Effects of pneumoperitoneum and Trendelenburg position on intracranial pressure and cerebral blood flow assessed using transcranial doppler: A prospective observational study

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Abstract

Background and Aims: Laparoscopic lower abdominal surgeries involve carbon dioxide (CO_2) insufflation and Trendelenburg position. The raised intra-abdominal pressure can increase intracranial pressure (ICP) and alter cerebral blood flow. This study was conducted to determine the effect of pneumoperitoneum and Trendelenburg position on ICP and cerebral perfusion pressure (CPP) measured using transcranial Doppler (TCD)

Material and Methods: A prospective observational study was conducted in 43 patients of either sex, aged between 18 and 60 years with American Society of Anesthesiologists physical status I and II, undergoing elective laparoscopic surgery in Trendelenburg position. After standard anesthesia induction, pneumoperitoneum was created to facilitate surgery, maintaining an intra-abdominal pressure of 10–15 mmHg and Trendelenburg position of 25°–30°. End-tidal carbon dioxide ($EtCO_2$) was maintained between 30 and 35 mmHg. The ICP was assessed non-invasively using TCD-based diastolic flow velocities (FVd) and pulsatility index (PI) of middle cerebral artery. Data was represented as mean ± standard deviation and compared using paired *t* test. A *P* value of < 0.05 was considered significant.

Results: Mean ICP_{PI} at baseline was 14.02 ± 0.89 mmHg which increased to 14.54 ± 1.21 mmHg at pneumoperitoneum and Trendelenburg position ($P = 0.005$). Mean ICP_{FVd} at baseline was 6.25 ± 2.47 mmHg which increased to 8.64 ± 3.79 mmHg at pneumoperitoneum and Trendelenburg position ($P < 0.001$). There was no statistically significant change in the CPP or mean arterial pressure values intraoperatively.

Conclusions: Laparoscopic procedures with CO_2 pneumoperitoneum in Trendelenburg position increase ICP as measured using TCD ultrasonography. The CPP was not significantly altered when $EtCO_2$ was maintained in the range of 30–35 mmHg.

Keywords: Cerebral blood flow, intracranial pressure, laparoscopy, pneumoperitoneum, transcranial doppler, trendelenburg position

Key Messages: Pneumoperitoneum in Trendelenburg position increases intracranial pressure. Cerebral perfusion pressure is not altered with pneumoperitoneum in Trendelenburg position.

Introduction

Laparoscopic surgery involves carbon dioxide (CO_2) insufflation to create pneumoperitoneum and often requires a concomitant Trendelenburg position for adequate surgical exposure. The raised intra-abdominal pressure from the pneumoperitoneum, alteration in the patient's position and effects of CO_2 absorption cause changes, especially in cardiac, respiratory, metabolic and cerebral physiology.[1–4] Pneumoperitoneum or intrabdominal insufflation and Trendelenburg position increases intracranial pressure (ICP) and alters cerebral blood flow (CBF) and

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blood volume.[4–6] There are few studies which show a positive correlation between intra-abdominal pressure and ICP.[7,8] Deeren *et al.*[9] conducted an observational study in 11 critically ill patients who simultaneously required intra-abdominal and ICP monitoring and demonstrated that increases in intra-abdominal pressure were associated with increases in ICP. The changes in ICP, CBF and cerebral blood volume, in turn, affect cerebral perfusion pressure (CPP).[10] These changes in cerebral hemodynamics can have a detrimental effect on cerebral oxygenation.[8] An acute rise in ICP may be harmful to patients with head injury or unrecognized intracranial mass lesions.

The effect of pneumoperitoneum and Trendelenburg position on ICP is less studied.[11,12] Out of many invasive and non-invasive techniques of monitoring ICP and CPP, Transcranial Doppler (TCD) is a non-invasive, safe, relatively inexpensive bedside tool. It provides real–time information on ICP and CPP with high temporal resolution and allows continuous monitoring. The TCD measures blood flow velocities from major vessels of the circle of Willis, but most published data refer to the middle cerebral artery (MCA). Various formulae have been described to derive ICP from the variables obtained from TCD.[13] Budohoski *et al*.[14] determined a method based on the pulsatility index (PI) to calculate ICP. Diastolic flow velocity (FVd)–based measurements of CPP and ICP were proposed by Czosnyka.[15] In the present study, TCD (RIMED, Digi-Lite, Israel) was used to assess the effect of pneumoperitoneum and Trendelenburg position on ICP. The aim of the study was to determine the effect of pneumoperitoneum and Trendelenburg position on ICP in patients with no neurological diseases. The primary objective was to detect changes in ICP with pneumoperitoneum and Trendelenburg position compared to baseline value. Other objectives were to compare changes in mean arterial pressure (MAP) and CPP with pneumoperitoneum and Trendelenburg position.

Material and Methods

This prospective study was conducted in a tertiary care hospital between September 2018 and September 2019. Patients aged between 18 and 60 years with American Society of Anesthesiologists (ASA) physical status I and II, of either sex, undergoing elective laparoscopic surgery requiring Trendelenburg position were included in the study. Patients with history of central nervous system disorder, pregnancy, and those undergoing laparoscopy for trauma or emergency were excluded from the study. Patients with inadequate temporal window, prolonged surgeries with duration of more than three hours and surgeries converted into open technique were considered dropouts and excluded from the analysis.

The study was approved by the hospital's Ethics Committee. Written informed consent was obtained from all patients. The sample size was estimated using data from a previous study by Robba *et al*.[4] Considering a standard deviation of difference in ICP of 0.95 with a medium Cohen's d effect size (d = 0.5), at 5% alpha error and at 90% power, a sample size of 40 was obtained. Considering a dropout rate of 10%, a total of 45 patients were recruited. No premedication was given to the patients. After shifting the patients to the operation theatre, standard monitors like pulse oximetry, electrocardiography and non-invasive arterial blood pressure were connected and monitored. Anesthesia was induced with fentanyl 1–2 μg/kg and propofol titrated to loss of verbal response to commands. Muscle relaxant, atracurium 0.5 mg/kg, was given to facilitate tracheal intubation. Patients were ventilated with a tidal volume of 8 ml/kg. Respiratory rate was adjusted to maintain end-tidal carbon dioxide ($EtCO_2$) of 30–35 mmHg. Anesthesia was maintained with sevoflurane (0.8–1 minimum alveolar concentration) in 50% oxygen and air with intermittent atracurium boluses of 0.1 mg/kg to maintain train of four response of 0–1. Carbon dioxide pneumoperitoneum was created and maintained at an intra-abdominal pressure of 10–15 mmHg. Trendelenburg position of 25°–30° was also given simultaneously to facilitate surgical exposure.

TCD study was done to assess MCA blood flow velocity using a 2-MHz Doppler probe over the temporal window. A gel head rest was used and the head was placed in neutral position. The probe was placed just above the zygomatic arch and in front of the tragus of the ear, orienting it slightly upward and anteriorly. A red colour signal (direction of flow toward the probe) at a depth range between 40 and 65 mm represents the flow in the ipsilateral MCA. A continuous band for the period of 6 seconds was ensured to obtain a reliable value. Both the sides were insonated when window was available, and the highest value was taken. Patients with reliable insonation on one side were also included. Patients with poor tracing were considered as dropouts. The measurements were taken at the following time points:

i. (B) Baseline, 10 min after induction (to allow the hemodynamic response of tracheal intubation to settle)
ii. (PP + TP) 10 mins after providing Trendelenburg position with pneumoperitoneum
iii. (N) At the end of the surgery, 10 min after placing the patient in neutral position before stopping sevoflurane.

All insonations were done by a single seasoned anesthesiologist, and measurements were recorded at similar MAP and $EtCO_2$ values of the baseline.

The following MCA flow velocities in cm/s were determined from TCD: systolic flow velocities (FVs), FVd, and mean flow velocities (FVm). From these variables PI, ICP and CPP were calculated. The MAP was also noted at the same time points.

ICP was calculated via two different methods.[4]

I. ICP calculated from PI

PI was calculated using Gosling's method: PI = FVs-FVd/FVm

ICP_{PI} was given by Budohoski *et al.*[14] as, $ICP_{PI} = 8.35 + 7.60 \times PI$

II. ICP calculated from FVd (ICP_{FVd})

Non-invasive CPP ($nCPP_{FVd}$) was calculated from FVd using the formula given by Czosnyka *et al.* They had validated the formula in patients with head injury demonstrating less prediction error with a high positive predictive value.[15]

$$nCPP_{FVd} = MAP \times \frac{FVd}{FVm} + 14mmHg$$

From $nCPP_{FVd}$, ICP_{FVd} was calculated as: $ICP_{FVd} = MAP - nCPP$

Statistical analysis

Categorical data was represented in the form of frequencies and proportions. Continuous data was represented as mean and SD. Paired *t* test was used to compare data at different time points. Data was analyzed using Microsoft Excel and Statistical Package for the Social Sciences version 22 (Somers NY, USA). A *P* value (probability) of <0.05 was considered as statistically significant.

Results

A total of 45 patients satisfying the inclusion criteria, as defined earlier, were recruited in the study. Two patients were excluded from analysis due to poor insonation. All the patients included in the study were males undergoing either unilateral or bilateral, uncomplicated laparoscopic inguinal hernia repair.

Mean height of subjects was 170.4 ± 4.3 cm, mean weight was 65.5 ± 9.9 kg and mean body mass index (BMI) was 22.4 ± 2.6 kg/m^2. In the study, 51.2% were ASA physical status I and 48.8% were ASA physical status II. The mean duration of surgery was 104.4 ± 30.6 min.

Mean FVs at baseline was 70.06 ± 13.16; at PP + TP position, it increased to 79.76 ± 18.80 and at neutral position, it decreased to 75.25 ± 15.42 (cm/s) but stayed above baseline values. The increase in mean FVs at PP + TP position ($P = 0.003$) and neutral position ($P = 0.03$) compared to baseline value was significant.

Mean FVm at baseline was 46.94 ± 9.32; at PP + TP position, it increased to 52.20 ± 13.66, and at neutral position, it decreased to 49.68 ± 10.89 (cm/s) but stayed above baseline values. The increase in mean FVm at PP + TP position was significant ($P = 0.03$), but the increase at neutral position compared to baseline value was not significant.

Mean FVd at baseline was 35.38 ± 7.75; at PP + TP position it, increased to 38.35 ± 11.58, and at neutral position, it decreased to 36.83 ± 9.18 (cm/s). There was no significant increase in mean FVd at PP + TP position and neutral position compared to baseline value.

Mean PI at baseline was 0.75 ± 0.12; at PP + TP position, it increased to 0.82 ± 0.16, and at neutral position, it came down to 0.79 ± 0.14 but stayed above baseline. The increase in mean PI at PP + TP position and at neutral position compared to baseline value was significant ($P = 0.005$ and $P = 0.03$, respectively).

Mean ICP_{PI} at baseline was 14.02 ± 0.88; at PP + TP position, it increased to 14.54 ± 1.21, and at neutral position, it decreased to 14.31 ± 1.04 but stayed above baseline. The increase in mean ICP_{PI} (mmHg) at PP + TP position and at neutral position compared to baseline value was significant ($P = 0.005$ and $P = 0.03$, respectively).

Mean ICP_{FVD} at baseline was 6.25 ± 2.47; at PP + TP position, it increased to 8.64 ± 3.79, and at neutral position, it decreased to 7.16 ± 3.53 but stayed above baseline. The increase in mean ICP_{FVD} (mmHg) at PP + TP position was significant ($P < 0.001$), but the increase at neutral position compared to baseline value was not significant. The results along with the *P* values are summarized in Table 1.

All patients were successfully extubated after surgery and their postoperative period was uneventful.

Discussion

A total of 43 patients completed the study. All the patients in the study were males as all the surgeries were done for inguinal hernia repair, which is common in males. Anesthesia protocol and surgical technique were standardized for the

Table 1: Mean values at (B) Baseline, (PP + TP) after pneumoperitoneum and Trendelenburg Position, and (N) neutral Position

Variables	Baseline (B) Mean±SD	PP + TP Mean±SD	Neutral (N) Mean±SD	*P* (PP + TP compared to B)	*P* (N compared to B)
FVs (cm/s)	70.06±13.16	79.76±18.80	75.25±15.42	0.003*	0.03*
FVd (cm/s)	35.38±7.75	38.35±11.58	36.83±9.18	0.15	0.32
FVm (cm/s)	46.94±9.32	52.20±13.66	49.68±10.88	0.03*	0.11
MAP (mmHg)	82.30±10.09	84.12±9.54	81.49±10.14	0.28	0.69
PI	0.75±0.12	0.82±0.16	0.78±0.14	0.005*	0.03*
ICP_{PI} (mmHg)	14.02±0.88	14.54±1.21	14.31±1.04	0.005*	0.03*
CPP_{FVd} (mmHg)	76.05±9.82	75.48±9.94	74.33±9.88	0.73	0.34
ICP_{FVd} (mmHg)	6.25±2.47	8.64±3.79	7.16±3.53	< 0.001*	0.09

** P values which are significant*

hernia repair. The mean duration of surgery was less than two hours, and hence, there were less chances of influence of prolonged positioning on the observed values. In the present study, ICP was assessed non-invasively using TCD.

In the current study, there was a significant increase in the mean value of FVs and FVm with pneumoperitoneum and Trendelenburg position, when compared to initial baseline values. But there was no significant change in the mean value of FVd with pneumoperitoneum and Trendelenburg when compared to baseline. Wang Y *et al.*[16] described that systolic and FVm show a positive correlation with the ICP and FVd show a negative correlation with ICP in patients with raised ICP following head injury. We observed a rise in systolic and FVm with rise in ICP in our study. The flow velocity values have to be interpreted in relation to hemodynamics. An increase in the systolic and diastolic and mean arterial pressures, usually seen with pneumoperitoneum,[17] can cause associated rise in the systolic flow velocities.[18] However, there was no significant variation in arterial pressure values intraoperatively with carbon dioxide insufflation and placement in Trendelenburg position. The changes in the flow velocity values can be attributed to reflect the changes in ICP and positioning in our cases. Nevertheless, an increase in the cerebrovascular resistance could have led to underestimation of ICP (measured using formula) in our cases.

There was significant increase in the mean ICP values derived using either method (both PI method and FVd method) with the introduction of pneumoperitoneum and placement in Trendelenburg position. Trendelenburg position can cause changes in cerebrospinal fluid dynamics due to changes in CBF and venous pressure and can increase ICP. Josephs LG *et al.*[19] conducted an animal study and found that with the establishment of pneumoperitoneum, ICP increased from a mean of 13.5 mmHg to 18.7 mmHg and from 22.6 mmHg to 27.4 mmHg ($P = 0.0001$) in a head injury model.

In our study mean ICP_{PI} at baseline was 14.02 ± 0.89 mmHg which increased to 14.54 ± 1.21 mmHg at pneumoperitoneum and Trendelenburg position. The mean ICP values decreased at the end of the surgery in neutral position compared to the values with pneumoperitoneum and Trendelenburg position, though they did not return to the initial baseline. The ICP_{PI} value at the end of the surgery in neutral position was 14.31 ± 1.04 mmHg. The majority of patients (62.8%) in our study population were above 50 years of age. As ICP has a decreasing function with age, we might have recorded lower IC*P* values in our study. Again, age-related increase in the cerebral compliance might explain the milder changes in ICP with pneumoperitoneum and Trendelenburg position in our study.[20] These results are comparable to the results obtained by Robba *et al.*[4] wherein, ICP_{PI} values increased from 12.91 mmHg to 13.67 mmHg with pneumoperitoneum alone and remained the same with both pneumoperitoneum and Trendelenburg position. It decreased back to 12.91 mmHg at the end of the surgery. They found that ICP_{FVd} values increased from 3 mmHg to 8.5 mmHg with pneumoperitoneum alone. With both pneumoperitoneum and Trendelenburg position, it further increased to 12 mmHg and returned to 5 mmHg at end of the surgery. Additionally, they found an increase in $EtCO_2$ following pneumoperitoneum before application of Trendelenburg position, and hence, described a two-level rise in ICP_{FVd}, unlike our study where the $EtCO_2$ was maintained at a constant level by adjusting the respiratory rate based on the patient's pre-pneumoperitoneum values. In our study, mean ICP_{FVd} at baseline was 6.25 ± 2.47 mmHg which increased to 8.64 ± 3.79 mmHg at pneumoperitoneum and Trendelenburg position, and the ICP_{FVd} value at the end of the surgery in neutral position was 7.16 ± 3.53 mmHg. ICP_{PI} is the most commonly used TCD measure to estimate ICP as it correlates better with absolute values. However, Robba *et al.*[13] found that ICP_{FVd} method may be able to detect changes in estimated ICP modulated by intra-abdominal pressure variations, whereas TCD-derived PI may not. We performed both the methods to increase the validity of our findings. Additionally, TCD-derived methods are helpful to detect relative changes in ICP and may be less accurate in absolute measurement of ICP.[13] Hence, they are more useful in distinguishing the changes in ICP values between different points of time.

Kamine *et al.*[7] reviewed patients who underwent laparoscopic-assisted ventriculoperitoneal shunt for variation of ICP on abdominal insufflation, measured through a ventricular catheter. The mean ICP increase, with 15 mmHg insufflation, was 7.2 (95% CI, 5.4–9.1 [$P < .001$]) cm of water. The increase in ICP correlated with increasing insufflation pressure ($P = 0.04$).

In the current study, out of the 43 patients, 5 did not show an increase in ICP by either PI method or FVd method; rather, there was a decrease in the ICP values with pneumoperitoneum and Trendelenburg position. Arterial partial pressure of CO_2 was not measured in the current study due to logistic issues, and $EtCO_2$ was maintained with hyperventilation. An increase in dead space ventilation during pneumoperitoneum in Trendelenburg position can increase the gradient between arterial and end-tidal CO_2. Hence, the observed increases in the ICP may be additionally influenced by an increased partial pressure of CO_2 ($PaCO_2$) in these cases. However, we maintained $EtCO_2$ in the narrow range of 30–35 mmHg throughout the procedure in our study. All patients required adjustments in respiratory rate so as to maintain the desired level of $EtCO_2$ after the creation of pneumoperitoneum. This can increase the airway pressures, further contributing to the increase in the ICP values.

There was a decrease in the CPP as derived from FVd values with pneumoperitoneum and Trendelenburg position when compared to initial baseline values. Mean CPP_{FVd} at baseline was 76.05 ± 9.82 mmHg, and at pneumoperitoneum and Trendelenburg position, it decreased to 75.48 ± 9.94 mmHg. But the change was not statistically significant. This result is similar to those obtained by Robba *et al.*[4] A favorable observation is that in spite of the increased ICP with pneumoperitoneum and Trendelenburg position the CPP is maintained so that cerebral tissue oxygenation is not compromised. Nonetheless the correlation between CBF velocity and invasive ICP is not continuous and reflects a normal autoregulatory response.[21] The changes in CPP derived from FVd are mathematical estimates and are hence influenced by ICP both directly and indirectly. Nevertheless, the changes in CPP occurring in our study are measured at controlled conditions such as stable MAP and $EtCO_2$.

The highest ICP recording obtained in our study was 19.4 mmHg which was obtained at the end of the surgery in neutral position. None of the TCD-derived ICP values in our study exceeded 20 mmHg even with pneumoperitoneum and Trendelenburg positioning. None of our patients reported any neurological symptoms in the postoperative period. In the study done by Robba *et al.*,[4] four patients presented with TCD derived values between 20 and 25 mmHg, but no neurological complications were observed at the end of the procedure. Other studies done by Cooke *et al.*[22] and J R Lee *et al.*,[23] reported patients with headache and nausea post-operatively which they attributed to the increased ICP in association with hypercapnia.

The current study has the following limitations. The results are not generalizable to populations at risk, that is, patients with neurological diseases and with altered ICP-volume relationship. The results may vary when other anasthetics like desflurane or propofol are used for maintenance. Inter-observer variability in results can be seen with ultrasonographic measurement and the derived measures cannot be treated on par with absolute values. This might interfere with setting a threshold level for intervention, that is, treatment of raised ICP with agents such as mannitol. Arterial $PaCO_2$ was not measured due to logistic issues, and depth of anesthesia monitors were not used to standardize the effect of inhalational agents. These might have had an influence on the observed values of ICP in the current study.

Conclusions

Laparoscopic procedures with carbon dioxide pneumoperitoneum in moderate Trendelenburg position increases ICP as measured using TCD-based indices. Although ICP increases, it is not alarming and does not cause significant neurological problems when normocapnia is maintained. Patients with undiagnosed neurological conditions or brain injury undergoing laparoscopic procedures are susceptible to an increase in ICP due to poor intracranial compliance. TCD measurements can be done in these patients to reflect changes in ICP.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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