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SCIENTIFIC ARTICLE

Effects of carbon dioxide insufflation on regional cerebral oxygenation during laparoscopic surgery in children: a prospective study

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KEYWORDS
Pediatric anesthesia;
Carbon dioxide insufflation;
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Abstract
Background and objectives: Laparoscopic surgery has become a popular surgical tool when compared to traditional open surgery. There are limited data on pediatric patients regarding whether pneumoperitoneum affects cerebral oxygenation although end-tidal CO_2 concentration remains normal. Therefore, this study was designed to evaluate the changes of cerebral oxygen saturation using near-infrared spectroscope during laparoscopic surgery in children.
Methods: The study comprised forty children who were scheduled for laparoscopic (Group L, $n = 20$) or open (Group O, $n = 20$) appendectomy. Hemodynamic variables, right and left regional cerebral oxygen saturation ($RrSO_2$ and $LrSO_2$), fraction of inspired oxygen, end-tidal carbon dioxide pressure (P_{ETCO2}), peak inspiratory pressure (Ppeak), respiratory minute volume, inspiratory and end-tidal concentrations of sevoflurane and body temperature were recorded. All parameters were recorded after anesthesia induction and before start of surgery (T0, baseline), 15 min after start of surgery (T1), 30 min after start of surgery (T2), 45 min after start of surgery (T3), 60 min after start of surgery (T4) and end of the surgery (T5).
Results: There were progressive decreases in both $RrSO_2$ and $LrSO_2$ levels in both groups, which were not statistically significant at T1, T2, T3, T4. The $RrSO_2$ levels of Group L at T5 were significantly lower than that of Group O. One patient in Group L had an rSO_2 value <80% of the baseline value.
Conclusions: Carbon dioxide insufflation during pneumoperitoneum in pediatric patients may not affect cerebral oxygenation under laparoscopic surgery.

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PALAVRAS-CHAVE
Anestesia pediátrica;
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Laparoscopia

Efeitos da insuflação de dióxido de carbono sobre a oxigenação cerebral regional durante cirurgia laparoscópica em crianças: um estudo prospectivo

Resumo
Justificativa e objetivos: A cirurgia laparoscópica se tornou uma ferramenta cirúrgica popular em comparação com a cirurgia aberta tradicional. Há poucos dados sobre pacientes pediátricos no que se refere ao pneumoperitônio afetar a oxigenação cerebral enquanto a concentração de CO_2 ao final da expiração continua normal. Portanto, este estudo teve como objetivo avaliar as alterações da saturação de oxigênio cerebral usando espectroscopia de infravermelho próximo durante cirurgia laparoscópica em crianças.
Métodos: O estudo recrutou quarenta crianças programadas para apendicectomia laparoscópica (Grupo L, n = 20) ou aberta (Grupo A, n = 20). Variáveis hemodinâmicas, saturação de oxigênio cerebral regional direita e esquerda ($RrSO_2$ e $LrSO_2$), fração inspirada de oxigênio, pressão expiratória final de dióxido de carbono ($PETCO_2$), pico de pressão inspiratória (Ppico), volume minuto respiratório, concentrações de sevoflurano inspirado e expirado e temperatura corporal foram registados. Todos os parâmetros foram registados após a indução da anestesia e antes do início da cirurgia (T0, basal), 15 minutos após o início da cirurgia (T1), 30 minutos após o início da cirurgia (T2), 45 minutos após o início da cirurgia (T3), 60 min após o início da cirurgia (T4) e no final da cirurgia (T5).
Resultados: Houve diminuição progressiva em ambos os níveis de RrSO2 e LrSO2 nos dois grupos, mas não foi estatisticamente significativa em T1, T2, T3, T4. Os níveis de RrSO2 do Grupo L em T5 foram significativamente menores que os do Grupo A. Um paciente do Grupo L apresentou um valor rSO2 < 80% do valor basal.
Conclusões: A insuflação de dióxido de carbono durante o pneumoperitônio em pacientes pediátricos pode não afetar a oxigenação cerebral em cirurgia laparoscópica.

Introduction

Laparoscopic surgery has become a popular surgical tool due to its less invasive nature, thereby providing a more rapid recovery with a shorter hospital stay, decreased postoperative pain and improved cosmetic outcome when compared to traditional open surgery.[1,2] The successful application of laparoscopic techniques in adults has led to their increasing use in pediatric surgery.[3,4] An investigation in adult patients has shown that although relatively uncommon, significant changes in cerebral oxygenation occur in some patients during CO_2 insufflation for laparoscopic surgery.[5] There are limited data on pediatric patients regarding whether pneumoperitoneum affects cerebral oxygenation although end-tidal CO_2 concentration remains normal.

Our hypothesis was that cerebral oxygen saturation would decrease in pediatric patients during laparoscopic surgery because of pneumoperitoneum and CO_2 absorption. Therefore, this study was designed to evaluate the changes of cerebral oxygen saturation using near-infrared spectroscope (NIRS) during laparoscopic surgery in children.

Methods

After receiving approval from the ethics committee of the Kırıkkale University, forty children with ASA physical status I who were scheduled for laparoscopic (Group L, $n = 20$) or open (Group O, $n = 20$) appendectomy surgery were enrolled in this prospective study. Written informed consent was obtained from all the patients' parents before the surgery. Exclusion criteria were as follows: patients whose parents did not give consent, ASA II and above, age ≥ 18 and ≤ 2 years.

The children's ages, weights and heights were noted. All patients were monitored by electrocardiogram (ECG), non-invasive blood pressure (BP), heart rate (HR), peripheral oxygen saturation (SpO_2), right and left regional cerebral oxygen saturation ($RrSO_2$ and $LrSO_2$), fraction of inspired oxygen, end-tidal carbon dioxide pressure (P_{ETCO2}), peak inspiratory pressure (Ppeak), respiratory minute volume, inspiratory and end-tidal concentrations of sevoflurane and body temperature continuously throughout the anesthesia.

In all patients for $RrSO_2$ and $LrSO_2$ measurement, sensors for cerebral oximeter (NIRS model INVOS 5100; Somanetics, Troy, MI) were placed bilaterally at least 2 cm above the eyebrow on the right and left sides of the forehead according to the manufacturer's instructions before induction of anesthesia. Cerebral oxygen desaturation was defined as an rSO_2 value <80% of the baseline value. In the event of such a decrease in rSO_2, 100% oxygen was administered.

All children received a standardized anesthetic technique. Anesthesia was induced with intravenous thiopenthal (5 mg kg^{-1}), remifentanyl (0.2 μg/kg/min) and atracuryum besilat (0.5 mg/kg). When maximum neuromuscular blocking effect was achieved, the same anesthesiologist performed

Table 1 Demographic and clinical data for each group.

	Group L ($n = 20$)	Group O ($n = 20$)	p-value
Age (years)	11.4 ± 3.13	11.0 ± 4.28	0.989
Weight (kg)	37.5 ± 13.52	39.4 ± 17.14	0.818
Height (cm)	137.8 ± 20.30	133.5 ± 28.13	0.860
Duration of anesthesia (min)	42.6 ± 16.76	36.0 ± 14.28	0.126
Duration of procedure (min)	37.5 ± 16.53	31.3 ± 15.64	0.210

Data are mean ± SD or *n*.

endotracheal intubation. Anesthesia was maintained with a minimum alveolar anesthetic concentration (MAC) of sevoflurane of 1% and 66% air in oxygen. A remifentanyl infusion (0.05–0.2 μg/kg/min) was continued to maintain surgical analgesia. Mechanical ventilation was performed using a pressure-controlled mode (AS3; Datex-Engstroem, Helsinki, Finland). Respiratory rate was adjusted to keep P_{ETCO2} value between 35 and 45 mmHg throughout the surgery in both groups. In both groups, all patients were arranged in supine position throughout the surgery and during laparoscopic procedures; the abdominal pressure was maintained at 8–12 mmHg. At the end of the surgery, the neuromuscular block was reversed with neostigmine and atropine.

All parameters were recorded after anesthesia induction and before start of surgery (T0, baseline), 15 min after start of surgery (T1), 30 min after start of surgery (T2), 45 min after start of surgery (T3), 60 min after start of surgery (T4) and end of the surgery (T5). The duration of the anesthesia and the surgery were also recorded.

Statistical analysis

Data were analyzed using the IBM SPSS (version 15.0 for Windows) statistical package. Data were expressed as mean ± standard deviation (SD) or *n* where appropriate. The Mann–Whitney *U* test was employed for the comparison of continuous variables among groups. A *p*-value of less than 0.05 was accepted as statistically significant.

Results

The two groups were similar with respect to their demographic data (Table 1).

The duration of both the anesthesia and the procedure were also comparable between the groups (Table 1).

The hemodynamic parameters such as HR mean arterial BP, SpO_2 and P_{ETCO2} levels were comparable between the groups (Table 2).

The change in rSO_2 is shown in Table 3. Although there was a progressive decrease in both $RrSO_2$ and $LrSO_2$ levels in both groups, it was not statistically significant at T1, T2, T3, T4 ($p > 0.05$). The $RrSO_2$ levels of Group L at T5 were significantly lower than that of Group O ($p = 0.032$).

Only one patient in Group L had an rSO_2 value <80% of the baseline value.

Discussion

The main finding of this study is that CO_2 insufflation during pneumoperitoneum in pediatric patients may not affect cerebral oxygenation under laparoscopic surgery.

Pneumoperitoneum exerts its effects on organ systems primarily via the physical pressure on those systems and secondly due to the systemic absorption of carbon dioxide (the diffusion of CO_2 across the peritoneum and into the bloodstream). The physiological effects are increased with decreasing age and weight due to decreased muscle bulk, an increased peritoneal surface area to mass ratio, decreased peritoneal thickness and decreased organ-specific reserve.[3]

Intra-abdominal pressure (IAP) is a critical determinant of cardiovascular stability during laparoscopy. Raised IAP during pneumoperitoneum determines bradycardia or asystole because of a high level of vagal tone in children.[6] To keep the physiological changes to a minimum, the lowest IAP required to carry out the procedure safely is recommended as less than 15 mmHg in children.[7] Insufflation with an IAP <10 mmHg augments preload through the displacement of blood from the splanchnic vasculature, while pressures of >15 mmHg impedes venous return.[8] According to these recommendations, we keep IAP between 8 and 10 mmHg during laparoscopic surgery.

Cerebral oximetry has been extensively evaluated in adults as well as in pediatric surgery and neonatology.[5,9,10] Cerebral oximetry with near-infrared spectroscopy (NIRS) allows continuous and non-invasive monitoring of rSO_2, which reflects a balance between cerebral oxygen supply and demand.[11] NIRS quantitates a venous-weighted ratio of oxygenated and deoxygenated hemoglobin in the region of the cerebral cortex underlying the sensors, which are usually placed on the forehead.[12] An rSO_2 value <80% of the baseline or rSO_2 <50% were associated with a higher incidence of cerebral ischemia, postoperative cognitive dysfunction and longer hospital stays.[2,11,13] Additionally, if the baseline is lower than 50%, the critical threshold should be reduced to 15%.[11] In the present study, one patient had an rSO_2 value <80% of the baseline at the fortieth min of surgery during pneumoperitoneum.

There are a limited number of studies focusing on the relationship between laparoscopic surgery and rSO_2 in pediatrics. De Waal et al. demonstrated that insufflation of CO_2 at low IAPs (≤8 mmHg) in children causes considerable increases in P_{ETCO2} and arterial CO_2 pressure ($PaCO_2$) that are reflected in increases in rSO_2 and cerebral blood volume, even when superimposed on a baseline of mild hypocapnia.[14]

Table 2 Hemodynamic parametres and number of cases for each group.

Variables	T0	T1	T2	T3	T4	T5
HR (bpm)						
Group L	113.1 ± 14.10	100.3 ± 16.31	95.8 ± 19.05	83.0 ± 11.25	85.0 ± 12.54	111.0 ± 19.14
Group O	113.2 ± 16.06	102.2 ± 19.80	101.8 ± 19.46	93.1 ± 15.12	95.0 ± 13.74	106.5 ± 18.79
MAP (mmHg)						
Group L	84.0 ± 10.58	89.2 ± 11.84	84.3 ± 7.22	84.2 ± 9.73	86.8 ± 9.33	96.0 ± 13.67
Group O	90.1 ± 9.88	84.3 ± 9.06	84.5 ± 9.89	79.6 ± 7.43	87.6 ± 15.37	90.3 ± 7.74
SpO_2						
Group L	99.2 ± 0.71	99.4 ± 0.82	99.3 ± 0.79	99.7 ± 0.70	99.2 ± 1.11	99.3 ± 0.97
Group O	99.4 ± 0.75	99.4 ± 0.68	99.4 ± 0.51	99.0 ± 1.22	99.3 ± 0.57	99.4 ± 0.82
$PETCO_2$ (mmHg)						
Group L	39.1 ± 3.22	40.0 ± 2.88	40.7 ± 2.72	41.0 ± 1.69	41.8 ± 2.26	41.0 ± 2.08
Group O	30.0 ± 2.61	38.9 ± 2.31	37.8 ± 2.73	39.8 ± 1.30	40.2 ± 2.21	41.3 ± 0.57

Data are mean ± SD or *n*.
To, baseline, after anesthesia induction, before start of surgery; T1, 15 min after start of surgery; T2, 30 min after start of surgery; T3, 45 min after start of surgery; T4, 60 min after start of surgery; T5, end of the surgery; HR, heart rate; MAP, mean arterial pressure; SpO_2, peripheral oxygen saturation; P_{ETCO2}, end-tidal carbon dioxide pressure.

In contrast, Tsypin et al. reported an average of a 3% reduction in regional cerebral tissue saturation in children during gynecological laparoscopic interventions, which was measured by the Critikon RedOx Monitor 2020 device.[9] According to our results, we found no difference in reduction of rSO_2 between laparoscopy and open surgery.

The limitation of the current study is that we did not monitor $PaCO_2$ changes during CO_2 insufflation. It was reported that P_{ETCO2} may not correlate with $PaCO_2$, therefore arterial blood gas analysis monitoring should be performed during long laparoscopic procedures.[15] Because of laparoscopic appendectomy is a minimal invasive surgery, so that $PaCO_2$ monitorization may not be appropriate ethically.

In conclusion, the results of the present study showed that all patients, except one from the laparoscopic group, tolerated CO_2 insufflation without significant affects on cerebral oxygenation. Although cerebral rSO_2 changes are insignificant and there is no standard care for the use of NIRS-based cerebral oximetry in pediatric anesthesia, the INVOS cerebral oxymeter may be a helpful monitoring tool for detecting real-time rSO_2 changes during pneumoperitoneum with CO_2.

Table 3 Changes in cerebral oxygenation.

Variables	Group L (n = 20)	Group O (n = 20)	*p*-value
$RrSO_2$			
To	75.1 ± 9.73	79.4 ± 9.51	NS
T1	71.3 ± 11.53	76.2 ± 7.05	NS
T2	70.7 ± 9.12	76.0 ± 9.62	NS
T3	67.2 ± 7.61	71.8 ± 12.27	NS
T4	65.2 ± 8.13	70.0 ± 7.07	NS
T5	76.2 ± 9.11	82.5 ± 7.97[a]	0.03
$LrSO_2$			
To	72.9 ± 11.64	79.2 ± 8.52	NS
T1	72.2 ± 10.25	74.1 ± 7.80	NS
T2	70.9 ± 11.62	72.3 ± 8.17	NS
T3	69.1 ± 12.62	68.2 ± 14.3	NS
T4	67.8 ± 12.87	67.7 ± 7.54	NS
T5	76.0 ± 10.97	79.5 ± 6.95	NS
Number of case with rSO_2 value <80% of the baseline value (*n*)	1	0	NS

Data are mean ± SD or *n*.
Bold *p*-value is significant. $RrSO_2$, right regional cerebral oxygen saturation; $LrSO_2$, left regional cerebral oxygen saturation; To, baseline, after anesthesia induction, before start of surgery; T1, 15 min after start of surgery; T2, 30 min after start of surgery; T3, 45 min after start of surgery; T4, 60 min after start of surgery; T5, end of the surgery.
[a] $p < 0.05$ versus Group L.

Conflicts of interest

The authors declare no conflicts of interest.

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