Effect of transient steep Trendelenburg position on optic nerve sheath diameter as a surrogate for intracranial pressure under general anesthesia: a prospective observational study

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Abstract

Background: It remains to be elucidated whether the Trendelenburg position increases intracranial pressure. We investigated the effect of the steep Trendelenburg position on intracranial pressure, by measuring the noninvasive sonographic optic nerve sheath diameter which has been correlated with intracranial pressure.

Methods: Twenty-one patients without neurovascular disease were evaluated. Sonographic optic nerve sheath diameter was measured in the supine and steep Trendelenburg (35° incline) position under general anesthesia. An optic nerve sheath diameter above 5.0 mm was considered to indicate high intracranial pressure.

Results: The optic nerve sheath diameter was significantly higher immediately after the patients was placed in the steep Trendelenburg position than in the supine position (5.1 ± 0.3 mm vs. 4.5 ± 0.4 mm, P < 0.05), even though the end-tidal CO₂ partial pressure decreased during such a position change.

Conclusions: Use of the isolated steep Trendelenburg position, for even a short duration, increased the optic nerve sheath diameter to what may be a clinically significant level, in patients without neurologic problems, suggesting that this kind of position should be carefully implemented.

Key words: intracranial pressure, optic nerve sheath diameter, Trendelenburg position
Background

The Trendelenburg position has long been believed to increase intracranial pressure (ICP), an idea that may be derived from previous reports [1, 2]. In these studies, the ICP increased, when prolonged comatose patients with severe brain injury and neurosurgical patients were placed in the head-down position [1, 2]. However, the Trendelenburg position differs from the head down position used in those studies. It is notable that the specific effect of the Trendelenburg position on ICP has not been fully evaluated, given a frequent use of the Trendelenburg position in non-neurologic patients in daily practice. The invasiveness of the conventional method for measuring ICP might not allow the ICP of non-neurologic patients to be evaluated.

It has recently been introduced that the ICP can be evaluated by noninvasive ocular sonography [3-6]. The retrobulbar segment of the optic nerve is surrounded by a distensible subarachnoid space, which can inflate, when cerebrospinal fluid pressure increases [7, 8]. An increased optic nerve sheath diameter (ONSD) detected by ocular sonography is associated with clinical signs of high ICP in adults with traumatic brain injury and in children with hydrocephalus or liver failure [8-12]. Moreover, the ONSD has been correlated with ICP invasively measured by an intraparenchymal catheter inserted into the frontal lobe in sedated patients receiving neurocritical care, including patients with severe traumatic brain injury [13]. Rapid and safe sonographic measurement of ONSD may enable patients to be screened for increased ICP.

We, therefore, aimed to investigate the effect of the isolated Trendelenburg position on ONSD to examine possible changes in ICP in patients undergoing robot-assisted laparoscopic radical prostatectomy. Additionally, the effect of the Trendelenburg position combined with pneumoperitoneum on ONSD was evaluated in these patients.
Methods

Patients

The study protocol was approved by the Institutional Review Boards at Asan Medical Center (AMC IRB-2013-0408) and written informed consent was obtained from each patient. This study was registered with the Clinical Research Information Service (KCT0000746). Twenty-one patients scheduled for robot-assisted laparoscopic radical prostatectomy were enrolled and evaluated. Patients with pre-existing neurological disease, or cerebrovascular disease were excluded.

After applying routine hemodynamic monitoring (electrocardiogram, noninvasive blood pressure, and pulse oximetry) and attaching cerebral oximeter sensors (INVOS 5100) to the right and left frontal areas, anesthesia was induced using a bolus intravenous injection of 5 mg/kg thiopental sodium followed by 0.1 mg/kg vecuronium. After tracheal intubation, patients were mechanically ventilated with a tidal volume of 8 ml/kg at a respiratory rate of 10-16 breaths/min to maintain end-tidal CO$_2$ partial pressure (ETCO$_2$) between 30 and 35 mmHg. Positive end-expiratory pressure was not applied and the inspiratory-to-expiratory time ratio was set at 1:2. Anesthesia was maintained with 2-4 vol% sevoflurane plus a continuous infusion of 2-5 ng/ml remifentanil with 50% oxygen using medical air.

Ocular sonography

The ONSD was measured sonographically by investigators trained in ocular sonography, as described previously [14, 15]. Briefly, patients were placed in the supine position with their eyes closed, and a thick gel layer was applied to the closed upper eyelid. A 7.5 MHz linear probe was placed on the gel without excessive pressure and adjusted to the proper angle to display the optimal contrast between the retrobulbar echogenic fat tissue and the vertical hypoechoic band. An ultrasound beam was focused on the retrobulbar area using the lowest possible acoustic power that could measure the ONSD. The ONSD was measured 3 mm behind the optic disc. Measurements were performed in the transverse and sagittal planes of both eyes, and the mean values of four measurements at each time
point were used for analysis. To determine intra-observer and inter-observer variability, a random sample of 25% of ONSD was submitted twice to the first investigator and once to a second investigator. The inter-observer variability was then calculated as the mean absolute difference between the two readings from the first and second investigator divided by their mean and expressed as a percentage. Similarly, the intra-observer variability was calculated as the mean absolute difference between the two readings from the first investigator divided by their mean and expressed as a percentage.

**Study protocol**

When hemodynamically stable conditions were reached, four measurements were taken, as follows: in the supine position after induction of anesthesia (T\textsubscript{SUP}), 3 min after the steep Trendelenburg position (35° incline) (T\textsubscript{TREN}), 3 min after the steep Trendelenburg position combined with pneumoperitoneum (15 mmHg of insufflation pressure) (T\textsubscript{T+P}), and in the supine position after desufflation of the pneumoperitoneum (T\textsubscript{END}). Parameters measured at each time point included the ONSD, systolic blood pressure, diastolic blood pressure, mean blood pressure, heart rate, tympanic body temperature, airway peak pressure, airway plateau pressure, ETCO\textsubscript{2}, and regional cerebral oxygen saturation (rSO\textsubscript{2}) using near-infrared spectroscopy. In addition, arterial CO\textsubscript{2}, partial pressure (PaCO\textsubscript{2}) and hemoglobin concentration were measured at T\textsubscript{SUP} and T\textsubscript{END}.

**Statistical analysis**

Continuous variables are expressed as mean (SD). Categorical variables are expressed as number (percentage). A power analysis based on our pilot study data suggested that a minimum sample size of 17 patients would be required to detect a 0.5 mm in mean (SD: 0.58 mm) for ONSD difference between T\textsubscript{SUP} and T\textsubscript{TREN} with a power of 90% at the p < 0.05 of significance. Expecting a dropout rate of about 20%, we aimed to enroll 21 patients. One-way repeated measures analysis of variance (ANOVA) or one-way repeated measures ANOVA on rank were used to evaluate the effect of several different positions under general anesthesia on the change in the ONSD, hemodynamic variables,
respiratory variables, and rSO₂. If any interaction was significant, post hoc analysis was performed using Bonferroni or Dunn’s test. A p value < 0.05 was considered statistically significant. All statistical analyses were performed using SigmaPlot software, version 12.3 (Systat Software Inc, San Jose, CA, USA).
Results

All 21 enrolled patients completed the study protocol. The patient’s characteristics are shown in Table 1. No patients required a blood transfusion.

The ONSD at several positions was significantly different from that of the supine position during surgery (p < 0.001) (Table 2). The ONSD was 4.5 ± 0.4 mm at T_SUP. The ONSD at T_TREN significantly increased to 5.1 ± 0.3 mm, compared with that at T_SUP (Fig 1). In addition, the ONSD at T_T+P increased to 4.9 ± 0.4 mm, compared with that at T_SUP. At T_END, the ONSD was similar to that at T_SUP.

The intra- and inter-observer variabilities of measuring the ONSD were 1.8% and 2.8%, respectively.

Hemodynamic and respiratory variables at each time point are shown in Table 2. The mean blood pressure at T_TREN was similar to that at T_SUP, and the ETCO2 at T_TREN decreased compared with that at T_SUP. The rSO2 did not show significant changes across all time points.
Discussion

In our present study, we found that the ONSD, as measured by ocular sonography, increased immediately after establishing the isolated steep Trendelenburg position in mechanically ventilated patients. Our results suggest that there is a potential for ICP to be increased in the steep Trendelenburg position, even if performed for a short duration. In addition, we observed that the ONSD increased after the patient was placed in the steep Trendelenburg position combined with pneumoperitoneum.

The ONSD measured by ocular sonography has recently been found to correlate with ICP, suggesting a role as a surrogate for ICP. Various cut-off values have been used to distinguish high from normal ICP, with most studies using a cut-off value of 5.0 mm [5, 10, 12, 13]. On the other hand, a previous study used several lower cut-off values, from 4.7 mm to 4.9 mm, as well as 5.0 mm to investigate the accuracy of each in detecting high ICP in patients with fluctuating and stable ICP [16].

The Trendelenburg position is often performed in surgical and non-surgical conditions, such as when implementing central venous catheterization to facilitate venous access, performing surgical procedures on the lower abdominal or pelvic organs to obtain a good surgical field, and treating hypotensive patients to improve hemodynamics despite a lack of evidence for its effects. However, this position has been considered to increase ICP, to a clinically significant level. This increase might be derived from previous studies showing that the head down position increased ICP in neurologic patients with or without symptoms of increased ICP [1, 2]. However, the head down position, which is frequently performed during neurologic surgery, is different from the Trendelenburg position. The head down position extends the head and neck from the normal supine position, whereas the Trendelenburg position inclines the whole body in a supine position. In addition, few reports have included non-neurologic patients when evaluating the effect of the isolated Trendelenburg position on ICP. Therefore, we believe that our study design assessing effects of the position on ICP is unique.

We have found that the ONSD increased to approximately 5.0 mm immediately after patients were placed in the isolated steep Trendelenburg position, reflecting a high ICP defined as 20 mmHg [5, 10, 12, 13]. The Trendelenburg position may disturb cerebral venous drainage by increasing the impedance of the lungs to inflation [17]. Therefore, when the lungs are ventilated with the same tidal
volume used for the supine position, the Trendelenburg position may lead to higher intrathoracic pressure, increasing the ICP, as reflected by an increased ONSD. Importantly, our results suggest that an increase in ONSD might primarily be attributable to the change in the position. We think that the effect of ETCO$_2$ on ICP did not accentuate the increase in the ONSD observed in the steep Trendelenburg position, because ETCO$_2$ decreased in our results. Additionally, the change in the ONSD when the position was changed under general anesthesia can differ from that in awake patients, who did not show significant changes in the ONSD when placed in the Trendelenburg position [18]. An attenuated ability to maintain homeostasis in cerebral blood flow during general anesthesia using volatile anesthetics would be a plausible explanation, because volatile anesthetics have a dose-dependent cerebral vasodilatory effect [19]. Our present study indicated that the ONSD significantly increased 3 min after establishing the steep Trendelenburg position, implying the substantial effect of only a transient steep Trendelenburg position on ICP. Therefore, the steep Trendelenburg position should be applied cautiously when it is used under general anesthesia, even in patients without neurologic problems and for a short duration, avoiding clinical situations that increase cerebral blood flow, such as hypercapnia.

We also found that the ONSD increased to approximately 5.0 mm shortly after pneumoperitoneum combined with the steep Trendelenburg position, compared with that in the supine position. This combination may result in a higher intrathoracic pressure, followed by impeded intracranial venous drainage. Thus, cerebral venous stasis could lead to a higher ICP, as shown by an increased ONSD. Our result is consistent with a report of increased ONSD during laparoscopic prostatectomy [20], suggesting the importance of careful control of the ETCO$_2$. However, this report might confuse clinicians when adjusting the ETCO$_2$ during laparoscopic surgery, because it showed an unexplained small difference between the ETCO$_2$ and the PaCO$_2$ over the whole period when the combined position was adopted [20], unlike the results of the present study and other previous studies [21-23].

In addition, the rSO$_2$ was unchanged at all of the predetermined time points under general anesthesia. The rSO$_2$, which reflects a regional balance between cerebral oxygen supply and demand, has been studied to identify the effects of various positions on cerebral blood flow under diverse
positions during laparoscopic surgery, yielding conflicting results [24-27]. The inconsistencies among studies may be partly due to the characteristics of near-infrared spectroscopy, which mainly reflects the venous compartment (artery: vein = 25%:75%) and its lack of accuracy for reflecting cerebral blood flow, compared with jugular bulb oxygen saturation [28].

Our study had the following limitation. We studied a fixed degree of incline when establishing the Trendelenburg position. Further study of whether there is a graded association between the degree of incline during the Trendelenburg position and the change in the ONSD is needed.
Conclusions

The sonographic ONSD increased to a level that may be clinically relevant when patients without neurologic problems were placed in the isolated steep Trendelenburg position even for a short duration. Therefore, we suggest that attention should be given to controlling the modifiable factor that could affect ICP and to monitoring of the sonographic ONSD to determine an increased ICP, when the steep Trendelenburg position is inevitably performed.
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<tr>
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<th><strong>List of abbreviations</strong></th>
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<tr>
<td>2</td>
<td>ICP: intracranial pressure</td>
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<tr>
<td>3</td>
<td>ONSD: optic nerve sheath diameter</td>
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<tr>
<td>4</td>
<td>ETCO(_2): end-tidal CO(_2) partial pressure</td>
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<td>5</td>
<td>rSO(_2): regional cerebral oxygen saturation</td>
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<td>6</td>
<td>PaCO(_2): arterial CO(_2) partial pressure</td>
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<td>7</td>
<td>ANOVA: analysis of variance</td>
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</table>
Acknowledgements

Competing interest

No external funding and no competing interests declared.

Authors’ contributions

Ji-Hyun Chin: conception and design of study, acquisition of data, analysis and interpretation of data, drafting the manuscript

Hyungseok Seo: acquisition of data, analysis and interpretation of data

Eun-Ho Lee: conception and design of study, analysis and interpretation of data

Joohyun Lee: acquisition of data, analysis and interpretation of data

Jun Hyuk Hong: conception and design of study, revising the manuscript critically for important intellectual content

Jai-Hyun Hwang: conception and design of study, supervision of the study

Young-Kug Kim: conception and design of study, analysis and interpretation of data, revising the manuscript critically for important intellectual content, supervision of the study
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Figure legend

Figure 1. Change in optic nerve sheath diameter (ONSD) between the supine and the steep Trendelenburg position. There was a significant increase in the sonographic ONSD immediately after changing the patient’s position from the supine to the steep Trendelenburg position. \(T_{\text{SUP}}\): in the supine position after induction of anesthesia; \(T_{\text{TREN}}\): 3 min after the steep Trendelenburg position (35° incline).
**Table 1** Demographic and perioperative data

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<tr>
<td>Age (years)</td>
<td>63.6 ± 7.5</td>
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<tr>
<td>Height (cm)</td>
<td>167.1 ± 5.9</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>66.9 ± 7.3</td>
</tr>
<tr>
<td>Hypertension</td>
<td>12 (57.1%)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>3 (14.3%)</td>
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<tr>
<td>Hemoglobin (g/dl)</td>
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<tr>
<td>Immediately after induction</td>
<td>13.4 ± 0.9</td>
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<tr>
<td>At the end of surgery</td>
<td>11.9 ± 1.1</td>
</tr>
<tr>
<td>Operation time (min)</td>
<td>172.9 ± 33.3</td>
</tr>
<tr>
<td>Anesthetic time (min)</td>
<td>227.5 ± 38.9</td>
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</table>

Values are mean ± SD or number (percentage).
<table>
<thead>
<tr>
<th></th>
<th>$T_{SUP}$</th>
<th>$T_{TREN}$</th>
<th>$T_{T+P}$</th>
<th>$T_{END}$</th>
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<tbody>
<tr>
<td>ONSD (mm)</td>
<td>4.5 ± 0.4</td>
<td>5.1 ± 0.3*</td>
<td>4.9 ± 0.4*</td>
<td>4.4 ± 0.4</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>106.9 ± 20.2</td>
<td>99.6 ± 14.2</td>
<td>132.7 ± 19.8*</td>
<td>112.5 ± 16.6</td>
</tr>
<tr>
<td>DBP (mmHg)</td>
<td>56.8 ± 10.5</td>
<td>56.0 ± 7.0</td>
<td>76.7 ± 10.8*</td>
<td>61.7 ± 13.0</td>
</tr>
<tr>
<td>MBP (mmHg)</td>
<td>73.5 ± 13.1</td>
<td>70.5 ± 8.9</td>
<td>95.3 ± 11.7*</td>
<td>78.6 ± 13.8</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td>66.4 ± 9.6</td>
<td>59.2 ± 8.5</td>
<td>60.2 ± 7.5</td>
<td>65.3 ± 9.1</td>
</tr>
<tr>
<td>BT (°C)</td>
<td>36.6 ± 0.7</td>
<td>36.4 ± 0.4</td>
<td>36.0 ± 0.3*</td>
<td>35.9 ± 0.6*</td>
</tr>
<tr>
<td>$P_{peak}$ (cmH$_2$O)</td>
<td>12.1 ± 2.2</td>
<td>18.1 ± 3.1*</td>
<td>26.8 ± 4.0*</td>
<td>15.5 ± 2.4*</td>
</tr>
<tr>
<td>$P_{plat}$ (cmH$_2$O)</td>
<td>11.5 ± 2.1</td>
<td>17.5 ± 3.1*</td>
<td>25.9 ± 4.0*</td>
<td>14.3 ± 2.5</td>
</tr>
<tr>
<td>ETCO$_2$ (mmHg)</td>
<td>32.2 ± 1.5</td>
<td>30.4 ± 1.7*</td>
<td>33.2 ± 2.0</td>
<td>35.3 ± 2.8*</td>
</tr>
<tr>
<td>PaCO$_2$ (mmHg)</td>
<td>40.3 ± 3.0</td>
<td>NA</td>
<td>NA</td>
<td>47.1 ± 4.0*</td>
</tr>
<tr>
<td>rSO$_2$ (%)</td>
<td>73.6 ± 5.5</td>
<td>70.3 ± 4.6</td>
<td>70.9 ± 5.3</td>
<td>72.8 ± 3.8</td>
</tr>
</tbody>
</table>

Values are mean ± SD. ONSD: optic nerve sheath diameter; SBP: systolic blood pressure; DBP: diastolic blood pressure; MBP: mean blood pressure; HR: heart rate; BT: tympanic body temperature; $P_{peak}$: airway peak pressure; $P_{plat}$: airway plateau pressure; ETCO$_2$: end-tidal CO$_2$ partial pressure; PaCO$_2$: arterial CO$_2$ partial pressure; rSO$_2$: regional cerebral oxygen saturation by near-infrared spectroscopy; NA: not available; $T_{SUP}$: in the supine position after induction of anesthesia; $T_{TREN}$: 3 min after the steep Trendelenburg position ($35^\circ$ incline); $T_{T+P}$: 3 min after the steep Trendelenburg position combined with pneumoperitoneum; $T_{END}$: in the supine position after desufflation of the pneumoperitoneum. * $P < 0.05$ compared with $T_{SUP}$. 