



Laparoscopy in infants: close intraoperative hemodynamic monitoring for patient safety

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Abstract

Background Hemodynamic changes during laparoscopy have not been well defined in very young children. In this study, intraoperative monitoring of hemodynamic parameters and oxygenation was evaluated during laparoscopy in infants weighing < 10 kg.

Patients and methods Thirty infants (5.07 ± 2.51 kg), undergoing laparoscopy (LAP Group, $n = 15$) or open surgery (Open Group, $n = 15$), were enrolled. Cerebral regional (crScO₂), renal regional oxygenation (rrScO₂), peripheral oxygen saturation (SpO₂), heart rate (HR), blood pressure, transcutaneous CO₂ (TcCO₂), end-tidal CO₂ (EtCO₂), and core temperature (TC) were analyzed at five intervals: T0 = basal; T1 = anesthesia induction; T2 = CO₂ PP insufflation in the LAP group; T3 = intraoperative; T4 = cessation of CO₂ PP in the LAP group; and T5 = before extubation.

Results The LAP group showed differences in crScO₂ at T1, T3, and T4 compared with T0 ($p < 0.05$) and in rrScO₂ from T1 to T4 versus T0 ($p < 0.05$), without hypoxemia. In addition, in the LAP group, an increase in TcCO₂ from T2 to T5 versus T0 ($p < 0.01$) was related to anesthesia time ($p = 0.01$) and sex ($p = 0.03$). The SpO₂ values were not different during laparoscopy; on the contrary, the OPEN group exhibited a decrease in SpO₂ at T4 ($p < 0.001$) and an increase at T5 versus T0 ($p = 0.001$) compared with T0. HR and TC changes were detected in both groups ($p < 0.01$). No significant variations were recorded in blood pressure or end-tidal CO₂.

Conclusion Limited effects on oxygenation, cardiac output, and thermoregulation were detected in infants during laparoscopy. Many factors, including the child's age, may play different roles in the regulation of these parameters. Close monitoring is essential to guarantee the infant's safety.

Keywords Laparoscopy · Children · Infant · Pediatric surgery · Oxygenation · Hemodynamic

Introduction

Laparoscopy in the pediatric population is now common [1–6]. The great majority of surgical procedures in infants and young children, that in the past would have required an open operation, can now be safely and effectively conducted using the laparoscope [6]. These include a wide spectrum of gastrointestinal tract interventions, uro-gynecological procedures, herniotomy, laparoscopic reconstructive procedures, e.g., oesophageal anastomosis for oesophageal atresia and surgery for choledochal cysts and biliary atresia [6, 7]. Evidence to date suggests that minimal access surgery results in a more rapid recovery with a shorter hospital stay, decreased postoperative pain, reduced wound complications, minimal scarring, and an earlier return to normal activities including feeding,

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bowel movements, and work/school when compared with traditional open surgery [6–8].

Some critical factors associated with mini-invasive surgery (MIS), such as carbon dioxide (CO₂) insufflation, CO₂ absorption, and intra-abdominal pressure, are also the same factors that limit this approach in neonates and infants [9, 10]. CO₂ is usually accepted as the optimal gas for insufflation; however, increases in PaCO₂ and resultant alterations in cerebral blood flow may occur with its use [9, 10]. In addition, an increase in intra-abdominal pressure (IAP) due to peritoneal insufflation may result in increased systemic vascular resistance and decreased cardiac output [9, 10]. Changes from fetal to neonatal life lead to a lower functional residual capacity of the lung, lower blood pressures, and higher heart rates [11, 12]. Consequently, neonates and infants have fewer physiologic hemodynamic and respiratory reserves than older children. For these reasons, MIS may be challenging in these patients; however, the effects on systemic and cerebral haemodynamics during laparoscopy are not yet well defined in very small children [7, 13–17].

The aim of this study was to evaluate intraoperative changes in hemodynamic parameters, peripheral and cerebral oxygenation during pediatric laparoscopy in infants. Results from this study will provide important knowledge and help define the optimal monitoring parameters to guarantee infant safety during minimally invasive surgical procedures.

Patients and methods

Patients

Thirty infants weighing less than 10 kg, scheduled for abdominal surgical procedures, were consecutively enrolled in the study between February 01, 2016 and October 01, 2018, at the Pediatric Surgery Unit of the Children's Hospital "G. Di Cristina", Palermo (Italy). The treatment group (LAP Group, *n* = 15) underwent laparoscopic surgery, while the control group underwent traditional open surgery (OPEN Group, *n* = 15). Surgery was performed, by an experienced surgeon, under general anesthesia.

The study was performed according to the Declaration of Helsinki and with the approval of the Institutional Review Board of the Children's Hospital, ARNAS Civico-Di Cristina-Benfratelli, Palermo, Italy (CE n.registro 353 Civico 2016). The parents and/or legal guardian, after receiving information about the study, gave their written consent.

Methods

Surgical intervention

All surgeries were performed in the same operating theater with a stable temperature of 22 ± 1 °C. Patients were placed on a warm air mattress with a controlled temperature (38 ± 1 °C). The laparoscopic approach was accomplished, following a standard protocol, via the transabdominal approach using one 3 mm telescope and two, 3 mm or 2 mm operative instruments, placed into the lower abdomen. The pneumoperitoneum (PP) was created through the 3 mm infraumbilical camera trocar placed via an open approach. A PP CO₂ pressure of 8 mmHg was used.

Intraoperative transcranial near-infrared spectroscopy (NIRS; Oximeter Medtronic INVOS 5100C, Minneapolis USA) was used to assess cerebral regional (crScO₂) and renal regional oxygenation (rrScO₂); while pulse oximetry was used to measure peripheral oxygen saturation with an SatO₂ Monitor Infinity Delta (Dräger, Lübeck, Germany), heart rate (HR) was measured with an HR Monitor Infinity Delta (Dräger, Lübeck, Germany), and diastolic and systolic pressures were, respectively, measured with DP/SP Monitor Infinity Delta (Dräger, Lübeck, Germany). Transcutaneous CO₂ was monitored with a TcCO₂ Monitor TCMA4 Combi m, (Radiometer Medical ApS, Brønshøj, Denmark), end-tidal CO₂ and core body temperature (TC) were measured continuously with an oropharyngeal probe during the entire procedure.

The following parameters were analyzed, every minute in 5 min intervals (mean values were used for the statistical analysis), at five intervals: basal (T0) in the LAP and Open groups; anesthesia induction (T1) in the LAP and OPEN groups; CO₂ PP insufflation (T2) in the LAP group; intraoperative (T3) in the LAP and OPEN groups; cessation of CO₂ PP (T4) in the LAP group; before extubation (T5) in the LAP and OPEN groups. The operative times and anesthesia duration were also recorded.

Anesthesia protocol

All of the children received the same anesthesia protocol. Inhalation induction was performed with 6% sevoflurane, and 1 mcg/kg fentanyl de-escalation to reach a deep anesthetic state; for muscle relaxation, 0.6 mg/kg rocuronium was administered. After tracheal tube positioning, patients underwent pressure control ventilation–volume-guaranteed (PCV–VG) mechanical ventilation with a tidal volume of 6–7 ml/kg, PEEP 3–5 cmH₂O. The respiratory rate was adjusted to achieve an end-tidal CO₂ of 35–40 cmH₂O, and I:E ratio of 1:2–1:1.5 (avoiding dynamic hyperinflation)

with a low-flow breathing system and an inspired mixture of air and oxygen (fresh gas flow of 4 l min^{-1} with $0.4 \text{ F}_i\text{O}_2$ during anesthesia). Anesthesia was maintained via administration of sevoflurane gas (MAC 1.5), a bolus of 1 mcg/kg fentanyl and 0.3 mg/kg rocuronium. The respiratory rate (RR) was adjusted to achieve an EtCO_2 of $35\text{--}45 \text{ cmH}_2\text{O}$. The anesthesiologists were not blinded to the data readings to prevent intraoperative alterations in the infants.

The anesthesiology protocol to prevent hypotension included the administration of a 10 ml/kg NaCl 0.9% bolus both before induction of general anesthesia and before peritoneum insufflation. The maintenance of blood volume was managed with NaCl 0.9% 4 ml/kg fluid therapy. Thirty minutes before the end of the intervention, all patients received 7.5 mg/kg paracetamol, as an analgesic. The analgesia was consolidated with surgical wound infiltration prevention using 0.2% ropivacaine and 2% lidocaine for both open and laparoscopic surgical patients.

Statistical analysis

Quantitative variables were described as the mean (SD) and compared between the different time intervals with population averaged, mixed multilevel models to take into account the clustered nature of the data. Probability values of less than 0.05 were considered statistically significant. All statistical analyses were performed using the SPSS statistical package (SPSS, Chicago IL, USA) and Stata 15.1.

Results

Thirty infants (7 females and 23 males) with an average weight of $5.0 \pm 2.51 \text{ kg}$ were evaluated. In Table 1, the clinical features of the patients, interventions, surgical procedure, and anesthesia times, according to the treatment group, are reported. No major complications were recorded.

Table 1 Features of the enrolled patients in the laparoscopy (LAP) and open (OPEN) groups

	LAP group	OPEN group
Sex (F/M)	5/10	2/13
Age (days)	121.13 ± 161.32	99.40 ± 82.4
Weight (kg)	5.48 ± 2.44	4.66 ± 2.66
Operative time (h)	1.60 ± 1.98	3.04 ± 1.52
Anesthesia time (h)	2.66 ± 2.3	3.91 ± 1.49
Surgical intervention		
Gastrointestinal tract procedure	8	6
Abdominal/perineal procedure	4	7
Uro-gynecological procedure	3	2

Cerebral and renal region oxygenation

In the LAP group, a significant increase in crScO_2 was noted at T1 ($p = 0.002$), T3 ($p = 0.005$), and T4 ($p = 0.03$) compared with T0. Significant changes were also recorded in rrScO_2 from T1 to T4 versus T0 ($p = 0.03$; $p = 0.006$; $p = 0.003$ and $p < 0.001$, respectively), Table 2, Fig. 1. The changes in crScO_2 and rrScO_2 did not correlate with age, sex, anesthesia, or operative times. No significant changes in crScO_2 or rrScO_2 ($p > 0.05$) were observed in the OPEN group during the procedure (Table 2, Fig. 1).

Peripheral oxygen saturation

The SpO_2 values were not statistically different during the laparoscopic surgical intervals ($p > 0.05$), Table 2, Fig. 1. The OPEN group had a significant decrease in SpO_2 at T4 compared with T0 ($p < 0.001$) and a significant increase at T5 versus T0 ($p = 0.001$). These changes were related to operative times ($p = 0.05$) and age ($p = 0.01$) (Table 2, Fig. 1).

Heart rate

In the LAP group, a significant decrease in HR was recorded at T3 compared with T5 ($p = 0.01$), and a significant increase at T5 compared with T0 ($p = 0.05$) was noted, Table 2, Fig. 1. In the OPEN group, a significant increase in HR was observed at T3 ($p = 0.01$) and T5 ($p = 0.02$) compared with T0, Table 2, Fig. 1. The changes in HR in both groups were related to age ($p < 0.001$). No other correlations were detected.

Diastolic and systolic blood pressure

No significant changes were recorded in diastolic and systolic blood pressures in either the LAP or OPEN groups ($p > 0.05$, Table 2).

Transcutaneous CO_2

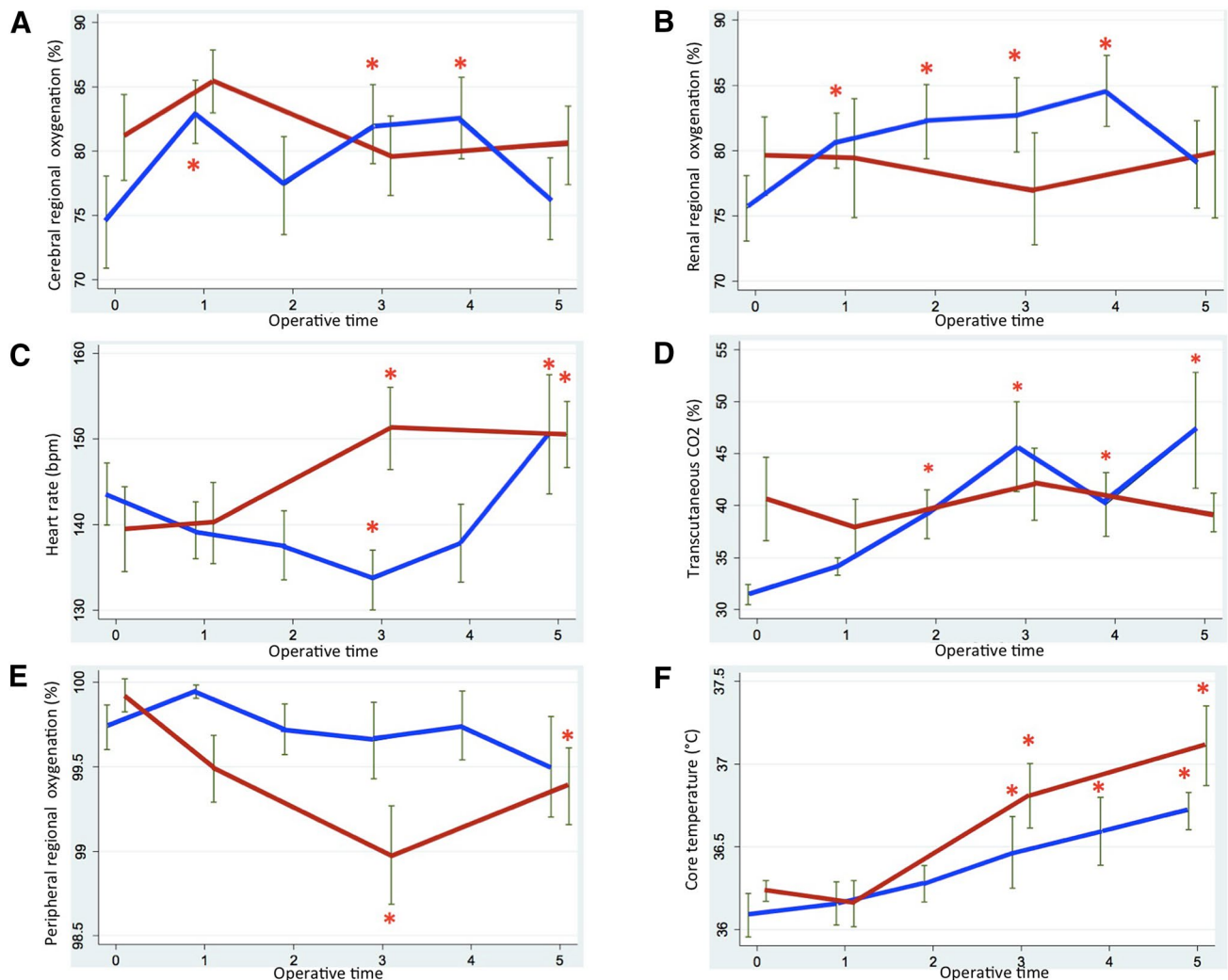
A significant increase in TcCO_2 from T2 to T5 versus T0 ($p < 0.01$, Table 1, figure) in the LAP group was observed. These changes were related to anesthesia time ($p = 0.01$) and sex ($p = 0.03$). Table 2, Fig. 1. No relevant changes in TcCO_2 during surgery ($p > 0.05$, Table 2) were observed in the OPEN groups.

Table 2 Hemodynamic changes and oxygenation monitoring at different surgical timepoints in the laparoscopy (LAP) and open (OPEN) groups: T0=basal; T1=anesthesia induction; T2=CO₂ PP insufflation in the LAP group; T3=intraoperative in LAP and OPEN groups; T4=cessation of CO₂ PP in the LAP group; T5=before extubation

Parameters	LAP group	<i>p</i> versus T0	OPEN group	<i>p</i> versus T0
Cerebral region oxygenation				
T0	74.48 ± 13.81		81.06 ± 12.80	
T1	83.04 ± 9.60	0.002	85.42 ± 9.45	0.11
T2	77.31 ± 14.77	0.30	–	
T3	82.08 ± 11.90	0.005	79.63 ± 12.00	0.60
T4	82.56 ± 12.24	0.003	–	
T5	76.30 ± 11.91	0.69	80.44 ± 11.81	0.82
Renal region oxygenation				
T0	75.57 ± 9.70		79.57 ± 11.65	
T1	80.76 ± 8.20	0.03	79.43 ± 17.64	0.96
T2	82.22 ± 10.99	0.006	–	
T3	82.74 ± 11.02	0.003	77.07 ± 16.58	0.50
T4	84.57 ± 10.52	<0.001	–	
T5	78.94 ± 12.49	0.21	79.86 ± 12.49	0.93
Heart rate				
T0	143.58 ± 13.94		139.46 ± 19.14	
T1	139.32 ± 12.77	0.28	140.17 ± 18.34	0.88
T2	137.60 ± 15.65	0.13	–	
T3	133.55 ± 13.52	0.01	151.22 ± 18.59	0.01
T4	137.83 ± 17.51	0.15	–	
T5	150.52 ± 26.04	0.05	150.52 ± 14.92	0.02
Peripheral oxygen saturation				
T0	99.73 ± 0.51		99.92 ± 0.37	
T1	99.94 ± 0.14	0.27	99.48 ± 0.76	0.06
T2	99.72 ± 0.57	0.95	–	
T3	99.65 ± 0.87	0.68	98.97 ± 1.13	<0.001
T4	99.74 ± 0.78	0.95	–	
T5	99.50 ± 1.11	0.25	99.38 ± 0.98	0.01
Diastolic blood pressure				
T0	53.97 ± 10.42		43.73 ± 11.79	
T1	49.43 ± 10.61	0.13	42.2 ± 14.79	0.53
T2	49.56 ± 7.14	0.85	–	
T3	46.11 ± 10.07	0.74	41.87 ± 15.78	0.45
T4	49.26 ± 10.28	0.84	–	
T5	53.14 ± 10.57	0.97	61.62 ± 81.90	0.08
Systolic blood pressure				
T0	92.38 ± 13.86		72.90 ± 20.09	
T1	91.80 ± 44.17	0.93	71.06 ± 22.10	0.60
T2	86.60 ± 8.70	0.39	–	
T3	80.67 ± 13.02	0.08	69.43 ± 20.23	0.32
T4	84.54 ± 11.87	0.25	–	
T5	88.94 ± 13.16	0.63	69.57 ± 16.71	0.34
End-tidal CO₂				
T0	–		–	
T1	41.67 ± 5.77	0.97	36.05 ± 5.53	0.08
T2	38.34 ± 4.99	0.06	–	
T3	44.16 ± 5.22	0.16	38.08 ± 7.02	0.10
T4	41.65 ± 5.00	0.10	–	
T5	–		–	
Transcutaneous CO₂				
T0	31.45 ± 1.95		40.64 ± 8.96	

Table 2 (continued)

Parameters	LAP group	<i>p</i> versus T0	OPEN group	<i>p</i> versus T0
T1	34.16 ± 1.17	0.27	37.88 ± 7.21	0.23
T2	39.16 ± 4.04	0.005	–	–
T3	45.66 ± 7.50	<0.001	42.05 ± 8.50	0.56
T4	40.11 ± 5.29	0.001	–	–
T5	47.25 ± 7.89	<0.001	39.33 ± 4.10	0.73
Core temperature				
T0	36.08 ± 0.50	–	36.32 ± 0.20	–
T1	36.15 ± 0.50	0.37	36.05 ± 5.53	0.99
T2	36.27 ± 0.42	0.10	–	–
T3	36.46 ± 0.83	0.005	36.80 ± 0.75	<0.001
T4	36.59 ± 0.79	<0.001	–	–
T5	36.71 ± 0.79	<0.001	37.11 ± 0.93	<0.001

**Fig. 1** Monitoring profiles of cerebral regional oxygen saturation (a), renal regional oxygen saturation (b), heart rate (c), transcutaneous CO₂ (d), peripheral oxygen saturation (e), and core temperature (f) in LAP (blue line) and OPEN (red line) groups at different surgical timepoints

End-tidal CO₂

No significant changes were recorded in End-tidal CO₂ in either the LAP or OPEN groups ($p > 0.05$, Table 2).

Body temperature

In the LAP group, a significant increase in TC was noted at T3 ($p = 0.005$), T4 ($p \leq 0.001$), and T5 ($p \leq 0.001$) as compared with T0, Table 2, Fig. 1. A significant increase in TC was also detected in the OPEN group at T3 ($p < 0.001$) and T5 ($p < 0.001$) in comparison with T0, Table 2, Fig. 1. The changes in TC were not correlated with age, sex, anesthesia, or operative times ($p > 0.05$), Table 2.

Discussion

The successful application of laparoscopic surgery in the pediatric age has also led to its increased use in neonates and infants, as it offers the advantages of fewer postoperative complications, early discharge, and minimal scarring [1–8, 11–17]. However, laparoscopy may be associated with hemodynamic alterations, which are generated by the high intra-abdominal pressure brought on by PP creation and by the existence of insufflation gas that is absorbed by the blood. These systemic hemodynamic alterations may result in changes in end-organ blood flow and oxygen delivery. In addition, the impact of anesthesia on hemodynamic changes has also been described [9, 10, 18].

There are limited studies on the effects of pneumoperitoneum during laparoscopy in the pediatric age, particularly in small children [13–26]. For this reason, the aim of this study was to monitor adaptive changes in cerebral and systemic oxygenation and hemodynamic parameters in infants weighing less than 10 kg. We found that a CO₂ pneumoperitoneum with 8 mm Hg IAP has minimal effects on cerebral oxygenation, without hypoxemia. The data on the relationship between laparoscopic surgery and regional effects on cerebral oxygenation in infants are non-homogenous. Tygat et al. [14] reported that regional brain oxygenation remained unaltered during surgical treatment of hypertrophic pyloric stenosis in young infants; Bishay et al. [15] showed a significant decrease in cerebral oxygenation in infants who underwent thorascopic surgery for treatment of esophageal atresia and congenital diaphragmatic hernia. As reported by Oztan [18], cerebral oxygen saturation is not only strongly related to the concentration of CO₂ delivered during the pneumoperitoneum, but also to the hydration status. We propose that the stability of this parameter depends on the anesthesiology protocol used to prevent hypotension before the induction of anesthesia and peritoneum insufflation. Therefore, we recommend that patients be well hydrated throughout

the procedure. In addition, the use of NIRS-based cerebral oximetry in pediatric anesthesia, as in this study, may be a helpful monitoring tool for detecting and correcting changes in oxygenation. Indeed, we previously reported on changes in cerebral oxygenation during laparoscopic procedures in pediatric patients when stringent monitoring was not adopted [21].

Having observed no decrease in renal rSO₂ during laparoscopy suggests that laparoscopy and the increased pressure caused by the CO₂ pneumoperitoneum does not decrease renal oxygenation to unacceptable intra-abdominal pressures with regard to renal perfusion.

Increased HR during laparoscopy has been well described in several studies. This has been attributed to the neurohumoral effect of CO₂, which stimulates the sympathoadrenal system causing a significant release of catecholamines and cortisol and thus increases HR and arterial pressure [17]. We noted a variation in HR in both groups and these changes were significantly related to patient age. These data suggest that because of the age-related homeostatic vulnerability, hemodynamic status should be closely monitored in infants.

Pathophysiological hemodynamic values may also be affected by both the procedure and the anesthesia times. In particular, we observed that the LAP group exhibited a significant increase in TcCO₂ differences related to anesthesia times. The monitoring of TcCO₂ allowed the evaluation of the difference in CO₂ partial pressures between the blood and alveoli and, therefore, the ventilation/perfusion ratio which can be an indication of pulmonary flow and the possible response to the elimination of CO₂ on the volumic expansion with fluid. However, TcCO₂ might not correlate with PaCO₂. In most patients, controlled ventilation, end-tidal CO₂ closely reflects arterial CO₂ tension [19]; however, we did not monitor arterial CO₂ and arterial pH levels. Arterial blood gas analysis monitoring should be performed during long laparoscopic procedures to exclude hypercapnia [19, 21, 22].

The accurate measurement of TC is an essential aspect of intraoperative management in children. However, little attention has been paid to the effect that surgical factors have on thermogenesis, such as surgical stress and anesthetic agents [27]. In neonates and infants, thermoregulation includes basic heat production resulting from increased cellular metabolic activity and extra-heat production such as nonshivering termogenesis, which is heat produced by brown adipose tissue, and the more limited shivering termogenesis, muscle produced heat [28]. In our infants, a significant rise in TC was noted in both groups. As reported by McHoney [29], laparoscopy in children is associated with an intraoperative hypermetabolic response characterized by increased oxygen consumption and core temperature; these changes are more markedly recorded in younger children. In very small children, the hypermetabolic response seems to be activated

during open surgery. The influence of extra-heat production on intraoperative TC changes should not be underestimated.

We recognize that there are some limitations to this study starting from the limited sample size; therefore, a larger cohort of patients is mandatory to confirm the results. The ‘broad’ range in type of intervention influences anesthesia choice and operative time, and consequently, the exact impact of these parameters on hemodynamics could not be defined. Further studies focused on the duration of surgery are mandatory to detect the appearance of early signs related to hemodynamic adaptation. Finally, arterial blood gas analysis monitoring would be useful during laparoscopic procedures to estimate hypercapnia. Despite these limitations, studies like ours, focused on specific populations of very small children, are very important to support the safety of laparoscopy when close monitoring is adopted.

In conclusion, the results of the present study showed that infants tolerated CO₂ insufflation without significant effects on cerebral oxygenation, with minimal effects on cardiac output and thermoregulation. Many factors, including the child’s age, play different roles in the regulation of hemodynamics and oxygenation and during laparoscopy; each of these requires further research. Knowledge of pathophysiological changes, standardization of intraoperative surgical evaluation, and anesthesia management are all necessary to prevent adverse hemodynamic outcomes.

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Compliance with ethical standards

Conflict of interest The authors have no competing interests to declare.

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