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

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Purpose: We hypothesized that regional cerebral oxygen saturation (rSO_2) could replace jugular bulb oxygen saturation ($SjvO_2$) in the steep Trendelenburg position under pneumoperitoneum. Therefore, we evaluated the relationship between $SjvO_2$ and rSO_2 during laparoscopic surgery. **Materials and Methods:** After induction of anesthesia, mechanical ventilation was controlled to increase $PaCO_2$ from 35 to 45 mm Hg in the supine position, and the changes in $SjvO_2$ and rSO_2 were measured. Then, after establishment of pneumoperitoneum and Trendelenburg position, ventilation was controlled to maintain a $PaCO_2$ at 35 mm Hg and the CO_2 step and measurements were repeated. The changes in $SjvO_2$ (rSO_2) -CO_2 reactivity were compared in the supine position and Trendelenburg-pneumoperitoneum condition, respectively. **Results:** There was little correlation between $SjvO_2$ and rSO_2 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%. $SjvO_2$ and rSO_2 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 $SjvO_2$-CO_2 reactivity was higher than rSO_2-CO_2 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 $SjvO_2$ and rSO_2 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.[1] However, when this position is combined with CO_2 pneumoperitoneum, the risk of potential changes in cerebral hemodynamics such as an increase in cerebral blood flow (CBF) is increased.[2,3]

Jugular bulb oxygen saturation ($SjvO_2$) reflects the relationship between global cerebral oxygen supply and demand. Provided that the cerebral metabolic rate is constant, $SjvO_2$ is a useful indicator of CBF.[4,5] 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 (rSO_2).[4,6] It is widely used in patients undergoing various procedures because real-time information is provided non-invasively.[7,8] Previous studies evaluated the agreement between $SjvO_2$ and rSO_2 with contradictory results in various situations.[9-11] To our knowledge, the relationship between $SjvO_2$ and rSO_2 in the supine and Trendelenburg-pneumoperitoneum condition has not been investigated. In this study, we hypothesized that rSO_2 could reflect $SjvO_2$ in the steep Trendelenburg position under pneumoperitoneum. Therefore, we evaluated the relationship between $SjvO_2$ and rSO_2 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 $mg \cdot kg^{-1}$, remifentanil 1 $\mu g \cdot kg^{-1}$ and rocuronium 0.6 $mg \cdot kg^{-1}$. After endotracheal intubation, the lungs were ventilated with 50% oxygen. Anesthesia was maintained with 1 minimum alveolar concentration end-tidal concentration of sevoflurane and remifentanil infusion of 0.1-0.2 $\mu g \cdot kg^{-1} \cdot min^{-1}$. 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 $mL \cdot kg^{-1}$ to maintain $PaCO_2$ at 35 mm Hg, and the concordance between $PaCO_2$ and end-tidal CO_2 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 $SjvO_2$ 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 (CCOmbo/SvO_2 Model 744HF75™, Baxter Healthcare Corporation, Irvine, CA, USA) for continuous $SjvO_2$ monitoring and *in vivo* calibration was done by drawing a blood sample from the catheter. For rSO_2 measurement, sensors for cerebral oximetry were placed bilaterally at least 2 cm above the eyebrow on both sides of the forehead. The rSO_2 value was continuously monitored using near-infrared spectroscopy (INVOS 5100™, Somanetics 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, $SjvO_2$, rSO_2, mean arterial pressure, heart rate and BIS were all measured in the supine position with $PaCO_2$ maintained at 35 mm Hg for 10 min (T_1). Mechanical ventilation was then adjusted to increase $PaCO_2$ to 45 mm Hg for 10 min, and all measurements were repeated (T_2). After the patient was placed in a 30° Trendeleburg position and CO_2 pneumoperitoneum was established (intra-abdominal pressure <18 mm Hg), ventilation was controlled to maintain $PaCO_2$ at 35 mm Hg for 10 min and all measurements were repeated (T_3). Ventilation was adjusted once more to increase and maintain $PaCO_2$ at 45 mm Hg for 10 min, and all measurements were repeated (T_4).

At each 30 second point in time, the rSO_2 values from both sides recorded during blood sampling were averaged for the same time at which the blood sample for the $SjvO_2$ 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 $SjvO_2$ and rSO_2.[12] The CCC covers components of both precision (degree of variation) and accuracy (degree of location or scale shift), thus providing sound intuitive interpretations. Ranging from 0 to 1, higher values of CCC indicate more concordant data. Bland-Altman analysis was done to determine the magnitude of the difference between two measurements.[13] Based on a previous study,[9] we postulated that a difference of 5% between the two parameters would be clinically acceptable under the hypothesis that the two methods are interchangeable. All data were analyzed using MedCalc software 9.3.6.0 (MedCalc Inc., Mariakerke, Belgium).

We also compared the change in $SjvO_2$ (or rSO_2) -CO_2 reactivity in the supine position and Trendelenburg-pneumoperitoneum condition. The $SjvO_2$ (or rSO_2) -CO_2 reactivity was defined as the % change in $SjvO_2$ (or rSO_2) by the step change induced in $PaCO_2$. Comparison of the reactivity values of $SjvO_2$ (or rSO_2) -CO_2 calculated in the supine position and Trendelenburg-pneumoperitoneum condition were done using the paired t-test. Analysis of other intraoperative variables at each time period was done with repeated measures ANOVA. Data were analyzed using SPSS version 13.0 (SPSS Inc., Chicago, IL, USA). A p value <0.05 was considered statistically significant.

RESULTS

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.

$SjvO_2$ values ranged from 59.0 to 92.7% whereas the values for rSO_2 ranged from 52 to 88% during study periods. Cerebral oxygen saturation as measured by rSO_2 was about 12% lower than that measured by $SjvO_2$. With an increase of $PaCO_2$, $SjvO_2$ increased significantly both in the supine and Trendelenburg position (p<0.001).

Seventy comparative measurements were performed between $SjvO_2$ and rSO_2 in the supine position and Trendelenburg-pneumoperitoneum condition, respectively. There was little correlation between $SjvO_2$ and rSO_2 in the supine position (concordance 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, $SjvO_2$ and rSO_2 were not correlated during Trendelenburg-pneumoperitoneum condition (concordance 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 $SjvO_2$-CO_2 reactivity was higher than rSO_2-CO_2 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 ($kg \cdot m^{-2}$)	23.7±2.5 (19.6-29.4)
Duration of operation time (min)	176±22
Duration of pneumoperitoneum (min)	142±24

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

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

	T_1	T_2	T_3	T_4
$SjvO_2$ (%)	74.2±4.9	81.0±7.5†	72.6±7.1	84.0±7.5‡
rSO_2 (%)	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 ($beats \cdot min^{-1}$)	64.3±12.9	65.6±10.4	69.4±9.5	67.5±14.8

$SjvO_2$, jugular bulb oxygen saturation; rSO_2, regional cerebral oxygen saturation; MAP, mean arterial pressure; HR, heart rate.
Values are mean±SD. T_1 and T_2, $PaCO_2$ of 35 and 45 mm Hg in supine position, respectively; T_3 and T_4, $PaCO_2$ of 35 and 45 mm Hg in the Trendelenburg position under pneumoperitoneum, respectively.
*p<0.05 and $^{\dagger}p$<0.001 compared with the value at T_1.
$^{\ddagger}p$<0.001 compared with the value at T_3.

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 ρ)	0.5104	0.6977
Accuracy (Bias correction factor)	0.5523	0.5241

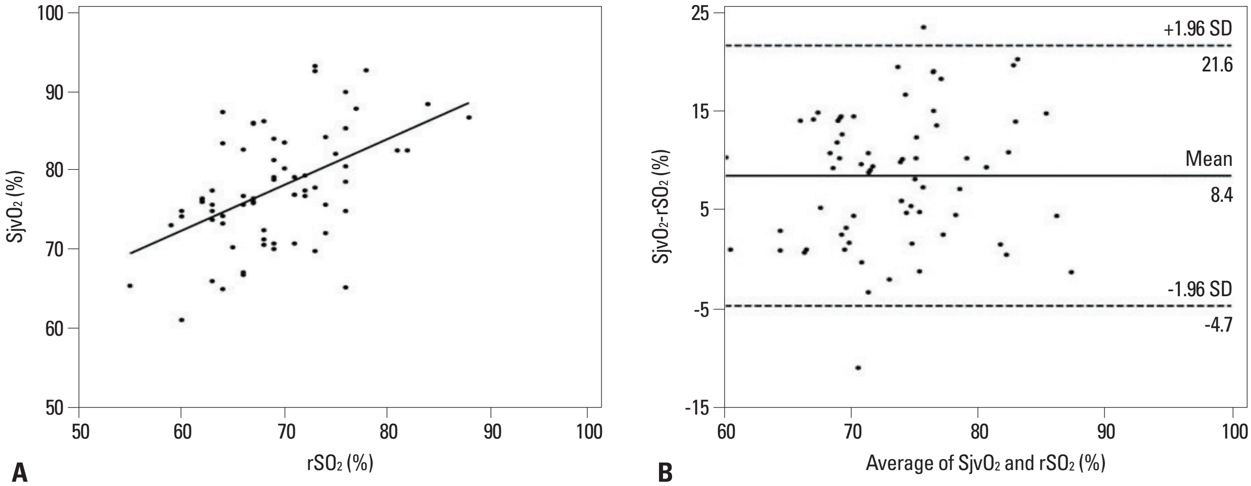

Fig. 1. Concordance correlation (A) and Bland-Altman analysis (B) of the measured difference between jugular bulb oxygen saturation ($SjvO_2$) and regional cerebral oxygen saturation (rSO_2) in the supine position.

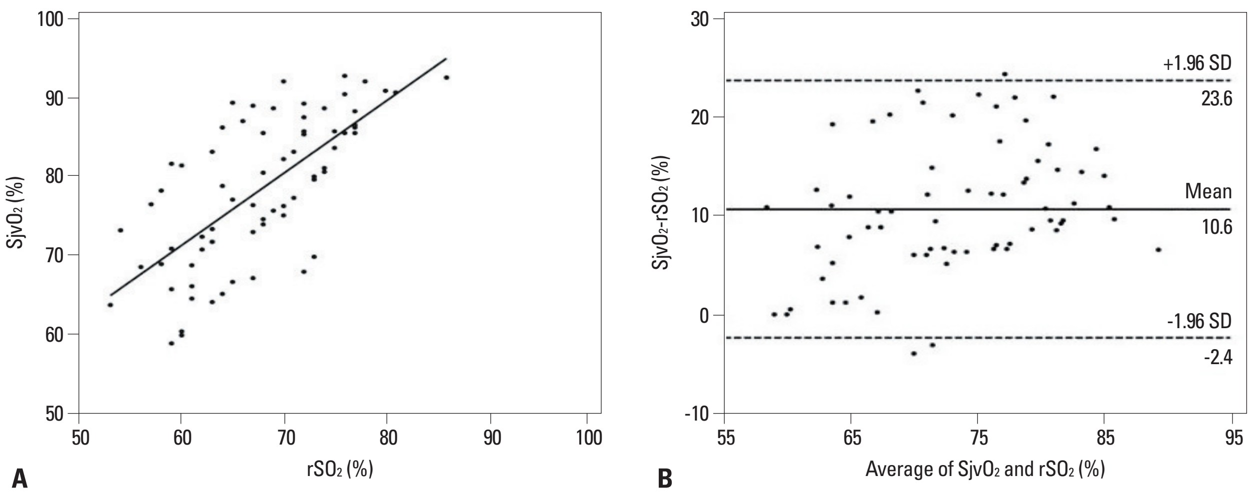

Fig. 2. Concordance correlation (A) and Bland-Altman analysis (B) of the measured difference between jugular bulb oxygen saturation ($SjvO_2$) and regional cerebral oxygen saturation (rSO_2) in the Trendelenburg-pneumoperitoneum condition.

Hg^{-1}, p=0.04; 1.7±1.3 vs. 0.5±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.

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.

There are some studies investigating the correlation between rSO_2 and $SjvO_2$ under specific clinical situations with contrary results. Kim, et al.[14] reported good agreement between rSO_2 and $SjvO_2$ measurements in healthy volunteers during isocapnic hypoxia. However, Leyvi, et al.[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.[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 difference in measuring cerebral oxygen saturation between $SjvO_2$ and rSO_2. rSO_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,[15,16] and $SjvO_2$ represents global cerebral oxygen saturation. Furthermore, Knirsch, et al.[17] demonstrated that rSO_2 correlates better with central venous oxygen saturation than $SjvO_2$. rSO_2 is influenced by both cerebral and extracerebral components; therefore, the impact of extracerebral components on the rSO_2 reading should not be underestimated. In our study, cerebral oxygen saturation as measured by rSO_2 was about 12% lower than that measured by $SjvO_2$. 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_2.[18,19]

Body position and $PaCO_2$ can also influence cerebral oxygen saturation. A previous study demonstrated that rSO_2 was decreased in association with the Trendelenburg position and was further impaired by hypercapnia and pneumoperitoneum during laparoscopic surgery.[20] Another study demonstrated that rSO_2 increased during Trendelenburg-pneumoperitoneum condition and $PaCO_2$ increased in a similar manner,[21] which is in accordance with our study. In this study, an increase of $PaCO_2$ also increased $SjvO_2$ significantly both in the supine and Trendelenburg position, and rSO_2 increased slightly in this period. Therefore, it is suggested that $PaCO_2$ should be maintained within the normal range during the Trendelenburg-pneumoperitoneum position. It has also been suggested that rSO_2 measurements can best be assessed if patient's body position and $PaCO_2$ are held constant.[22]

The rSO_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_2 is questionable in this situation.

CBF-CO_2 reactivity represents the ability of cerebral vasculature to respond to changes in cerebral metabolic demands. In this study, the $SjvO_2$-CO_2 reactivity was higher than rSO_2-CO_2 reactivity in the supine position and Trendelenburg-pneumoperitoneum condition, respectively. We previously demonstrated that CBF-CO_2 reactivity measured by $SjvO_2$ was preserved in the modest Trendelenburg position under pneumoperitoneum during sevoflurane anesthesia if $PaCO_2$ was controlled.[23] Therefore, it is suggested that $SjvO_2$ may represent the change of CBF in relation to the change of $PaCO_2$ more accurately than rSO_2 during laparoscopic surgery. There is general agreement that rSO_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_2 is also questionable during Trendelenburg-pneumoperitoneum condition.

In this study, $SjvO_2$-CO_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 $PaCO_2$ was greater in the Trendelenburg-pneumoperitoneum condition than in the supine position. Therefore, we suggested that it is necessary to control $PaCO_2$ for the prevention of an increase of CBF during laparoscopic surgery.

There were some limitations in this study. First, we measured $SjvO_2$ unilaterally and compared it with the average value of rSO_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_2 pneumoperitoneum cannot be guaranteed.

In conclusion, there is little correlation between $SjvO_2$ and rSO_2 in the supine position and Trendelenburg-pneumoperitoneum condition. Therefore, both rSO_2 and $SjvO_2$ are not interchangeable values in this condition.

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