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ORIGINAL RESEARCH

Evaluation of oxygenation of brain and kidneys with NIRS (near infrared spectrometry) technique in laparoscopic and thoracoscopic operations in children and determination of safe limits of carbon dioxide insufflation

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Abstract

Purpose This study aimed to measure the effects of the upper or lower limit of the carbon dioxide (CO2) insufflation pressure applied in children who underwent laparoscopic and thoracoscopic interventions, on the changes in the brain and kidney Near Infrared Spectrometry (NIRS) values.

Patients and Methods Demographic information, carbon dioxide insufflation pressure and the operation time data were recorded. During the procedure the NIRS probes monitored the brain and left kidney during laparoscopic procedures and the brain only during thoracoscopic procedures. Basal NIRS values were recorded after anesthesia induction, after CO2 insufflation-beginning of insufflation, near the end of the procedure-end of insufflation, and after carbon dioxide desufflation. During the procedure, when ≥20% decrease was observed in the basal value during carbon dioxide insufflation, the carbon dioxide pressure was decreased and the procedure was continued. In case of a decrease of ≥50% in either brain or kidney NIRS it was planned to be recorded as an absolute decrease, and to terminate laparoscopy or thoracoscopy.

Results Two hundred four laparoscopic and 19 thoracoscopic cases were included in the study. The mean age of the patients undergoing laparoscopic procedures was 120 months, the mean body weight was 33 kg, and the mean operative time was 43 minutes; whereas the mean age of the patients undergoing thoracoscopic procedures was 62 months, the mean body weight was 17 kg, and the mean operative time was 80 minutes. No statistically significant difference was found in NIRS values between upper or lower insufflation pressures ($p>0.05$).

Conclusion The pressures provided at the upper limit of the safe range may expand the surgical area and can help prevent problems that may be encountered due to the limited space during the surgery. In this study, it has been shown that pressures at the upper limit of the safe range do not impair patient brain and kidney oxygenation.

Keywords Children · Insufflation · Laparoscopy · Minimally invasive

Introduction

The application of minimally invasive surgery in children is a logical step after its successes in adult surgery [1]. However, the common use of many minimally invasive techniques in children have progressed relatively slowly due to the delay in production of smaller size surgical instruments, the relatively longer learning curve, and the development of more reliable techniques in anesthesia [2].

Laparoscopic and thoracoscopic surgery are commonly used methods in children today. One of the most common indication for surgery in children is appendicitis. There are

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many studies indicating that laparoscopic appendectomy has advantages over the open method and can be used safely in children [3].

The importance of thoracoscopic surgery is gradually increasing especially in the treatment of esophageal atresia and diaphragmatic hernia, in newborns. Exposure of a newborn with an immature cardiopulmonary system to carbon dioxide (CO_2) during thoracoscopy and the reduction in the ventilation of lungs due to pneumothorax is a cause for concern that needs to be carefully taken into account [4].

There are relatively few studies on the cardiopulmonary outcomes of thoracoscopic procedures performed in newborns and the effects of pneumoperitoneumon renal perfusion in children [5, 6].

NIRS (Near Infrared Spectroscopy) is a noninvasive method that can measure regional organ oxygenation with infrared lights. It evaluates tissue oxygenation down to a depth of 6 cm by taking advantage of the light absorption and reflection properties of hemoglobin [7].

In this study, it was aimed to determine safe CO_2 pressures during insufflation by evaluating brain and kidney oxygenation in thoracoscopic and laparoscopic interventions in children.

Material and methods

The study was performed in accordance to the Declaration of Helsinki and was approved by the ethical committee of University (No:17B0230005). Written informed consent was obtained from all of the children and/or their parents. Patients aged 0–18 years who underwent thoracoscopic or laparoscopic interventions for any reason were included in the study. Patients with severe neurological or nephrological disorders were excluded from the study. Sociodemographic data were recorded.

All children were premedicated with 0.5 mg/kg midazolam before surgery. Induction of anesthesia was achieved with 8% sevoflurane in a 50% O_2/CO_2 mixture without vascular access. Induction anesthesia was provided with 2–3 mg/kg propofol and 1–1.2 mg/kg rocuronium bromide in patients with intravenous access.

After anesthesia, NIRS probes were placed on the temporal region and over the left kidney, the position of which was determined by ultrasonography. Measurement was started 15 min before the surgical procedure to record the basal values and continued uninterruptedly until 15 min after the CO_2 desufflation. In addition to the baseline NIRS value, the NIRS values at the start of insufflation, at the end of insufflation and after desufflation were also recorded. NIRS probes were applied continuously throughout the surgery. No signs of compression were found at the probe sites after the procedure.

Pressures during CO_2 insufflation were adjusted at the upper end of the range considered safe in the literature; in laparoscopic procedures: 6 mmHg in 0–1 month age groups, 8 mmHg in 2–12 months, 10 mmHg in 1–2 years, 12 mmHg in 2–8 years, 14 mmHg in 8–18 years; and in thoracoscopy 6 mmHg in 0–1 months, 8 mmHg in 2–12 months, 10 mmHg in 1–18 years. The carbon dioxide pressure was lowered when the NIRS values decreased between 20 and 50%. It was planned to terminate laparoscopy or thoracoscopy when a 50% or more decrease in NIRS value was observed. Simultaneously, oxygen saturation, heart rate, arterial blood pressure, end tidal carbon dioxide value, and insufflation pressure were also recorded during anesthesia. Intravenous fluid replacement was applied to the patients according to their body weight. Urine output was monitored throughout the surgery.

SPSS program (IBM SPSS Statistics 22, Chicago) was used for statistics. Continuous data were reported as mean ± SD. Categorical data were summarized as frequencies and percentages. Mann–Whitney test was used for quantitative data and Chi-square test was used for qualitative data for statistical analysis. In all tests, results were considered statistically significant if $p \leq 0.05$.

Results

Patients aged 0–18 years, who underwent laparoscopic or thoracoscopic procedures between 2017 and 2019 within the scope of the project were included in the study. Patients who were converted to open during surgery, those with severe neurological and nephrological problems, and in whom the NIRS measurements could not be performed until the end due to technical reasons, and patients who refused consent to participate in the study were excluded from the study. Out of a total of 223 patients, 204 underwent laparoscopic surgery and 19 underwent thoracoscopic surgery.

Patients who underwent laparoscopic surgery were divided into 5 groups according to age: 0–1 month, 2–12 months, 1–2 years, 2–8 years, 8–18 years age and similarly those who underwent thoracoscopic surgery were divided into 3 groups according to age: 0–1 months, 2–12 months and 1–18 years.

The numerical data for the patients are given in Table 1.

Analysis of patient data undergoing laparoscopic procedures

There were two patients in the 0–1 month group (mean age 16 days; range 5–27), 12 patients in the 2–12 month group (mean age 4 months; range 1–9 months), seven patients in the 1–2 years age group (mean age 1.5 year), 54 patients

Table 1 The numerical data for the patients

Age group	Number	CO_2 pressure (mmHg)	Mean age	Mean weight (kg)	Mean duration (min)
Laparoscopy group					
0–1 months	2	6–8	16 days (5–27 days)	2.7 (2.5–2.9)	62.5 (20–105)
1–12 months	12	8	4 months (1–9 months)	5.8 (2.7–8)	64 (25–125)
1–2 years	7	10	1.5 years (1–2 years)	12.8 (10–15)	33.8 (15–72)
2–8 years	54	12	6.1 years (2–8 years)	23.2(12.5–40)	41 (15–120)
8–18 years	129	14	12.8 years (8–18 years)	42.5 (18–87)	42.9 (11–160)
Thoracoscopy group					
0–1 months	3	6	1.5 days (1–2 days)	2.6 (2.4–3)	235 (125–400)
1–12 months	4	8–10	3.5 months 81–6 months)	4.9 (2.6–7)	57.5 (15–90)
1–18 yeas	12	10	8 years (1–17 years)	25.9 (8–62)	49.6 (20–95)

Table 2 Characteristics of laparoscopic surgeries

Age group	Time	Brain NIRS	Kidney NIRS	Heart rate	Mean blood pressure	O_2 saturation	End tidal CO_2
0–1 months	Baseline	78.5 + 23.3	72.5 + 12.0	127 + 15.5	37.8 + 19.5	98.5 + 0.7	35.5 + 0.7
	Start	76 + 19.7	61.5 + 0,7	134 + 7	39.6 + 9.8	98 + 1.4	36 + 0
	End	78.5 + 19	69 + 15.5	127.5 + 3.5	36.1 + 6.3	97.5 + 0.7	40 + 7
	Desufflation	76 + 19.7	70 + 14.1	124.5 + 4.9	34.1 + 2.5	97.5 + 0.7	37.5 + 6.3
2–12 months	Baseline	71.5 + 6.8	74 + 7.5	134.2 + 8.5	46.1 + 7.5	98.6 + 1.2	33.6 + 3.9
	Start	68.9 + 5.8	65.5 + 13.8	131.5 + 13.2	44.7 + 6	97.9 + 1.8	33 + 5.2
	End	67.6 + 9.5	68.4 + 12.6	128.9 + 16.7	44.7 + 10.2	98 + 2	35 + 3.7
	Desufflation	64 + 8.6	69.4 + 10.2	127.8 + 16.3	47 + 7.6	98.1 + 2.1	35.6 + 3.3
1–2 years	Baseline	86.8 + 11.5	78.8 + 12.4	133.7 + 29.9	60.4 + 7.01	98.8 + 2	32.7 + 5
	Start	84.5 + 10	76.7 + 12.4	128 + 21.1	64 + 8.1	99.1 + 1.8	33.5 + 3
	End	82 + 11.3	71.4 + 14.4	116.5 + 7	62.5 + 11.9	99.2 + 1.8	35.7 + 0.7
	Desufflation	81.7 + 11.3	73.1 + 12.2	112.4 + 14.2	61.3 + 16.6	99.8 + 0.3	34.8 + 2.6
2–8 years	Baseline	86.9 + 6	85.2 + 9.9	123.5 + 19.2	70.8 + 9.6	99.5 + 0.9	33.9 + 4.9
	Start	84.8 + 8.3	79.6 + 11.5	123.2 + 16.5	71.2 + 10.7	99.4 + 1.7	34.7 + 3.6
	End	82.5 + 7.9	78.8 + 12.2	114.9 + 14.3	67.5 + 9.9	99.5 + 0.9	34.9 + 3.6
	Desufflation	81.2 + 7.6	79.1 + 12.9	112.6 + 15.9	66.4 + 11	99.5 + 0.9	34.1 + 4.2
8–18 years	Baseline	87.9 + 7.5	88.1 + 9.2	114.1 + 17.3	79.1 + 12.4	98.8 + 5.6	33.6 + 5.5
	Start	86.1 + 8.1	82.8 + 11.9	114 + 16.1	76.9 + .11.7	99.2 + 1.1	33.3 + 3.5
	End	83.2 + 9.4	80.3 + 11.9	105.3 + 15	74.1 + 8.4	99.1 + 1.1	34 + 3.1
	Desufflation	82.9 + 10.1	81.7 + 10.9	102.1 + 15.6	71.7 + 8.6	99.2 + ..1	33.3 + 3.8

in the 2–8 years age group (mean age 6.1 years), and 129 patients in the 8–18 years age group (mean age 12.8 years) underwent laparoscopic procedure. Tables 2 and 3 show detailed information on the children.

These patients underwent 144 laparoscopic appendectomies, 15 laparoscopic Nissen fundoplications, 13 laparoscopic cholecystectomy, 12 laparoscopic assisted inguinal hernia repair, five ovarian interventions, and 15 other laparoscopic procedures.

Since there were only two patients in the 0–1 month group, statistical analysis could not be performed. However, there was no decrease of more than 20% in NIRS values in the patient who was given 6 mmHg pressure, whereas a decrease of more than 20% in the kidney NIRS value was observed in the patient who was given 8 mmHg pressure, and the operation was continued by reducing the pressure to 6 mmHg. Gestational age and weight information about newborn patients are presented in Table 4.

In other age groups that underwent laparoscopic procedures, it was observed that the decrease of 20% or more in the brain and kidney NIRS values at the time of CO_2 insufflation at the upper limit of the safe range was not statistically significant.

Table 3 Characteristics of thoracoscopic surgeries

Age group	Time	Brain NIRS	Heart rate	Mean blood pressure	O_2 saturation	End tidal CO_2
0–1 months	Baseline	94.3 + 1.1	142.3 + 6.6	38.1 + 3.4	97.3 + 2.5	35.6 + .6
	Start	92 + 2.6	150.3 + 37	40.8 + 4.4	94 + 9.5	27.3 + 4.1
	End	90.6 + 2.3	129.6 + 0.5	44.3 + 1.2	91.6 + 13.6	29 + 4.5
	Desufflation	92 + 3.6	134 + 10.5	37.8 + 4.2	93.6 + 8.35	37.3 + 16.6
1–12 months	Baseline	76.7 + 14.4	130.2 + 2.6	42 + 7.9	99.5 + 0.5	36.2 + 10.3
	Start	73.7 + 16.8	120.2 + 9.5	44.5 + 5.9	97.2 + 1.8	36 + 8.1
	End	59.2 + 19.8	121.5 + 9.3	45 + 13.1	96 + 4.8	39.2 + 2.7
	Desufflation	64 + 18.8	131.5 + 24	46.7 + 14.5	97.5 + 2.3	37 + 3.6
1–18 years	Baseline	73.5 + 17.1	119.9 + 17.9	61.1 + 13	97.3 + 4.1	35.3 + 4.6
	Start	70.1 + 12.8	119.9 + 17.9	62.6 + 8.6	97.3 + 3.8	35.8 + 5.4
	End	66.2 + 20.4	117.4 + 26.7	61.7 + 5.5	98 + 2.2	37.7 + 7
	Desufflation	70.4 + 17.3	117.7 + 27.4	61 + 7.1	98.3 + 2.2	35.2 + 7.7

Table 4 Data of children below 1 month of age

	Gestational age	Weight at the procedure	Comorbidity
Baby 1	38th week	2900 g	None
Baby 2	39th week	3200 g	PDA

There was no decrease of 50% or more in any patient. However, as the duration of the laparoscopic procedure increased, more decreases were observed in brain NIRS values, and this decrease was statistically significant ($p = 0.024$).

The decrease in renal NIRS values was higher in laparoscopic procedures performed in low-weight patients ($p = 0.048$).

In laparoscopy more than 20% decrease in renal NIRS values seen in 44 (21.5%) patients and brain NIRS values in 20 patients (9.8%).

Analysis of patient data undergoing thoracoscopic procedures

There were three patients in the 0–1 month group, 4 patients in the 2–12 month group, and 12 patients in the 1–18 years age group who underwent thoracoscopic procedures.

Six VATS pleurodesis, four thoracoscopic mass excisions, two thoracoscopic esophageal atresia repairs and three other thoracoscopic procedures were performed on patients in this group.

Since there were three patients in the 0–1 month group and four patients in the 1–12 month group, statistical comparison could not be made. In all three patients in the 0–1 month age group, 6 mmHg pressure was applied, and no more than 20% decrease was observed in the brain NIRS value. One patient in the 1–12 month group underwent 10 mmHg CO_2 insufflation for technical reasons so that the procedure could be completed thoracoscopically, this patient hd a 45.3% decrease in brain NIRS value. This decline was the highest that was observed in the entire thoracoscopy group.

In the 1–18 age group, decreases in brain NIRS values were not statistically significant in CO_2 insufflation at the upper limit (10 mmHg).

There was no decrease of 50% or more in any patient.

Prolongation of the operation time in the thoracoscopy group caused a greater decrease in brain NIRS values, and this decrease was statistically significant ($p = 0.033$).

In thoracoscopy, a decrease more than 20% in brain NIRS values seen in 6 (31.6%) patients.

It was observed that the decreases in brain and kidney NIRS values returned to normal after desufflation, and there was no permanent effect.

Oxygen saturation, heart rate, arterial blood pressure, end-tidal CO2 value, insufflation pressure and urine output did not exceed normal limits in all the patients during the procedure.

Discussion

Laparoscopic surgery is now a frequently employed approach in children, but there are concerns about the physiological consequences of pneumoperitoneum. Pneumoperitoneum shows its effect on organs primarily by physical pressure. However, another effect is due to the systemic absorption of CO_2. Physiological effects increase inversely with decreasing age and body weight. The reason for this is low muscle mass, increased peritoneal surface compared to mass ratio and less peritoneal thickness [8]. In our study, we found

that renal perfusion was more impaired during laparoscopy in low-weight patients.

A number of animal experiments and studies on adults have shown that decreased renal perfusion and functions are associated with pneumoperitoneum [9]. There are studies showing that the effects of pneumoperitoneum and increased intra-abdominal pressure on renal perfusion are irreversible after desufflation [5]. In the current study, it was observed that pneumoperitoneum decreased renal perfusion, but this decrease was not severe. At the same time, it was observed that the decreases in renal perfusion returned to normal values after the procedure.

In our study, it was observed that renal perfusion values worsen relatively more than brain perfusion values during laparoscopy.

In studies conducted in adults, it has been observed that CO_2 insufflation in laparoscopic surgery produces significant changes in cerebral oxygenation in some patients [10]. There are limited data in pediatric patients on whether the pneumoperitoneum affects cerebral oxygenation even if the end-tidal CO_2 concentration is normal. In our study, it was observed that changes in cerebral oxygenation were minimal during laparoscopy. But, as the duration of the laparoscopic procedure increased, more decreases were observed in brain NIRS values. It was observed that these changes returned to normal after the procedure [10].

Ventilation can be difficult when pneumothorax is used for minimally invasive procedures in the chest. Decreased ventilation of the ipsilateral lung with CO_2 pneumothorax and immature cardiopulmonary system during thoracoscopy in neonates is a cause of concern. At the same time, there are some concerns in the current literature about the decrease in venous return due to high intrathoracic pressure. This may be dangerous for neonatal physiology and the developing central nervous system [4]. In particular, low cerebral oxygenation levels have been reported in newborns undergoing thoracoscopic intervention [12]. There are relatively few studies on the effects of thoracoscopic procedures performed in newborns on cerebral oxygenation and cardiopulmonary outcomes. Most of these studies are retrospective studies based on anesthesia charts [6, 12, 13]. It has been observed that pressures reaching 10 mmHg during thoracoscopy result in hypercapnia with severe acidosis [11]. However, in our study, it was observed that cerebral oxygenation did not decrease significantly in the thoracoscopy group and returned to normal values after the procedure. It was also observed that end- tidal CO_2 values did not reach pathological dimensions in the patients during the operation.

Hemodynamic changes during laparoscopy are associated with increased intraabdominal pressure, CO_2 absorption, and neurohormonal response, due to the pressure and duration of pneumoperitoneum. Also, it has been reported that increasing intraabdominal pressure leads to a decrease in cardiac preload and cardiac outflow, and an increase in heart rate, mean blood pressure, systemic and pulmonary vascular resistance due to decreasing venous return [14]. Though there is an increase in blood pressure during peritoneal insufflation, changes in hemodynamic response might occur. A decrease in arterial blood pressure and heart rate is expected situation after anesthesia induction in all surgical procedures. In the study by Caliskan et al. [15], it was observed that arterial blood pressure was higher in the laparoscopy group than in the laparotomy group, and at the same time blood pressures were within physiological values throughout the operation. In our study, it was observed that hemodynamic indicators remained within physiological limits throughout the procedure.

There is no consensus on the evaluation of deviations from the basal value in renal oxygenation measurements with NIRS. In various studies, reductions such as 10%, 20%, 25%, 50%, 65% were accepted as clinically important or pathological values [16–18]. In another study, values of 20% were considered to be clinically significant and 50% rSO2 value was considered to be pathological for all measurement regions [19]. We also considered renal NIRS values of reduction $\geq$ 20% as clinically significant and 50% as pathological.

In a study, it was observed that the most significant decrease in renal oxygenation during laparoscopy was in the left kidney [15]. Therefore, since our study measured simultaneous brain and kidney oxygenation, the left kidney was preferred for measurement.

There are limited studies on the measurement of cerebral oxygenation during thoracoscopy in children. The vast majority of available studies have been conducted in infants [11, 20, 21].

A large number of pediatric surgical indications can be successfully managed by minimally invasive techniques [22]. The thoracoscopic approach favors advantages supportive of less postoperative pain, shorter hospital stay [23], less scoliosis caused by rib fusion, decreased respiratory impairment, and improved overall cosmetic result [24, 25].

Despite the advantages of thoracoscopy, safety concerns still remain, especially in neonates. These concerns focus mostly on the impact of the applied pressurized CO_2 pneumothorax on neonatal hemodynamics and organ perfusion [4, 24]. Intrathoracic CO_2 insufflation collapses the lung, which adversely affects the O_2 and CO_2 exchange causing hypoxia and hypercarbia. Another factor that causes hypercarbia is the excessive systemic CO_2 load that is absorbed from the thoracic cavity during the pneumothorax CO_2 gas insufflation. Bishay et al. reported that severe perioperative hypercarbia, acidosis, and decreased cerebral oxygenation were seen in newborns who underwent thoracoscopic surgery under high insufflation pressures. It

has been reported that the decrease in cerebral oxygenation continues up to 24 h postoperatively. However, the $rScO_2$ value, which was 87% at the start of the operation, was too high, probably due to the initial hyper-oxygenation. It decreased to 75% at the end of the procedure. Cerebral oxygenation levels remained within the reference range in the postoperative phases as well [26].

Furthermore, in the published series on neonatal thoracoscopic interventions that describe the negative impact of CO2 application, pressures of up to 10 mmHg were applied [26, 27]. A recent experimental study in piglets showed that 10 mmHg pressures caused severe hemodynamic instability and decreased cerebral perfusion, whereas these conditions remained stable with pneumothorax pressures of 5 mmHg [27]. In our study, it was observed that 6 mmHg pressure applied during thoracoscopy to patients aged 0–1 months did not impair cerebral oxygenation. It was observed that 10 mmHg pressure applied to a patient aged 1–12 months reduced cerebral oxygenation by 45.3%, while 8 mmHg pressure did not cause serious changes.

Conclusion

Pneumoperitoneum during laparoscopy affected kidney and brain oxygenation, and CO_2 pneumothorax during thoracoscopy affected brain oxygenation, but this effect was not severe and was well tolerated. In laparoscopic and thoracoscopic procedures performed in children, although the procedure is performed at predetermined acceptable pressures that are considered safe, higher pressures may be encountered due to limited area in surgery and when technical difficulties are encountered. In this study, it has been proven that pressures at the upper limit of the safe range do not impair the patients brain and kidney oxygenation (in the specified age ranges).

It should also be considered that renal oxygenation is more affected in low-weight patients during laparoscopy, and that cerebral oxygenation decreases more as the duration of thoracoscopy increases.

NIRS can be used as a reliable monitoring tool in minimally invasive procedures, especially in newborns and underweight patients, and in patients with severe neurological, nephrological and vascular problems.

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Data availability The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethical permission Ethical committee of the University granted permission for this study No:17B0230005.

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