Original Article

Ultrasonographic measurement of optic nerve sheath diameter during laparoscopic surgeries in pediatric patients: An observational study

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Abstract

Background and Aims: Laparoscopic surgery involves creation of carbondioxide (CO_2) pneumoperitoneum leading to a rise in intracranial pressure (ICP), which can cause expansion of optic nerve sheath diameter(ONSD).We aimed to study the magnitude of changes in ONSD occurring during pediatric laparoscopic surgery and correlate them with changes in end-tidal CO_2 ($EtCO_2$), intrabdominal pressure (IAP), and a change in patient position (P).
Material and Methods: Thirty-five pediatric patients between 1 and 12 years undergoing laparoscopic surgeries under general anesthesia were included.The ONSD, $EtCO_2$, IAP, and position (P) in degrees from supine were recorded 15 min post-anesthesia induction(T1) and 30 min following the establishment of pneumoperitoneum (T2).The difference between the two groups was analyzed using a paired or unpaired *t*-test for quantitative variables and using Chi-square or Fisher's exact test for qualitative data.Correlation between two quantitative variables was performed using Pearson's correlation coefficient.
Results: Mean ONSD showed a significant change ($P < 0.001$) 30 min (T2) following pneumoperitoneum increasing by an average of 0.04cm as compared to 15 min (T1) post-anesthesia induction (0.57 ± 0.06 vs. 0.61 ± 0.06). There was a moderate to strong positive correlation between change in ONSD and change in $EtCO_2$(correlation coefficient = 0.629, $P = 0.001$) 30 min post pneumoperitoneum. There was a weak correlation between change in ONSD and change in position (correlation coefficient = 0.276) and a very weak correlation between change in ONSD and change in IAP (correlation coefficient = 0.19).
Conclusions: Laparoscopic surgeries in children can cause significant increases in ICP as measured by the ONSD; changes in $EtCO_2$ are the predominant factor responsible. Increasing minute ventilation to maintain normal $EtCO_2$ may help mitigate changes in ICP in children undergoing laparoscopic surgery.

Keywords: Intracranial pressure, laparoscopy, optic nerve sheath diameter, pediatric, pneumoperitoneum

Introduction

Laparoscopic surgery has become a commonly performed procedure in pediatric patients with numerous advantages. However, it may be associated with physiological perturbations in the cardiovascular, respiratory, renal, endocrine and central nervous systems. An increase in the intracranial pressure (ICP) is one of the effects resulting from carbon dioxide (CO_2) pneumoperitoneum.[1,2] The cause of the increase in ICP is multifactorial. The creation of pneumoperitoneum causes an increase in the absorption of CO_2 from the peritoneal surface, resulting in an increase

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in partial pressure of arterial carbondioxide ($PaCO_2$) and ICP subsequently. Furthermore, there is a direct mechanical effect of pneumoperitoneum, which results in impaired cerebrospinal (CSF) fluid drainage at the lumbar venous plexus leading to a rise in ICP.[3,4]

The optic nerve is an extension of the central nervous system surrounded by CSF and continues in a nerve sheath. An increase in ICP can cause expansion of the optic nerve sheath and an increase in its diameter.[5] It has been shown that an increase in the optic nerve sheath diameter (ONSD) can reflect an increase in ICP even before papilledema sets in[6,7] being validated in traumatic brain injury and intracranial hemorrhage.[8]

Arise in ICP is of paramount importance and can lead to complications in patients with poor intracranial compliance such as hydrocephalus, brain tumor, and neurosurgical cases. In a study conducted by Newman *et al.*,[9] 23 children with shunted hydrocephalus were examined by ocular ultrasound and they concluded that ONSD is a simple, non-invasive procedure for assessment of raised ICP in pediatric hydrocephalus. However, the literature is sparse when looking into changes in ONSD in pediatric laparoscopic surgeries.

We aimed to study the magnitude of changes in ONSD occurring during pediatric laparoscopic surgery and correlate it with changes in EtCO2, intrabdominal pressure (IAP), and a change in patient position (P). The primary objective of our study was to measure the change in ONSD 30 min after establishing CO_2 pneumoperitoneum in children between 1 and 12 years undergoing laparoscopic surgery. The secondary objective was to correlate the change in ONSD with changes in end-tidal CO_2($EtCO_2$), change in IAP, and degree of Trendelenburg position 30 min after pneumoperitoneum.

Material and Methods

Following approval from the Institutional Ethics Committee, (EC/NEW/INST/2019/203), this prospective observational study was conducted from February 2022 to January 2023. Thirty-five pediatric patients of ASA PS I and II, ages ranging from 1 to 12 years undergoing laparoscopic abdominal surgeries requiring the Trendelenburg position under general anesthesia were included. Patients with congenital heart disease, hydrocephalus, ocular or neurologic complications, glaucoma, intracranial tumor, and previous history of neurosurgery and ophthalmic surgery were excluded. A written informed consent was taken by the anesthesiologist involved in the study from the parents/guardians of children satisfying the inclusion criteria before the planned surgical procedure. The children were premedicated with 0.75mg/kg midazolam orally 20 min before anesthesia induction, once their nil per oral status was confirmed. On arrival into the operating room, the patients were monitored using standard ASA monitors with ECG, NIBP, pulse oximetry, and capnography. Induction of anesthesia was then commenced with a face mask with (50:50) nitrous oxide: oxygen mixture at 6L/min and incremental sevoflurane (2–8%) with the patient breathing spontaneously. On achieving adequate depth of anesthesia, intravenous access was secured and an injection of propofol 2mg/kg was administered. After confirming the adequacy of bag-mask ventilation, endotracheal intubation was facilitated with an injection of cis-atracurium 0.2mg/kg. General anesthesia was maintained with 50:50 nitrousoxide: oxygen mixture and sevoflurane to attain age-adjusted minimal alveolar concentration (MAC) of 0.8–1.2. Volume-controlled ventilation was used with a tidal volume of 8mL/kg, positive end-expiratory pressure (PEEP) of 5 cmH_2O, and the respiratory rate was initially adjusted to maintain $EtCO_2$between 35 and 45 mmHg with no further adjustments made until the completion of study measurements. All patients received ultrasound-guided bilateral transverse abdominal plane block with 0.4mL/kg of 0.25% bupivacaine and 1μ/kg of clonidine administered on each side. Baseline hemodynamic parameters (HR, NIBP, $EtCO_{2)}$ were recorded. The ONSD, $EtCO_2$, IAP, and position (P) in degrees from the neutral or supine position were recorded 15 min post anesthesia induction (T1) and 30 min following the establishment of pneumoperitoneum (T2). CO_2 pneumoperitoneum was established, and IAP was kept between 8 and 12 mm Hg (IAP <10mmHg [1–2 years of age] and <12mmHg [2–8 years of age and older children)] as per surgical requirement and age of the patient. Following the collection of study data, the consultant anesthesiologist managed the case, with maintenance, termination, and recovery from anesthesia left to their discretion.

ONSD measurements were performedby an investigator with an experience of at least 30 ocular scans, as described previously by Moretti and Pizzi.[10] After covering both eyes with a Tegaderm patch and ensuring a thick layer of conductive gel, a high-frequency (7.5–12 Hz) linear ultrasound probe (GE 12L –RS of the Wipro GE LOGIQ™ ER7GE Medical system Co, Ltd.) with a footprint of 4.2 × 0.7 cm was placed on either eye. Measurements were taken in the horizontal and vertical axis for each eye, ensuring visualization of the optic nerve sheath and avoidance of ultrasound beam passing through the lens. The ONSD was measured 3mm posterior to the point where the optic nerve entered the globe. The ONSD was measured as the distance between the hypoechoic outer borders surrounding the hyperechoic nerve sheath [Figure 1]. The average of four values (twofor each eye) was taken as the final ONSD value at that time point andused subsequently for statistical analysis.

The degree of Trendelenburg position was administered as per the surgical requirements and measured using the clinometer android app. The angle in degrees below the supine position (0 degrees) was calculated using the app and noted. This professional tool called the clinometer is the most precise slope measurement tool and the app was calibrated before the measurement of the angle of Trendelenburg. Clinometer app is designed by plaincode and it utilizes the gyroscope sensor in smartphones to determine the degree of inclination or tilt from a neutral position beingvalidated previously by Jones*et al.*[11]

Based on the observations of Min *et al.*[12] and aknown observer variation (±0.2 mm) in ONSD (Ballantyne *et al.* 2002),[13] 28 patients were needed to detect a 0.3mm change in ONSD before and after the induction of CO_2 pneumoperitoneum at a two-tailed significance level of 5% and power of 80%. Considering 20% dropouts, the final sample size calculated was 35.

The sample size was calculated using PASS V15.0 (NCSS, LLC) software. The data were collected, compiled, and analyzed using EPI info (version 7.2). The qualitative variables are expressed in terms of percentages. The quantitative variables were both categorized and expressed in terms of percentages or terms of mean and standard deviations. The difference between the two groups was analyzed using a paired or unpaired *t*-test for quantitative variables and using Chi-square or Fisher's exact test for qualitative data. The correlation between two quantitative variables was performed using Pearson's correlation coefficient. All analyses were two-tailed, and the significance level was set at 0.05.

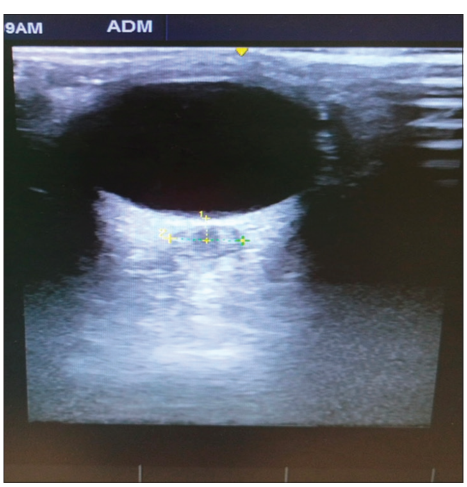

Figure 1: Ultrasonographic measurement of ONSD

The degree of association between the change in ONSD with various factors such as change in $EtCO_2$, change in IAP, and change in positioning was measured by a multivariate regression analysis.

Results

Thirty-five pediatric patients were included in the analysis from February 2022 to January 2023. No patient was excluded. No study protocol violation was reported during the entire study period. The baseline patient characteristics and type of surgery performed are summarized in Table 1. Laparoscopic hernia repair was the most common surgery performed (57.14%), followed by laparoscopic appendicectomy (22.86%), laparoscopic orchiopexy (14.29%), laparoscopic endo-anal pull-through (2.86%), and diagnostic laparoscopy (2.86%).

The mean ONSD showed a significant change ($P < 0.001$) 30 min (T2) following pneumoperitoneum increase by an average of 0.04 cm [Table 2] as compared to 15 min (T1) post-anesthesia induction (0.61 ± 0.06 vs. 0.57 ± 0.06). Pearson's correlation analysis[Table 3] indicated that there was a moderate to strong positive correlation between change in ONSD and change in $EtCO_2$(correlation coefficient = 0.629, P = 0.001) 30 minpost-pneumoperitoneum. There was a weak correlation between change in ONSD and change in position (correlation coefficient = 0.276, P = 0.276) and a very weak correlation between change in ONSD and change in IAP (correlation coefficient = 0.19, $P > 0.05$) 30 min post-pneumoperitoneum, which was not statistically significant.

Table 1:Demographic data

Variables	Values
Age (years)	5.83±3.5
Gender (male/female)	28 (80%)/7 (20%)
Weight (Kg)	16.67±6.52
Type of surgery	
1. Laparoscopic hernia repair	20 (57.14%)
2. Laparoscopic appendicectomy	8 (22.86%)
3. Laparoscopic endo-anal pull-through	1 (2.86%)
4. Diagnostic laparoscopy	1 (2.86%)
5. Laparoscopicorchiopexy	5 (14.29%)

Values are expressed in mean±SD or number (percentage).

Table 2: Change in optic nerve sheath diameter (ONSD), end-tidal carbon dioxide ($EtCO_2$), intra-abdominal pressure (IAP), position change (P), and hemodynamic parameters before and after pneumoperitoneum

	Before pneumoperitoneum 15 min post-anesthesia induction (T1)	30 Minutes post-pneumoperitoneum (T2)	*P*
ONSD (cm)	0.57±0.06	0.61±0.06	<0.001
ET CO_2(mm Hg)	35.26±3.92	41.89±5.87	<0.001
IAP (mm Hg)	0±0.00	9.46±1.77	<0.001
Positionchange (angle in degreesfrom the supine)	0±0.00	36.29±4.16	<0.001
Systolic blood pressure (mm Hg)	85.49±5.55	88.60±8.75	0.060
Diastolic blood pressure (mm Hg)	46.80±7.90	50.14±8.37	0.1046
Pulse rate (per minute)	105.29±16.38	111.23±12.53	0.080

Values are in mean±SD. ONSD – Optic nerve sheath diameter. ET CO_2 – End-tidal carbon dioxide. IAP – Intra-abdominal pressure. P-Position change

Table 3: Correlation of change in optic nerve sheath diameter (ONSD) with change in end-tidalCO_2, intra-abdominal pressure, and positioning

Correlations				Change in position
Correlations of Change in ONSD		Change in $EtCO_2$	Change in IAP	
Change in ONSD	Pearson correlation	0.629	0.194	0.276
	Significant (2-tailed)	0.001	0.264	0.109
	n	35	35	35

*** SPSS Tutorials Pearson Correlation.Correlation is significant at the 0.01 level (2-tailed)*

The multivariate linear regression analysis [Table 4] indicated that change in $EtCO_2$ was an important predictor of change in ONSD. A change in the position was a weak predictor of change in ONSD and the change in IAP had an insignificant effect on the change in ONSD, as given by the equation below:

$$\text{Change in ONSD} = -0.056 + 0.005EtCO_2 + 0.002P,$$

where $EtCO_2$ represents a change in end-tidal carbon dioxide and P represents a change in the position.

In this equation, a change in ONSD represents the dependent variable, a change in $EtCO_2$ represents the first independent variable, and a change in the position represents the second independent variable. The coefficients are $b = -0.056$, $b1 = 0.005$, $b2 = 0.002$. This equation suggests that for every one-unit increase in the change in the $EtCO_2$ variable, achange in ONSD is expected to increase by 0.005 units, holding the change in the position constant. Similarly, for every one-unit increase in the change in position variable, the change in ONSD is expected to increase by 0.002 units, holding the change in the $EtCO_2$ constant.

$EtCO_2$ trends are summarized in Table 2. There was a significant increase in $EtCO_2$ ($P < 0.001$) 30 min (T2) following pneumoperitoneum (41.89 ± 5.87) [Table 2] as compared to 15 min (T1) post-anesthesia induction (35.26 ± 3.92).

Hemodynamic parameters are summarized in Table 2. There was no significant difference in hemodynamic parameters (systolic blood pressure, diastolic blood pressure, and heart rate) 30 min post-pneumoperitoneum (P value > 0.05).

Discussion

Using the ONSD as a surrogate marker for ICP, we found that there were significant increases in the ONSD following pneumoperitoneum in our study. This increase, though statistically significant, was not clinically significant for our study population although it could be detrimental in patients with poor intracranial compliance. The validity of ONSD measurements to detect elevated ICP is well established in adults. However, large-scale pediatric data are lacking though there is some suggestion of its usefulness to detect elevated ICP. McAuley *et al.*[14] found that ONSD was a reliable, non-invasive technique for the assessment of ICP in pediatric hydrocephalus. Robba *et al.*,[15] in a pilot study to evaluate the interaction between ICP and various ultrasound-based techniques in pediatric patients requiring neurocritical care, demonstrated that among the non-invasive ICP measuring methods, ONSD had the best correlation with ICP. Comparing transcranial middle cerebral artery Doppler and ONSD with invasive intraparenchymal ICP monitoring in children between 2 and12 years, Sharawat *et al.*[16] found that ONSD measurements had good diagnostic accuracy in identifying children with an ICP of greater than 20mmHg. In 22 pediatric patients with hepatic failure who were examined by ocular ultrasonography and followed up clinically, poor prognosis related to raised ICP in pediatric liver failure could be identified by ONSD measurements.[17]

The cut-off value of ONSD to suggest raised ICP has not been well defined in children, with wide variability in the literature.[5,18,19] Older studies obtained lower cut-offs of 2.1 to 4.3 mm (mean of 3.08mm, cut-off of 4 mm in

Table 4: Linear regression analysis of the factors with change in ONSD as outcome parameter

Forward linear regression analysis	Unstandardized coefficients		Standardized coefficients	*t*	Sig.
	B	Std. error	Beta		
(Constant)	−0.056	0.026		−2.185	0.036
Change in EtCO2	0.005	0.001	0.639	5.032	0.000
Change in position	0.002	0.001	0.298	2.348	0.025

infants less than 1 year, and 4.5 mm in older children).[20] Recently, Steinborn *et al.*[21] reported significantly higher mean ONSD (5.75 ± 0.52) values than previously defined, which was corroborated by magnetic resonance imaging (MRI) (5.69 ± 0.31) in children (5–18 years) without neurological or ophthalmological disease. They concluded that the main reason for this variability wasmeasurements taken at the optic nerve rather than the sheath (inadequate sonographic differentiation of optic nerve and arachnoid membrane), an incorrect cutting plane of the ultrasound path (failure to exclude the lens), operator dependency, and lack of standardized measurement methods.

In our study, the baseline ONSD values during 0.8 to 1.2 MAC of sevoflurane anesthesia were similar to that shown by Steinborn *et al.*[21] (5.70 ± 0.6 vs. 5.69 + 0.31). Though our measurements were taken under general anesthesia, the effect of general anesthesia on ONSD would seem insignificant if compared to the normal values obtained by Steinborn *et al.* in unanesthetized children. This may imply that the vasodilatory effects of sevoflurane on the cranial vasculature and the institution of positive pressure ventilation had minimal effects on ICP.

Looking further into our study findings, it would seem that $EtCO_2$ was the predominant factor in determining the changes in ONSD and suggests a control of the $EtCO_2$ may mitigate significant increases in ICP. The results are consistent with a study conducted by Dinsmore *et al.*[22] who demonstrated the dynamic responsiveness of ONSD to $EtCO_2$ in alert adult patients breathing spontaneously. Jang *et al.*[23] found that ONSD showed rapid reactivity to $EtCO_2$ levels between 35 and 45mmHg in children below 18 years under general anesthesia. In our study, for every 1mmHg increase in $EtCO_2$, the ONSD was expected to increase by 0.005mm, as given by the multivariate linear regression equation[Table 4].

The degree of the Trendelenburg position showed a weak correlation with changes in ONSD in our study with every 1-degree change causing a change of 0.002mm in ONSD [Table 4]. This may in part be due to the fact that the degree of Trendelenburg position (36 degrees) provided in the study was not steep enough to inflict changes in cerebral flow dynamics. In one adult study by Shah *et al.*,[24] a steep Trendelenburg position (45 degrees) during robotic surgery was found to lead to significant increases in ONSD. In addition, children (especially those less than 5 years) have a lower blood volume sequestered in the lower limbs, meaning the effect of Trendelenburg position on preload and in turn cerebral flow dynamics may be minimal.[25] Oztan *et al.*[26] studied the effects of CO_2 insufflation and Trendelenburg position on brain oxygenation during laparoscopy in children and concluded that Trendelenburg and left lateral positions could be safely used during pediatric laparoscopic procedures without altering cerebral perfusion.

The effect of IAP on ONSD was minimal in our study. Adult data indicate that ONSD increases proportionally with IAP but remains low if IAP is kept below the safe limit (<15mmHg).[27] In children, the compliant abdominal wall allows adequate laparoscopic operating conditions at lower IAPs. When this minimum IAP (<10–12 mmHg) is observed, alterations in intrathoracic pressure and jugular venous outflow can be minimized.[28,29] In our study, the mean IA Pof 9–10 mm Hg appeared to have little effect on ONSD and in turn ICP.

Thus ultrasonographic measurement of ONSD will help in the evaluation of the rise in ICP occurring during pediatric laparoscopic surgery due to CO_2 pneumoperitoneum and the Trendelenburg position, thereby precluding the need for invasive ICP monitoring, which can lead to infection and bleeding. Further, maintaining $EtCO_2$ within the normal range will help in minimizing the changes in ONSD.

A major limitation of our study is that it was conducted in normal ASA PS I and II patients without any raised ICP. Whether the increases in ONSD during laparoscopy would translate to patients with raised ICP and the clinical significance of the same is uncertain. Also, with limited pediatric literature, the cut-off points for raised ICP in children are still unclear. In addition, the ONSD measurements made would have intra observer and interobserver variations. We took single measurements by a single operator, and even slight variations may be significant as the changes in ONSD were so small.

Conclusion

Laparoscopic surgeries in children can cause significant increases in ICP as measured by the ONSD. Change in

$EtCO_2$ is the predominant factor responsible.Theimpact of a rise in ICP is likely insignificant in children with normal intracranial compliance. However in pediatric patients with poor intracranial compliance, such as a tumor, hemorrhage, and hydrocephalus with ventriculoperitoneal shunt *in situ*, ICP may increase abruptly after the initiation of pneumoperitoneum because of increased CO_2 absorption from the small peritoneal cavity, reduced peritoneal fat, and highly pliable abdominal wall as compared to adults. Increasing minute ventilation to maintain normal $EtCO_2$ may help mitigate changes in ICP in children undergoing laparoscopic surgery.

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Conflicts of interest
There are no conflicts of interest.

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