P* value $\leq$ 0.05 was considered statistically significant in this study.

RESULTS

The groups were homogenous in terms of demographic variables, clinical variables, and baseline, intraoperative, and postoperative data (Table 1 & Table 2), except for Nitroglycerin as vasodilator (P = 0.029).

On second and third days after surgery, MMSE scores was statistically different between the groups (P = 0.49 and P = 0.73, respectively). The incidence of cognitive disorder in the SvO_2 and INVOS group was 4% and 3.8%, respectively, with a p-value of 0.73 on the second day after the operation. As depicted in Table 3, on the third day of post-operation, the incidence of cognitive disorder in SvO_2 and INVOS groups was 2% and 1.9%, respectively with a p-value of 0.49.

Arterial oxygen saturation was measured at the beginning of surgery in 3 time intervals (every 20 min) as well as 3 minutes after the injection of cardioplegia in the SvO_2 group. Before anesthesia, levels of arterial oxygen saturation changes were recorded in the study groups.

Table 1: Demographic and Clinical Variables in the Study Groups.

	SvO_2 Group (n=50)	INVOS Group (n=52)	*P* value
Age, y	53.7±7.4	54.0±6.2	0.791
Sex (M/F)	35/15	42/10	0.206
Body surface area, m^2	1.87±0.2	1.88±0.16	0.80
CPB duration, min	76.5±13.4	78.1±14.6	0.58
Aortic cross-clamp duration, min	40.2±9.8	42.0±118	0.41
Preoperative EF, %	44.32±9.02	44.20±7.09	0.28
Postoperative EF, %	46.25±8.21	47.9±7.36	0.93

EF: ejection fraction; SvO2: mixed venous oxygen saturation

Table 2: Usage* of Vasoactive/Vasodilator Agents and Blood Product Transfusion in the Study Groups

	SvO_2 Group (n=50)	INVOS Group (n=52)	*P* value
Epinephrine	21(42%)	21(40.4%)	0.86
Nitroglycerin	31 (62%)	21(40.4%)	0.029
Packed red blood cells	20(40%)	21(40.4%)	0.52
Fresh frozen plasma	15(30%)	14 (26.9%)	0.40
Platelets	15(30%)	13 (25%)	0.80

The number and percentage of the usage of drugs or products

Table 3: Postoperative Cognitive Impairment in the Study Groups by MMSE Scores

	SvO_2 Group (n=50)	INVOS Group (n=52)	*P* value
Second postoperative day MMSE score	28.62±1.77	28.96±1.63	0.31
Score of MMSE 25 to 30	48 (96%)	50 (96.1%)	
Score of MMSE 20 to 24	2 (4%)	2 (3.9%)	
Third postoperative day MMSE score	29.16±1.47	28.96±1.79	0.54
Score of MMSE 25 to 30	49 (98%)	49 (94.2%)	
Score of MMSE 20 to 24	1 (2%)	3 (5.8%)	

MMSE: Mini-Mental State Examination

DISCUSSION

Central nervous system complications, such as cerebral dysfunction, are a concern following CPB. We compared SvO_2 and INVOS groups to determine whether monitoring mixed venous oxygen saturation was as efficient as monitoring cerebral oxygen saturation in minimizing postoperative cognitive complications by providing early and accurate information for subsequent appropriate actions. Mixed and cerebral venous oxygen is deemed a crucial factor in central nervous system damage. [38]

Colaka et al [39] conducted a prospective randomized clinical investigation in which patients were categorized into 2 groups of INVOS and controls. They evaluated cognitive function before surgery and on the seventh postoperative day using G tests and MMSE. Their results showed a lower incidence rate of cognitive dysfunction in intraoperative monitoring by INVOS. Moreover, cerebral oximetry monitoring during surgery conferred better postoperative cognitive outcomes. The researchers concluded that prolonged rSO_2 desaturation could result in cognitive decline and must be avoided.

Heringlake et al [40] conducted a comparative study between central venous oxygen saturation and rSO_2 saturation at different time intervals. The study was carried out on 20 adult patients who underwent off-pump coronary artery bypass grafting. To determine the independent predicting factors of cerebral desaturation and their interactions, they recorded the secondary analysis of oxygen saturation, lactate, hematocrit, heart rate, partial CO_2 pressure, and mean arterial pressure. The results exhibited several moderate and strong positive correlations between right, left, and central venous oxygen saturation.

Schon et al [41] studied the relationship between rSO_2 and mixed venous oxygen saturation in patients who were awake with spontaneous breathing after cardiac surgery. The measurement of rSO_2 by near-infrared spectroscopy was reported to sufficiently represent mixed venous oxygen saturation. The finding was comparable to the relationship between rSO_2 and SvO_2; nonetheless, smaller differences were observed in the lower ranges of SvO_2.

Limitations

We could have achieved more robust results had we expanded the scope from the preoperative period to a more prolonged postoperative period to assess cognitive impairment in adult patients undergoing cardiac surgery with CPB. Finding no statistically significant differences between the groups could be due to the low statistical power in our study. Accordingly, a higher number of samples should be considered in future studies.

CONCLUSIONS

We investigated the incidence of cognitive complications and related risk factors on the second and third days after CPB surgery. The incidence of postoperative cognitive disorders did not show a statistically significant difference between the INVOS and SvO_2 groups.

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