Cerebral Oxygenation during Laparoscopic Surgery: Jugular Bulb versus Regional Cerebral Oxygen Saturation

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Purpose: We hypothesized that regional cerebral oxygen saturation (rSO₂) could replace jugular bulb oxygen saturation (SjvO₂) in the steep Trendelenburg position under pneumoperitoneum. Therefore, we evaluated the relationship between SjvO₂ and rSO₂ during laparoscopic surgery. Materials and Methods: After induction of anesthesia, mechanical ventilation was controlled to increase PaCO₂ from 35 to 45 mm Hg in the supine position, and the changes in SjvO₂ and rSO₂ were measured. Then, after establishment of pneumoperitoneum and Trendelenburg position, ventilation was controlled to maintain a PaCO₂ at 35 mm Hg and the CO₂ step and measurements were repeated. The changes in SjvO₂ (rSO₂) -CO₂ reactivity were compared in the supine position and Trendelenburg-pneumoperitoneum condition, respectively. Results: There was little correlation between SjvO₂ and rSO₂ in the supine position (concordance correlation coefficient=0.2819). Bland-Altman plots showed a mean bias of 8.4% with a limit of agreement of 21.6% and -4.7%. SjvO₂ and rSO₂ were not correlated during Trendelenburg-pneumoperitoneum condition (concordance correlation coefficient=0.3657). Bland-Altman plots showed a mean bias of 10.6% with a limit of agreement of 23.6% and -2.4%. The SjvO₂-CO₂ reactivity was higher than rSO₂-CO₂ reactivity in the supine position and Trendelenburg-pneumoperitoneum condition, respectively (0.9±1.1 vs. 0.4±1.2% mm Hg⁻¹, p=0.04; 1.7±1.3 vs. 0.5±1.1% mm Hg⁻¹, p<0.001). Conclusion: There is little correlation between SjvO₂ and rSO₂ in the supine position and Trendelenburg-pneumoperitoneum condition during laparoscopic surgery.

Key Words: Cerebral oxygenation, jugular bulb oxygen saturation, laparoscopy, pneumoperitoneum

INTRODUCTION

Lower abdominal laparoscopic surgery often requires the patient to be placed in a steep Trendelenburg position in order to secure a clear surgical field. However, when this position is combined with CO₂ pneumoperitoneum, the risk of potential changes in cerebral hemodynamics such as an increase in cerebral blood flow (CBF) is increased. Jugular bulb oxygen saturation (SjvO₂) reflects the relationship between global
cerebral oxygen supply and demand. Provided that the cerebral metabolic rate is constant, SjvO₂ is a useful indicator of CBF. However, jugular bulb catheterization is an invasive procedure and has inherent potential complications such as bleeding and nerve damage. Near-infrared spectroscopy is a monitoring device for non-invasive assessment of regional cerebral oxygen saturation (rSO₂). It is widely used in patients undergoing various procedures because real-time information is provided non-invasively. Previous studies evaluated the agreement between SjvO₂ and rSO₂ with contradictory results in various situations. To our knowledge, the relationship between SjvO₂ and rSO₂ in the supine and Trendelenburg-pneumoperitoneum condition has not been investigated. In this study, we hypothesized that rSO₂ could reflect SjvO₂ in the steep Trendelenburg position under pneumoperitoneum. Therefore, we evaluated the relationship between SjvO₂ and rSO₂ during laparoscopic surgery.

**MATERIALS AND METHODS**

After Institutional Review Board approval and the acquisition of written informed consent, 35 consecutive male patients scheduled for robot-assisted laparoscopic radical prostatectomy were enrolled in this study. Patients with neurological diseases, a history of carotid artery stenosis or transient ischemic attack were excluded.

**Conduct of anesthesia and monitoring**

No premedication was given. Continuous electrocardiography and pulse oximetry monitoring was done upon arrival at the operating room. General anesthesia was induced according to a standardized regimen of intravenous propofol 1.5 mg·kg⁻¹, remifentanil 1 μg·kg⁻¹ and rocuronium 0.6 mg·kg⁻¹. After endotracheal intubation, the lungs were ventilated with 50% oxygen. Anesthesia was maintained with 1 minimum alveolar concentration end-tidal concentration of sevofluorane and remifentanil infusion of 0.1-0.2 μg·kg⁻¹·min⁻¹. A 20-G catheter was inserted in the radial artery for arterial blood pressure monitoring and arterial blood gas analysis. Mechanical ventilation was done with a tidal volume of 8-10 mL·kg⁻¹ to maintain PaCO₂ at 35 mm Hg, and the concordance between PaCO₂ and end-tidal CO₂ tension was measured. A bispectral index score (BIS) monitor (A-2000 BIS Monitor™, Aspect Medical System Inc., Newton, MA, USA) was monitored continuously to maintain appropriate anesthetic depth during the procedure.

For SjvO₂ measurement, a 4-F dual oximeter catheter™ (Edwards Lifesciences, Irvine, CA, USA) was inserted into the left internal jugular vein according to the modified Seldinger technique. When resistance was sensed during advancement in the cephalad direction, the catheter was withdrawn about 1-2 mm and the position of the jugular bulb catheter tip was immediately confirmed radiographically. The ideal catheter tip position is cranial to the line extending from the atlanto-occipital joint space, and caudal to the lower margin of the orbit. Once correct position was confirmed, the catheter was connected to the monitor (CCOmb-o/SvO₂ Model 744HF75™, Baxter Healthcare Corporation, Irvine, CA, USA) for continuous SjvO₂ monitoring and in vivo calibration was done by drawing a blood sample from the catheter. For rSO₂ measurement, sensors for cerebral oximetry were placed bilaterally at least 2 cm above the eyebrow on both sides of the forehead. The rSO₂ value was continuously monitored using near-infrared spectroscopy (INVOS 5100™, Somnatecs Corp., Troy, MI, USA). Body temperature was maintained at 36.0-37.0°C by applying a forced-air warming system (Bair-Hugger™, Augustine-Medical, Eden Prairie, MN, USA) as needed.

**Conduct of the study and measurements**

After induction of anesthesia, blood gases, SjvO₂, rSO₂, mean arterial pressure, heart rate and BIS were all measured in the supine position with PaCO₂ maintained at 35 mm Hg for 10 min (T₁). Mechanical ventilation was then adjusted to increase PaCO₂ to 45 mm Hg for 10 min, and all measurements were repeated (T₂). After the patient was placed in a 30° Trendelenburg position and CO₂ pneumoperitoneum was established (intra-abdominal pressure <18 mm Hg), ventilation was controlled to maintain PaCO₂ at 35 mm Hg for 10 min and all measurements were repeated (T₃). Ventilation was adjusted once more to increase and maintain PaCO₂ at 45 mm Hg for 10 min, and all measurements were repeated (T₄).

At each 30 second point in time, the rSO₂ values from both sides recorded during blood sampling were averaged for the same time at which the blood sample for the SjvO₂ measurement was drawn.

**Statistical analysis**

The data are presented as means (SD) or range. We used a concordance correlation coefficient (CCC) to evaluate the agreement between SjvO₂ and rSO₂. The CCC covers components of both precision (degree of variation) and ac-
Patients’ characteristics and operation data are summarized in Table 1.

Measurements of the cerebral oxygen profiles and hemodynamic variables during study periods are listed in Table 2.

SjvO2 values ranged from 59.0 to 92.7% whereas the values for rSO2 ranged from 52 to 88% during study periods. Cerebral oxygen saturation as measured by rSO2 was about 12% lower than that measured by SjvO2. With an increase of PaCO2, SjvO2 increased significantly both in the supine and Trendelenburg position (p<0.001).

Seventy comparative measurements were performed between SjvO2 and rSO2 in the supine position and Trendelenburg-pneumoperitoneum condition, respectively. There was little correlation between SjvO2 and rSO2 in the supine position (correlation coefficient=0.2819) (Table 3) (Fig. 1A). Bland-Altman plots showed a mean bias of 8.4% with a limit of agreement of 21.6% and -4.7% (Fig. 1B). In addition, SjvO2 and rSO2 were not correlated during Trendelenburg-pneumoperitoneum condition (correlation coefficient=0.3657) (Table 3) (Fig. 2A). Bland-Altman plots showed a mean bias of 10.6% with a limit of agreement of 23.6% and -2.4% (Fig. 2B).

The SjvO2-CO2 reactivity was higher than rSO2-CO2 reactivity in the supine position and Trendelenburg-pneumoperitoneum condition, respectively (0.9±1.1 vs. 0.4±1.2%·mm

Table 1. Patients’ Characteristics and Operation Data

|                      | n=35       |
|----------------------|------------|
| Age (yrs)            | 61.7±11.0 (43-72) |
| Height (cm)          | 166.4±4.9 (158-175) |
| Weight (kg)          | 65.9±8.3 (53-81)   |
| Body mass index (kg·m⁻²) | 23.7±2.5 (19.6-29.4) |
| Duration of operation time (min) | 176±22 |
| Duration of pneumoperitoneum (min) | 142±24 |

Values are means±SD (range) or number of patients.

Table 2. Measurements of the Cerebral Oxygen Profiles and Hemodynamic Variables during Study Periods

|                      | T1  | T2  | T3  | T4  |
|----------------------|-----|-----|-----|-----|
| SjvO2 (%)            | 74.2±4.9 | 81.0±7.5† | 72.6±7.1 | 84.0±7.5† |
| rSO2 (%)             | 68.1±5.3 | 70.3±7.1 | 66.1±6.1 | 69.3±7.7 | |
| MAP (mm Hg)          | 83.1±10.2 | 85.1±13.2 | 92.2±10.1* | 88.8±11.2 | |
| HR (beats min⁻¹)     | 64.3±12.9 | 65.6±10.4 | 69.4±9.5  | 67.5±14.8 | |

SjvO2, jugular bulb oxygen saturation; rSO2, regional cerebral oxygen saturation; MAP, mean arterial pressure; HR, heart rate.

Values are means±SD, T1 and T2, PaCO₂ of 35 and 45 mm Hg in supine position, respectively; T3 and T4, PaCO₂ of 35 and 45 mm Hg in the Trendelenburg position under pneumoperitoneum, respectively.

* p<0.05 and † p<0.001 compared with the value at T1.

Table 3. The Relationship between Jugular Bulb Oxygen Saturation and Regional Cerebral Oxygen Saturation during Study Periods

|                      | Supine | Trendelenburg-pneumoperitoneum |
|----------------------|--------|---------------------------------|
| Concordance correlation coefficient | 0.2819 | 0.3657 |
| 95% confidence interval   | 0.1527-0.4017 | 0.2492-0.4718 |
| Precision (Pearson’s r)  | 0.5104  | 0.6977 |
| Accuracy (Bias correction factor) | 0.5523 | 0.5241 |
There are some studies investigating the correlation between rSO$_2$ and SjvO$_2$ under specific clinical situations with contrary results. Kim, et al.\textsuperscript{14} reported good agreement between rSO$_2$ and SjvO$_2$ measurements in healthy volunteers during isocapnic hypoxia. However, Leyvi, et al.\textsuperscript{10} demonstrated that there was only a weak correlation between rSO$_2$ and SjvO$_2$, and individual variation was wide during deep hypothermic circulatory arrest. Nagdyman, et al.\textsuperscript{9} reported that rSO$_2$ demonstrated a substantial bias of the measurements to SjvO$_2$ in children with congenital heart disease, which is in agreement with our results. In our study, there was poor agreement, significant bias, and imprecision between SjvO$_2$ and rSO$_2$ in the supine position and Trendelenburg-pneumoperitoneum condition during laparoscopic surgery.

The disagreement between SjvO$_2$ and rSO$_2$ may be attributed to several factors. First, there is a significant differ-

DISCUSSION

Our main result is that there is little correlation between SjvO$_2$ and rSO$_2$ in the supine position and Trendelenburg-pneumoperitoneum condition during laparoscopic surgery. Although episodes of clinically significant cerebral desaturation were not detected in this clinical setting, Bland-Altman analysis demonstrated that both rSO$_2$ and SjvO$_2$ are not interchangeable values in this study.

Hg$^{-1}$, $p=0.04$; 1.7±1.3 vs. 0.9±1.1%·mm Hg$^{-1}$, $p<0.001$). The SjvO$_2$-CO$_2$ reactivity was higher in the Trendelenburg-pneumoperitoneum condition compared to the supine position (1.7±1.3 vs. 0.9±1.1%·mm Hg$^{-1}$, $p<0.001$). No adverse effects related to jugular venous catheterization were observed.
ence in measuring cerebral oxygen saturation between SjvO\textsubscript{2} and rSO\textsubscript{2}. rSO\textsubscript{2} measures cerebral oxygen saturation in a small region of the brain and may be influenced by blood distribution or signals caused by extracerebral tissues,\textsuperscript{15,16} and SjvO\textsubscript{2} represents global cerebral oxygen saturation. Furthermore, Knirsch, et al.\textsuperscript{17} demonstrated that rSO\textsubscript{2} correlates better with central venous oxygen saturation than SjvO\textsubscript{2}. rSO\textsubscript{2} is influenced by both cerebral and extracerebral components; therefore, the impact of extracerebral components on the rSO\textsubscript{2} reading should not be underestimated. In our study, cerebral oxygen saturation as measured by rSO\textsubscript{2} was about 12\% lower than that measured by SjvO\textsubscript{2}. Also, changes in extracerebral blood flow, variation in inter-individual absorption differences and changed position of the probes over time may affect the measurements of rSO\textsubscript{2}.\textsuperscript{18,19}

Body position and PaCO\textsubscript{2} can also influence cerebral oxygen saturation. A previous study demonstrated that rSO\textsubscript{2} was decreased in association with the Trendelenburg position and was further impaired by hypercapnia and pneumoperitoneum during laparoscopic surgery.\textsuperscript{20} Another study demonstrated that rSO\textsubscript{2} increased during Trendelenburg-pneumoperitoneum condition and PaCO\textsubscript{2} increased in a similar manner,\textsuperscript{21} which is in accordance with our study. In this study, an increase of PaCO\textsubscript{2} also increased SjvO\textsubscript{2} significantly both in the supine and Trendelenburg position, and rSO\textsubscript{2} increased slightly in this period. Therefore, it is suggested that PaCO\textsubscript{2} should be maintained within the normal range during the Trendelenburg-pneumoperitoneum position. It has also been suggested that rSO\textsubscript{2} measurements can best be assessed if patient’s body position and PaCO\textsubscript{2} are held constant.\textsuperscript{22}

The rSO\textsubscript{2} value from near-infrared spectroscopy reflects saturation in a mixture of 25\% arterial, 70\% venous and 5\% capillary compartments. The changes in body position may alter the ratio of arterial and venous blood compartment in the cerebral circulation; therefore, the validity of rSO\textsubscript{2} is questionable in this situation.

CBF-CO\textsubscript{2} reactivity represents the ability of cerebral vasculature to respond to changes in cerebral metabolic demands. In this study, the SjvO\textsubscript{2}-CO\textsubscript{2} reactivity was higher than rSO\textsubscript{2}-CO\textsubscript{2} reactivity in the supine position and Trendelenburg-pneumoperitoneum condition, respectively. We previously demonstrated that CBF-CO\textsubscript{2} reactivity measured by SjvO\textsubscript{2} was preserved in the modest Trendelenburg position under pneumoperitoneum during sevoflurane anesthesia if PaCO\textsubscript{2} was controlled.\textsuperscript{23} Therefore, it is suggested that SjvO\textsubscript{2} may represent the change of CBF in relation to the change of PaCO\textsubscript{2} more accurately than rSO\textsubscript{2} during laparoscopic surgery. There is general agreement that rSO\textsubscript{2} may be valuable as a trend monitor, but that it is less useful as an indicator of cerebral ischemia. Our results demonstrate that the validity of rSO\textsubscript{2} is also questionable during Trendelenburg-pneumoperitoneum condition.

In this study, SjvO\textsubscript{2}-CO\textsubscript{2} reactivity was significantly higher in the Trendelenburg-pneumoperitoneum condition compared to the supine position. This result means that the change of CBF according to the change of PaCO\textsubscript{2} was greater in the Trendelenburg-pneumoperitoneum condition than in the supine position. Therefore, we suggested that it is necessary to control PaCO\textsubscript{2} for the prevention of an increase of CBF during laparoscopic surgery.

There were some limitations in this study. First, we measured SjvO\textsubscript{2} unilaterally and compared it with the average value of rSO\textsubscript{2} from both sides. Secondly, the patients of the study were all American Society of Anesthesiologists physical status I or II without any cardiopulmonary diseases. This may limit the extrapolation of our results to patients with severe cardiopulmonary compromise. Lastly, intraoperative variables were measured at arbitrary time points without exact information on time dependent cardiopulmonary changes. Therefore, the optimal time points of evaluation when the patient is in the Trendelenburg position with CO\textsubscript{2} pneumoperitoneum cannot be guaranteed.

In conclusion, there is little correlation between SjvO\textsubscript{2} and rSO\textsubscript{2} in the supine position and Trendelenburg-pneumoperitoneum condition. Therefore, both rSO\textsubscript{2} and SjvO\textsubscript{2} are not interchangeable values in this condition.

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