Pediatric laparoscopy and adaptive oxygenation and hemodynamic changes

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Abstract

Adaptive changes in oxygenation and hemodynamics are evaluated during pediatric laparoscopy. The children underwent laparoscopy (LAP Group, n=20) or open surgery (Open Group, n=10). Regional cerebral ($rScO_2$) and peripheral oxygen saturation (SpO_2), heart rate (HR), diastolic (DP) and systolic pressure (SP) were monitored at different intervals: basal (T0); anesthesia induction (T1); CO_2PP insufflation (T2); surgery (T3); CO_2PP cessation (T4); before extubation (T5). At T1, in both the LAP and Open groups significant changes in $rScO_2$, DP and SP were recorded compared with T0; a decrease in $SatO_2$ was also observed at T5. In the LAP group, at T2, changes in HR related to CO_2PP pressure and in DP and SP related to IAP were noted; at T4, a SP change associated with CO_2PP desufflation was recorded. Open group, at T3 and T5 showed lower $rScO_2$ values compared with T1. Pneuperitoneum and anesthesia are influent to induce hemodynamics changes during laparoscopy.

Introduction

The laparoscopic surgical technique in children and infants is still undergoing development and refinement. To date, its effects on systemic and cerebral oxygenation have not been completely investigated[1-3] and the exact effects of surgical maneuvers in combination with conventional anesthesiological procedures in hemodynamic regulation are still debated. Hemodynamic alterations, associated with abdominal laparoscopy are mainly caused by the increased intra-abdominal pressure (IAP), brought on by pneumoperitoneum (PP) creation. A decrease in venous return secondary to inferior vena cava compression and the increase in central venous pressure and arterial blood pressure, in the absence of heart rate (HR) changes, seem to be the main adaptive responses.[4-6] A 10% to 30% decrease in cardiac output with severe pathophysiologic modifications has also been reported in most studies,[7-9] underscoring the need for dedicated anesthesiological support in pediatric laparoscopy, especially in infants. Pathophysiological hemodynamic alterations during laparoscopic procedures in children have not been fully investigated.[10-15] Therefore, in small children and in surgical procedures of long duration, the standardization of mini invasive intraoperative assessment requires close anesthesiological monitoring to prevent adverse hemodynamic outcomes.[16,17]

The anesthesiologist should have a deep understanding of the consequences associated with PP creation; and it is critical that the anesthesiologist be prepared to detect and address possible alterations that may occur during laparoscopic interventions.

In the present study, we evaluated whether adaptive changes in cerebral and systemic oxygenation and in hemodynamics are intraoperatively induced by IAP increases and PP-associated CO2 changes. The contribution of knowledge on the real impact of anesthesia on hemodynamic regulation during pediatric laparoscopic procedures was also considered.

Materials and Methods

Patients

The initial inclusion criteria for recruitment in the study were as follows: thirty children (21M/9F), aged 1 to 18 years (mean age 8.1±5.1 yr), scheduled for elective abdominal surgical procedures for congenital unilateral inguinal hernia repair. The treatment group (LAP Group: 20 children, 12M/8F, mean age 9.6±5.1) underwent laparoscopic surgery, while the control group underwent traditional open surgery (Open Group: 10 children, 9M/1F, mean age 5.1±4.1).

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Surgery was performed by an experienced surgeon, under general endotracheal anesthesia. To critically analyze and synthesize current evidence, we performed an analysis of the completed results from both groups. Patients were consecutively recruited between 1 February 2016 and 31 June 2016, at the Pediatric Surgery Unit of the Fondazione IRCCS Policlinico San Matteo, Pavia, Italy. Written consent was obtained from the parents of the children before the scheduled surgical procedure. The study was performed according to the Declaration of Helsinki and with the approval of the Institutional Review Board.

Surgery

All surgeries were performed in the same operating theater with a stable temperature of 22±1°C. Patients were placed in the supine position on a heated operating table (36±1°C). Laparoscopic treatment was accomplished, following a standard protocol, via the trans-abdominal approach using one 3 mm telescope and two, 3 mm or 2 mm, surgical instruments, placed into the lower abdomen. The pneumoperitoneum (PP) was created with a 3 mm infra-umbilical camera-trocar placed via an open approach. The PP CO_2 pressure, which ranged from 8 to 12 mmHg (8 mmHg in children weighing <15 kg; 10 mmHg: 15-40 kg; 12 mmHg: >40 kg), was achieved with a CO_2 insufflation flow rate of 1 L/min.

Patients included in the control group underwent a traditional open-surgery procedure. All interventions were performed on a day hospital basis and patients were followed for one week.

Data acquisition

Intraoperative transcranial near-infrared spectroscopy (NIRS) was used to assess regional cerebral oxygen saturation ($rScO_2$), pulse oximetry was used to measure peripheral oxygen saturation using (SpO_2); and HR, diastolic (DP), systolic pressure (SP) and end-tidal CO_2 were monitored continuously during the entire procedure.

Changes in $rScO_2$ were measured using a near-infrared spectrometer. Prior to anesthesia induction, a transducer was placed on the frontal side of the child's head and attached with an elastic bandage to prevent displacement. The oximeter sensor was positioned on the middle finger of the left hand. HR was recorded during scanning also using pulse oximetry for heart timing and an index of pulse amplitude.

Indirect data on IAP during surgery were collected via dynamic urethral pressure measurements with a high-resolution manometry system and recorded with Medical Measurement Systems® (Enschede, the Netherlands).

The following parameters were analyzed, every minute for five minutes (mean values were used for the statistical analysis), at five intervals: basal (T0) in LAP and Open groups; induction of anesthesia (T1) in LAP and Open groups; CO_2 PP insufflation (T2) in the LAP group; surgery (T3) in LAP and Open groups; cessation of CO_2 PP (T4) in the LAP group; before extubation (T5) in LAP and Open groups.

The operative times were recorded, including data acquisition and anesthesia duration (interval from beginning of induction to cessation of sevoflurane inhalation). The anesthesiologists were not blinded to the data readings to prevent intraoperative alterations in the children.

Anesthesia protocol

All children were in good physical condition (ASA, American Society of Anesthesiologists, class 1) and received standard anesthesia. Induction was performed endovenously (e.v.) with propofol (2-4 mg/Kg) and fentanyl (1 μg/Kg); and for muscle relaxation, cisatracurium 0.1 mg/Kg was given e.v.

After tracheal tube positioning, patients underwent volume controlled mechanical ventilation with a tidal volume of 8 mL/Kg, the respiratory rate adjusted to achieve an end-tidal CO_2 of 32–37 mmHg, an I:E ratio of 1:2 (avoiding dynamic hyperinflaction) with a low-flow breathing system and an inspired mixture of air and oxygen (fresh gas flow of 4 l min^{-1} with 40% FiO_2 during anesthesia). Anesthesia was maintained via administration of Sevoflurane gas (0.9 to 1.3 MAC range). The anesthesiology protocol did not include hypotension management with fluid expansion or inotropes. Twenty minutes before the end of the intervention, all patients received Paracetamol 15 mg/kg, as an analgesic. The analgesia was consolidated with surgical wound infiltration using levobupivacaine and lidocaine for both open and laparoscopic surgery.

Statistical analysis

Quantitative variables were described as the mean (SD) and compared among 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 8.0.

Results

During the surgical procedure, a significant variation in $rScO_2$ was observed at the different time points in comparison with basal values (P<0.01). In the LAP group, a significant $rScO_2$ increase was noted at T1 (P<0.001). The intraoperative $rScO_2$ values at T2 (P=0.6), T3 (P=0.4), T4 (P=0.5) and T5 (0.7) were not different compared with T1. The minimal $rScO_2$ variations during the laparoscopic procedure were not related to PP pressure (P=0.5) or CO_2 flow rate (P=0.8).

In the Open group a significant rScO2 increase was recorded at T1 (P<0.001). At T3 (P=0.007) and T5 (P=0.007) rScO2 was significantly lower than at T1. The rScO2 profile and parameter mean values are reported in Figure 1A and Table 1.

Heart rate

HR showed significant changes during the entire surgical procedure in comparison with T0 (P=0.02). In the LAP group, HR was significantly higher at T2 compared with T0 (P=0.04). HR changes were related to CO_2 PP pressure (P=0.002). An HR increase was also observed at T5 (P=0.009) compared with basal values.

In the Open group, HR changes at T1 (P=0.4), T3 (P=0.6) and T5 (P=0.3) were not significantly different in comparison with T0. The HR profile and parameter mean values are given in Figure 1B and Table 1.

Peripheral oxygen saturation

The $SatO_2$ values were significantly different during the surgical intervention (P<0.001).

In the LAP group, a significant $rScO_2$ increase was noted at T1 (P=0.001). The $SatO_2$ values at T2 were not significantly different in comparison with T0 (P=0.3), but were lower than T1 (P=0.06). The $SatO_2$ differences between T0 and T3 and T4 were not significant (P=0.9 and P=0.4, respectively). A relevant decrease in $SatO_2$ was observed at T5 in comparison with T0 (P<0.001). In the Open groups, $SatO_2$ at T1 (P=0.27) and T3 (P=0.34) was not different in comparison with T0. A significant decrease in $SatO_2$ was recorded at T5 compared to T0 (P<0.001). The $SatO_2$ profile and parameter mean values are reported in Figure 1C and Table 1.

Diastolic pressure

The changes in DP values were significant during the surgical intervention (P<0.001). In the LAP group, a decrease in DP was significantly induced at T1 (P<0.001). At T2, even though the DP was lower than at T0 (P=0.01), an increase in pressure was recorded compared with T1 (p<0.001); these changes were related to CO_2 PP (P<0.001). During the surgical procedure, DP values remained significantly lower compared with T0 (P<0.001), without a significant difference between T4 and T1 (P=0.13). A DP recovery was observed at T5 (P=0.05).

In the Open group, a significant decrease in DP was revealed at T1 (P<0.001). A progressive DP increase was recorded at T3 (P=0.006) and T5 (P=0.05). The DP profile and parameter mean values are given in Figure 1D and Table 1.

Systolic pressure

The SP values were significantly different during the surgical intervention (P<0.001). In the LAP group, a decrease in

SP was significantly induced at T1 ($P<0.001$). At T2, an increase in pressure was recorded ($P=0.15$ *vs* T0; $P<0.001$ *vs* T1); these changes were related to IAP ($P<0.001$). SP remained lower at T3 ($P=0.006$) and T4 ($P=0.004$) compared with T0. At T4, the SP change was related to CO_2 PP desufflation ($P<0.001$). At T5, no significant SP difference was noted in comparison with T0 ($P=0.6$).

In the Open group, a significant decrease in SP was revealed at T1 ($P=0.01$). A progressive systolic PA increase was recorded at T3 ($P=0.13$) and T5 ($P=0.5$). The SP profile and parameter mean values are given in Figure 1E and Table 1.

End-tidal CO_2

During the surgical procedure, no significant variations in End-tidal CO_2 were observed at the different time points in comparison with T1 ($P=0.37$). The End tidal mean values are provided in Table 1. In Table 1, the hemodynamic mean values at the different surgical time points are reported.

Discussion

During laparoscopic procedures in children, adaptive changes in cerebral and systemic oxygenation and hemodynamic parameters are observed. These changes are related to pathophysiological consequences induced by PP creation and the impact of general anesthesia. Adverse hemodynamic events may be prevented with stringent intraoperative technical monitoring and strict standardization of the pediatric anesthesiological protocol. As in adults, pediatric laparoscopy is less invasive in nature, thereby providing a more rapid recovery, shorter hospital stay, decreased postoperative pain and improved cosmetic outcome when compared with traditional open surgery. Nevertheless, the procedure may be associated with hemodynamic alterations 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 during laparoscopy should be considered.[15,18-21] To date, data regarding hemodynamic changes during laparoscopy are conflicting and further evaluations in very small children represent new research perspectives for the near future. The most commonly studied parameters are HR, systemic vascular resistance, mean arterial pressure and central venous pressure. Increases and decreases in virtually all of the parameters noted above have been described after the institution of PP. The data vary in relation to the many factors affecting these values such as the child's weight and age.[22]

Significant changes in cerebral oxygenation occur in some patients during CO_2 insufflation. To date, the data collected regarding alterations in cerebral oxygenation during laparoscopic procedures in children have been limited and non-homogenous.[11-15]

Previously, we reported on changes in cerebral oxygenation during laparoscopic procedures in pediatric patients, when stringent monitoring was not adopted.[15] In this study, we closely monitored cerebral oxygenation with NIRS and the anesthesiologists were not blinded to the readings to prevent intraoperative alterations. Under these conditions, we showed that CO_2 insufflation during PP may not influence cerebral oxygenation during laparoscopic surgery. These results suggest that the impact of anesthesia on adaptive changes should not be underestimated and confirm that this technology may be useful to anticipate any potential decrease in brain oxygenation. Rapid recognition of low cerebral perfusion and prompt correction is a challenge and the main goal is to avoid negative postoperative neurodevelopmental outcomes following pediatric

Table 1. Hemodynamic mean values at the different surgical time points.

Parameters	LAP group	Open group
Operative time (mean±SD)	102±37.2	71±36.57
NIRS		
T0	73.8±5.7	74.9±9.0
T1	81.3±9.6	82.4±6.8
T2	82.0±11.1	-
T3	82.4±10	77.1±9.2
T4	82.1±9.7	-
T5	81.7±8.4	77.2±7.5
Heart rate		
T0	99.5±22.9	115.3±11.1
T1	100.3±21.6	111.4±20.3
T2	107.3±25.2	-
T3	103.5±24.1	113.1±18.3
T4	105.7±23.0	-
T5	106.1±20.3	120.2±24.3
$SatO_2$		
T0	98.2±1.0	98.6±1
T1	98.6±1.0	99.0±1
T2	97.9±0.9	-
T3	98.3±1.2	99.0±1.3
T4	97.9±0.1	-
T5	96.9±2.5	97.4±1.9
Diastolic PA		
T0	63.1±15.1	58.2±17.3
T1	47.3±7.6	46.6±7.2
T2	56.4±11.6	51.2±10.3
T3	50.7±9.3	51.2±10.2
T4	50.8±9.3	-
T5	57.6±11.0	55.5±10.3
Systolic PA		
T0	111.1±17.4	102.9±8.5
T1	94.2±6.8	95.0±9
T2	107.5±15.2	-
T3	103.8±12.7	101.7±11.9
T4	103.4±13.0	-
T5	110.8±13.7	105.3±13.5
End-tidal CO_2		
T0	-	-
T1	35.8±5.8	41.9±6.7
T2	36.7±5.3	-
T3	38.3±4.8	37.5±6.3
T4	37.8±4.8	-
T5	-	-

surgical procedures. The anesthesiologist should be specifically prepared to manage this vulnerable population.[23,24]

In this study we also collected data on the impact of CO_2 insufflation on peripheral oxygenation. Anesthesia induction and intraoperative management are critical determinants in peripheral oxygenation stability during laparoscopic procedures; in fact, during the latter part of surgery (last ten minutes), especially in very young children (whose muscles are very weak and do not intrude with surgical activity), a gradual reduction in ventilator assistance was adopted in order to facilitate gradual recovery of spontaneous breathing.[25,26]

According to the literature, increases in arterial pressure during peritoneal insufflation have been noted. Moreover, we showed that a significant decrease in diastolic and systolic pressures, occurred at induction of anesthesia and during intraoperative surgical time points.

The pressure profile was similar in both open surgery and the laparoscopic surgical approach; this observation supports the hypothesis that PP creation is only partially responsible for pressure variations and underlines the importance of dedicated anesthesiological management in pediatrics even for traditional surgery.

As previously reported,[15] during PP creation, an HR increase was recorded. The correlation between HR changes and CO_2 flow rate support the role of a neurohumoral CO_2 effect. CO_2 stimulates the sympathoadrenal system causing a significant release of catecholamines and cortisol and thus increased HR. The absorption of CO_2 during positive pressure pneumoperitoneum may lead to an increased CO_2 load. While a different CO_2 reabsorption in infants and children has already been reported based on the different characteristics in their peritoneal surface, CO_2 elimination is related to age with younger children eliminating more CO_2 than older children.[27]

In most patients undergoing controlled ventilation, end-tidal CO_2 closely reflects arterial CO_2 tension.[27] We did not measure arterial CO_2 and arterial pH levels in this study, but we assume that because there were only minor changes in end-tidal CO_2, that the blood gases did not change significantly. Clinically, we did not observe any adverse cardiovascular or respiratory events in our patients.

The present preliminary report has several limitations. The sample size was limited and a study on a larger number of chil-

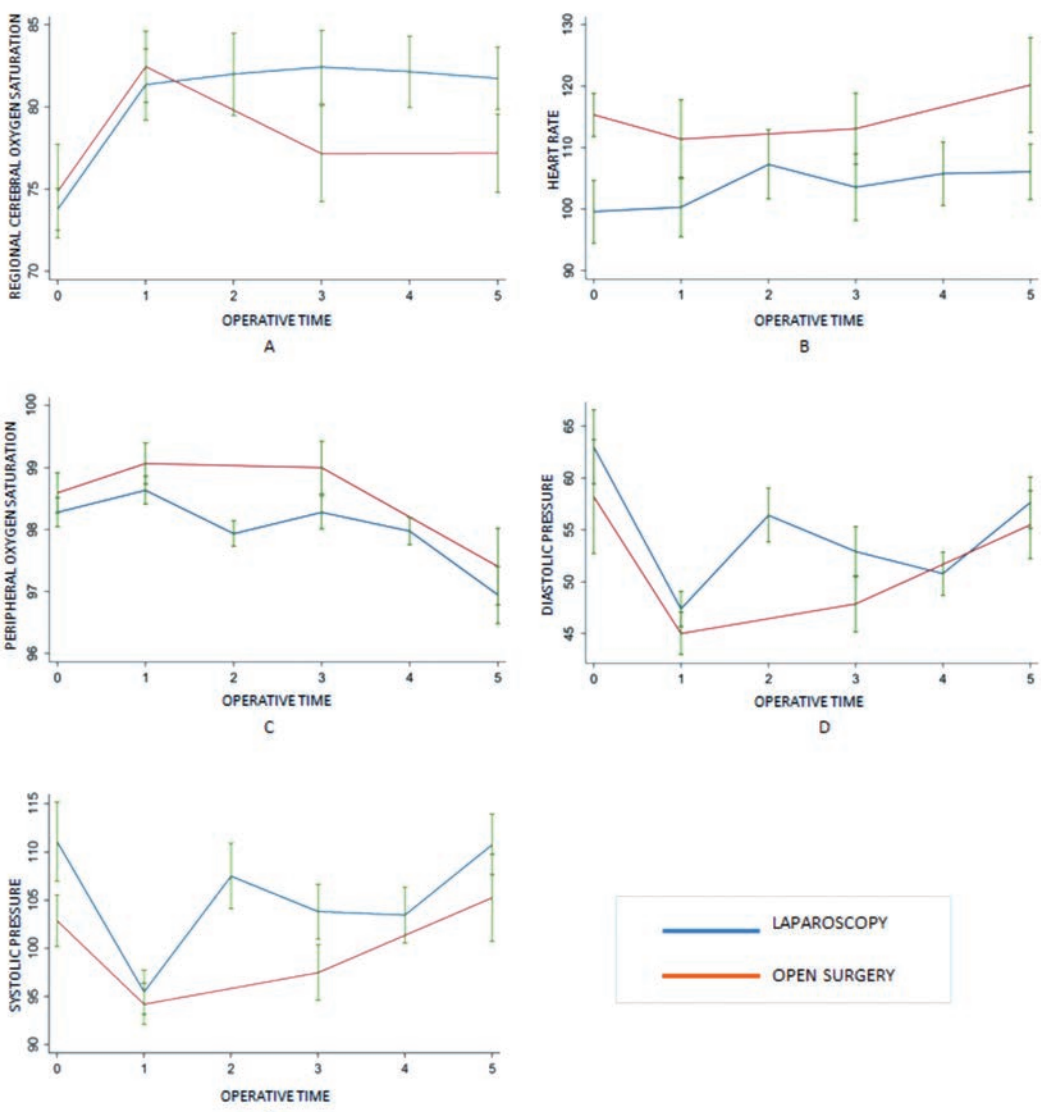

Figure 1. Profile of regional cerebral oxygen saturation (A), heart rate (B), peripheral oxygen saturation (C), diastolic pressure (D) and systolic pressure (E) in LAP and OPEN groups at the different surgical time points.

dren is mandatory to confirm the results. Secondly, it concerns a population with a *broad* range of ages, from 1 to 18 years, and the impact of IAP, absorption and elimination of CO_2 and anesthesia protocols are different for infants, children and adolescents. The initial inclusion criteria for recruitment in the study selected an homogenous group of procedures, however the influence of the different operative times on the rScO2 cannot be excluded. The anesthesiologist's anesthesia technique and ventilation strategy to obtain the best parameters were not standardized. Additionally, the exact impact of the anesthesia on hemodynamics could be supported by hemodynamic evaluation during the standard anesthesia protocol and using different anesthesiological agents. Finally, arterial blood gas analysis monitoring would be useful during laparoscopic procedures; in our study, the routine procedure, did not call for invasive $PaCO_2$ monitoring.

This study points to new study directions to ameliorate our knowledge on the combined surgical and anesthesiological role on hemodynamic status in pediatric laparoscopy. With the advent of new mini invasive surgical approaches, there is a need for specific and dedicated anesthesiological procedures, particularly in children. Although anesthesia for laparoscopic surgery does not require a major extension of the traditional methods for pediatric abdominal surgery, special consideration must be given to alterations in cardiovascular and respiratory status that occur during the laparoscopic procedure.[18-21] Children, infants and neonates represent an anesthesiological challenge because of age-specific anatomical and physiological issues. Apart from these pediatric-specific considerations, the pediatric anesthesiologist must understand the implications of laparoscopic surgery, and prevent or act accordingly to changes that will occur during these procedures.[18-21] There is room for improvement in quality of care during the laparoscopic surgical approach in pediatrics.

Conclusions

This study demonstrates that pathophysiological hemodynamic alterations are influenced by both the procedure and the anesthesia during pediatric abdominal laparoscopic surgery. However, the exact role of each factor needs further research. Due to age-related homeostatic vulnerability, hemodynamic status should not be underestimated in pediatrics. Knowledge of the pathophysiological changes, the standardization of intraoperative surgical assessment and anesthesia management are all mandatory to prevent adverse hemodynamic outcomes. Future challenges will include appropriate application of combined minimally invasive surgery and anesthesiological protocols, while maintaining the child's safety during and after laparoscopic procedures.

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