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Effects of Pneumoperitoneum on Splanchnic Oxygenation during Abdominal Laparoscopic Surgery in Paediatric Patients: A prospective, Observational Study

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Abstract

Objective: Pneumoperitoneum can cause disruption in splanchnic perfusion. This study aims to investigate effects of pneumoperitoneum on splanchnic oxygenation during abdominal laparoscopic surgery in paediatric patients with NIRS (Near-Infrared Spectroscopy).

Material and methods: A total of 45 patients between 1 and 4 years of age with ASA physical status I–II and scheduled to undergo abdominal laparoscopic surgery under general anaesthesia were enrolled in this prospective, observational surgery. No premedication was used. Standard monitoring and regional splanchnic saturation ($rSPcO_2$), regional cerebral oxygen saturation ($rScO_2$) with NIRS were established before anaesthesia. Anaesthesia was induced with an inhalational agent and maintained with an oxygen/air mixture and sevoflurane. Peripheral oxygen saturation (SPO_2), $rSPcO_2$, $rScO_2$, heart rate (HR), mean arterial pressure (MAP), end tidal CO_2 (Et-CO_2), and insufflation pressure (IP) were continuously monitored during administration of anaesthesia and recorded. After intubation (baseline T0); before CO_2 insufflation induced pneumoperitoneum (PP) (T1); CO_2 PP insufflation (T2); 5 minutes after PP insufflation (T3); 10 minutes after PP insufflation (T4); 15 minutes after PP insufflation (T5); 20 minutes after PP insufflation (T6); 30 minutes after PP insufflation (T7), 60 minutes after PP insufflation (T8), and after desufflation (T9). Bradycardia and hypotension were recorded. Paracetamol IV 10 mg kg^{-1} was applied for post-operative analgesia. $p<0.05$ wasconsidered significant.

Results: HR, $rScO_2$, and $rSPcO_2$ decreased at all measured time intervals when compared to T0 ($p<0.01$) MAP decreased at T1 compared to T0 ($p<0.001$). Et-CO_2 increased at T3-T4-T5-T6 compared to T0 ($p<0.001$).

Conclusion: We found that pneumoperitoneum reduced splanchnic oxygenation during laparoscopic abdominal surgery in paediatric patients, which was measured using NIRS.

Keywords: Cerebral oxygenation, NIRS, paediatric, pneumoperitoneum, splanchnic oxygenation

Introduction

Laparoscopic surgery is being routinely performed in children for abdominal surgical interventions. Small-sized wound site, faster recovery, less post-operative pain, early mobilisation, a less risk of brid-ileus development, and fluid loss are the most common advantages of this technique (1). Despite its advantages, pneumoperitoneum (PP); increased intra-abdominal pressure (IAP) and CO_2 insufflation lead to physiological changes. Decrease in respiratory compliance, functional residual capacity and deterioration of oxygenation, hypercarbia and related acidosis, increased intracranial pressure and increased release of vasopressin can cause regional blood flow changes, reduction of hepatic, splanchnic, renal blood flow and reduced cerebral and splanchnic oxygenation (2, 3).

Splanchnic circulation receives 30% of cardiac output and has a regional storage function. It is known that the first signs of increased intraabdominal pressure arise with the impairment of splanchnic perfusion (4). Intestinal

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ischemia, decreased gastric perfusion, and decreased portal circulation have been reported due to increased IAP (5, 6).

Mesenteric arterial blood flow and gastric pH measurements are used to indicate splanchnic macrocirculatory changes during CO_2 pneumoperitoneum (7). Gastric pH measurements and mixed venous oxygen saturation are used to show splanchnic perfusion, which are invasive methods requiring catheterization (7-9). Near-infrared spectroscopy (NIRS) is a non-invasive method for measuring local haemoglobin oxygen saturation in tissue (10). NIRS has been used for measuring cerebral regional oxygen saturation (11, 12). In neonatal intensive care units, abdominal NIRS measurements are used to monitor changes in perfusion and oxygenation of the intestinal and splanchnic tissue (13, 14).

Splanchnic organs lie near the skin surface in children and are more easily accessible with NIRS somatic sensors with an average penetration depth of 2 cm (15). In the existing literature, there is no study investigating the splanchnic oxygenation during pneumoperitoneum in children.

We aimed to investigate the effects of pneumoperitoneum on splanchnic oxygenation during abdominal laparoscopic surgery in paediatric patients with NIRS (Near-Infrared Spectroscopy).

Methods

The study was approved by the Sisli Hamidiye Etfal Training and Research Hospital Ethics Committee (SEEAH, 948, 06/02/2018). A total of 45 patients between the age of 1 and 4 years with ASA (American Society of Anaesthesiologists) physical status I–II and scheduled to undergo abdominal laparoscopic surgery under general anaesthesia in paediatric surgery clinic between February 2018 and June 2018 were enrolled in this prospective, observational study. Written informed consent from each patients' guardian was received. The exclusion criteria were the presence of cardiovascular disease, respiratory disease, and hemodynamic instability. The study was performed according to the Declaration of Helsinki.

Main Points:

- It is known that the first signs of increased intraabdominal pressure arise with the impairment of splanchnic perfusion.
- In neonatal intensive care units, abdominal NIRS measurements are used to monitor changes in perfusion and oxygenation of the intestinal and splanchnic tissue.
- In the existing literature, there is no study investigating the splanchnic area oxygenation during pneumoperitoneum in children.
- We aimed to investigate the effects of pneumoperitoneum on splanchnic oxygenation during abdominal laparoscopic surgery in paediatric patients with NIRS.
- We determined that pneumoperitoneum reduces splanchnic oxygenation during laparoscopic abdominal surgery in paediatric patients which was measured with NIRS.

Anaesthesia protocol

No premedication was applied to patients before surgery. Standard monitoring was established in the operating room with peripheral oxygen saturation SPO_2, non-invasive arterial pressure, electrocardiography, End-tidal CO_2 (Et-CO_2) (CardiocapII; Datex, Helsinki, Finland), and $rSPcO_2$ and $rScO_2$ were measured using a cerebral/somatic near-infrared spectroscopy (NIRS) (model INVOS 5100; Covidien, Mansfield, MA. INVOS™ OxyAlert™ NIRS Sensors for infants and neonates). Demographic data: age, gender, height, weight, ASA and operation types, and haemoglobin and haematocrit values were recorded before surgery. Cerebral sensor was placed on the left lateral forehead, and one somatic sensor was placed on anterior abdominal wall above the umbilicus for measurement of cerebral and splanchnic oxygenation before anaesthesia induction. Anaesthesia was induced with an inhalational 8% sevoflurane 50/50% oxygen–air mixture. An intravenous line was applied and 1-2 mcg kg^{-1} fentanyl, 0.6 mg kg^{-1} rocuronium were administered. After tracheal intubation, anaesthesia was maintained with an oxygen/air mixture and 2% sevoflurane. Patients were ventilated by volume-controlled mechanical ventilation with a tidal volume 6-8 mL kg^{-1}, and the respiratory rate was adjusted to achieve an end-tidal CO_2 level of 32–35 mmHg. The PP CO_2 pressure which ranged from 8 to 10 mmHg was achieved with a CO_2 insufflation flow rate of 1–5 L min^{-1}.

Intraoperative $rScO_2$, $rSPcO_2$, SPO_2, HR, MAP, Et-CO_2, and insufflation pressure were monitored continuously and recorded; one minute after intubation (baseline T0); before CO_2 insufflation induced pneumoperitoneum (PP) (T1); CO_2 PP insufflation (T2); 5 minutes after PP insufflation (T3); 10 minutes after PP insufflation (T4); 15 minutes after PP insufflation (T5); 20 minutes after PP insufflations (T6); 30 minutes after PP insufflation (T7), 60 minutes after PP insufflation (T8) and the 1 minute after desufflation (T9). Operation and anaesthesia time were recorded.

Side effects, such as bradycardia and hypotension were recorded. Bradycardia and hypotension defined with a rate of 20% under baseline and were treated with atropine 0.01 to 0.03 mg kg^{-1} IV and ephedrine 0.2 mg kg^{-1} IV, respectively.

Patients received paracetamol IV 10 mg kg^{-1} 10 min before end of the surgery. At the end of the surgery, 100% O_2 was started, antagonization of neuromuscular blocker was achieved with 0.015 mg kg^{-1} of atropine and 0.035 mg kg^{-1} of neostigmine.

Statistical analysis

Statistical Package for the Social Sciences version 15.0 for Windows (SPSS Inc., Chicago, IL, USA) statistical package was used for statistical analysis. Repeated analysis of variance (ANOVA) was used to test for any change in $rScO_2$, $rSPcO_2$ during the study time points. The $rScO_2$, $rSPcO_2$ changes during pneumoperitoneum were compared using a paired t test. All data were presented as the mean ± standard deviation of median with range. Descriptive statistics are given as number and percentage for categorical variables, mean ± standard deviation, minimum, maximum, and 95% CI for numerical variables. Dependent group comparisons were made by the Wilcoxon test because the differences of the numerical variables did not meet the normal distribution condition. Bonferroni correction was interpreted. Statistical significance was accepted as $p<0.05$.

Results

Demographic data: age, gender, height, weight, ASA and operation time, anaesthesia time, operation types, and haemoglobin and haematocrit values are presented in (Table 1).

HR values were found to decrease at T1-T2-T3-T4-T5-T6 and T9 compared to T0 ($p<0.001$, $p<0.002$, $p<0.001$, $p<0.001$, $p<0.001$, $p<0.001$, $p<0.001$). MAP value was found to be significantly decreased at T1 as compared to T0 ($p<0.001$) (Figure 1). SpO_2 values did not change at all measured time intervals when compared to T0 (Figure 1). Et-CO_2 values were increased at T3-T4-T5-T6 and T9 when compared to T0 ($p<0.001$, $p<0.001$, $p<0.001$, $p<0.002$, $p<0.001$) (Figure 1).

$rScO_2$ decreased at all measured time intervals when compared to T0 ($p<0.001$, $p<0.001$, $p<0.006$, $p<0.005$, $p<0.006$, $p<0.005$, $p<0.005$, $p<0.01$, $p<0.005$, $p<0.006$, $p<0.01$) (Table 2) (Figure 2).

Table 1. Demographic data, operation time, operation types, and haemoglobin and haematocrit values

	Mean±SD	Min-Max
Age (month)	30.08±5.9	12-48
Gender, n (%)		
Male	18 (40.0)	
Female	27 (60.0)	
Height (cm)	86.8±13.4	60-116
Weight (kg)	16.3±4.3	10-21
ASA, n (%)		
1	42 (93.3)	
2	3 (6.7)	
Operation time (min)	32.9±11.6	20-55
Pneumoperitoneum time (min)	25.5±9.3	15-60
Haemoglobin	12.4±1.0	10-14.5
Haematocrit	37.9±3.7	31-49
Operation types n (%)		
Appendectomy	13 (28.8)	
Inguinal hernia repair	26 (57.7)	
Undescended testicles	6 (13.3)	

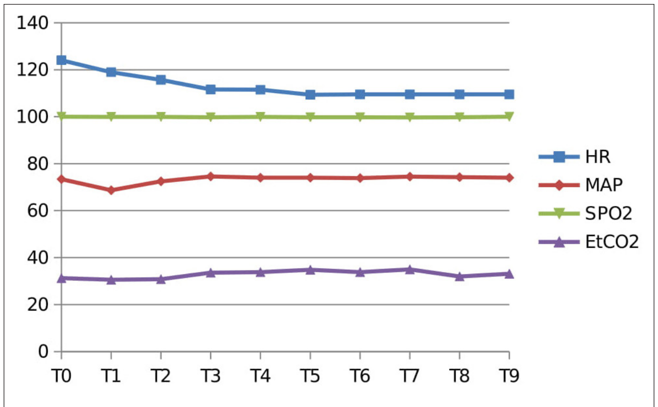

Figure 1. HR (beat min^{-1}), MAP (mm Hg^{-1}), SPO_2, Et-CO_2

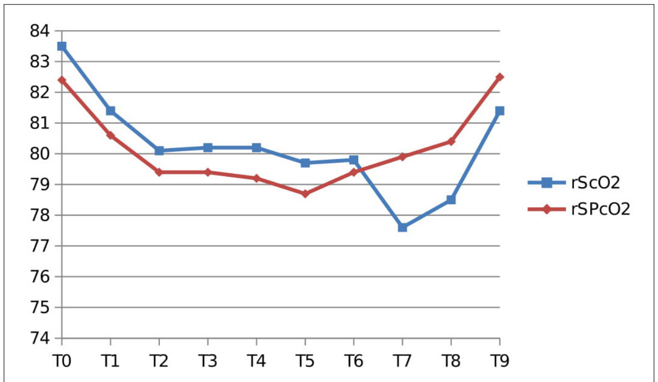

Figure 2. $rScO_2$ and $rSPcO_2$

Table 2. $rScO_2$ Values

		N	Mean±SD	95% CI
$rScO_2$	T0	45	83.5±8.4	79.1-87.1
	T1	45	81.4±8.9*	76.7-84.1
	T2	45	80.1±9.1*	74.6-83.7
	T3	45	80.2±9.3	73.4-84.5
	T4	45	80.2±8.8*	73.5-83.6
	T5	43	79.7±9.6	76.8-82.7
	T6	32	79.8±8.9	76.6-83
	T7	14	77.6±9.9	71.9-83.3
	T8	4	78.5±10.4	61.9-95.1
	T9	45	81.4±9.2	78.1-83.8

*$p<0.0055$

Table 3. $rSPcO_2$ Values				
		N	**Mean±SD**	**95% CI**
$rSPcO_2$	T0	45	82.4±8.8	76.3-84.5
	T1	45	80.6±8.6	74.3-83
	T2	45	79.4±7.9*	81.9-80.1
	T3	45	79.4±8.7	76.4-83.9
	T4	45	79.2±9.2*	76.9-83.9
	T5	44	78.7±9.4*	75.8-81.6
	T6	36	79.4±10.6	75.8-83
	T7	12	79.9±12.4	72.9-88.7
	T8	4	80.4±12.1	64.8-103.2
	T9	45	82.5±8.2	79.7-84.8

*p<0.0055

Table 4. Insufflation pressure (IP) (mm Hg)				
		N	**Mean±SD**	**95% CI**
IP	T2	22	10.3±2.1	9.3-11.3
	T3	43	10.6±2.1	9.6-11.5
	T4	42	10.6±2.1	9.9-11.2
	T5	37	10.5±2.0	9.8-11.2
	T6	28	10.6±2.3	9.7-11.5
	T7	14	10.6±2.5	9.1-12
	T8	4	10.3±1.5	9.9-11.6

$rSPcO_2$ decreased at all measured time intervals, except T9 when compared to T0 ($p<0.01$-$p<0.002$-$p<0.019$-$p<0.005$-$p<0.002$-$p<0.01$-$p<0.01$-$p<0.01$) (Table 3) (Figure 2). Insufflation pressure values are presented as mean+ SD deviation (Table 4).

There were no side effects shown (Figure 1).

Discussion

Laparoscopic surgery is being increasingly used in paediatric patients. In the existing literature, there is no study that has investigated the splanchnic area oxygenation during pneumoperitoneum in children. During follow-up with perioperative NIRS, it has been found that abdominal pneumoperitoneum reduces splanchnic oxygenation in paediatric patients during abdominal laparoscopic surgery.

During laparoscopic surgery, PP reduces the venous return by inferior vena cava compression. It causes significant reduction in contractility, left ventricular compliance, and cardiac output (16). Gentili et al. (17) revealed a significant decrease in cardiac function and volume in 20 healthy children who had undergone laparoscopic surgery at an intraabdominal pressure of 10 mmHg. Pelizzo et al. (11) compared laparoscopic and open techniques in children, and they found a decrease in the blood pressure and elevated HR in the laparoscopic surgery group. In another study by the same authors, high HR were found in children who underwent laparoscopic surgery, and it was inferred to be a response to CO_2 elevation and catecholamine discharge (18). In this study, while MAP was stable at all measurement times, a slight decrease was observed during induction; no PP-related change was observed. This can be attributed to the effects of anaesthetic drugs after induction and adequate fluid replacement in pre-operative and perioperative periods. HR decreased with insufflation, and the continued to decrease until the end of the operation. It could be an effect of increased vagal tone due to increased intraabdominal pressure.

PP can cause adaptive changes in the cerebrovascular system and decrease the brain oxygenation (19). Different results have been reported on the relationship between laparoscopic surgery and regional effects on cerebral oxygenation in children. De Waal et al. (20) demonstrated that insufflation of CO_2 at low IAPs (8 mmHg) in children causes increase in rSO_2. Westgarth-Taylor et al. (21) found an increase in cerebral oxygenation after insufflation in paediatric patients who had undergone laparoscopic surgery. In the other two studies, they found no change in cerebral oxygenation due to pneumoperitoneum compared to the open technique (22, 23). Tsypin et al. (24) reported an average reduction of 3% in regional cerebral tissue saturation in children during gynaecological laparoscopic interventions. Pelizzo et al. (11) observed a decrease in the cerebral oxygenation with insufflation at 10 IP in laparoscopic inguinal surgery. In case of 20% or more decrease in perioperative cerebral oxygenation, follow-up of neurological functions after surgery is recommended (10). In this study, $rScO_2$ values were observed to be 79 on an average during pneumoperitoneum, and it was lower compared to the baseline values. Increased ICP with decreased cardiac output and oxygen delivery, hypercarbia-related vasodilation can be explained by the decrease in $rScO_2$ and disruption of cerebral perfusion during PP. There was also a decrease in HR; however, this did not impair hemodynamic stability.

NIRS can be used as a routine monitoring technique to evaluate somatic tissue oxygenation especially splanchnic area in paediatric patients. Bailey et al. (25) reported mean rSPcO2 values of 69.9±12.1 on the first day of life, and this value increased with gestational age. Some authors have suggested the use of splanchnic cerebral oxygenation ratio (SCOR) to estimate splanchnic ischemia and rSO_2 was reported to be more effective in determining the mesenteric flow rate than mesenteric Doppler (26-28). Bhalala et al. (29) reported a decrease of 20 % and more compared to the baseline values. NIRS was recommended to determine the oxygen demand of regional oxygen saturation (rSO_2), transfusion requirement, and in the diagnosis of necrotizing enterocolitis (NEC) in neonatal intensive care units (5, 30-32). Kaufman et al. (33) found a strong correlation between splanchnic rSO2 and gastric pH measurement, mixed venous oxygen saturation, and serum lactate levels in 20 infants who underwent congenital cardiac surgery. It was reported that splanchnic rSO_2 measurement was rapid, reliable, and a non-invasive method for the evaluation of splanchnic oxygenation and perfusion.

We investigated the decrease in $rSPcO_2$ values during PP compared to the baseline. $rSPcO_2$ was observed to be 78 on average during PP. Decreased rSPcO2 values can be explained by impaired microcirculation, decreased organ blood flow, and splanchnic ischemia during CO_2 insufflation.

There are some limitations to this study. We could not compare $rScPO_2$ values in open surgical technique because abdominal surgical interventions are routinely performed by laparoscopic technique in paediatric patients in our hospital.

Tissue ischemia and impaired organ function can be a cause of laparoscopy-associated morbidity and mortality (34-36). In conclusion, we determined that pneumoperitoneum reduces the cerebral and splanchnic oxygenation measured with NIRS during laparoscopic abdominal surgery in paediatric patients. We recommend close and optimal perioperative and post-operative monitoring with NIRS, which can reduce laparoscopic surgery-related complications.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Sisli Hamidiye Etfal Training and Research Hospital Ethics Committee (SEEAH, 948, 06/02/2018).

Informed Consent: The verbal or written consent was obtained from each patient's guardian.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – L.K., H.Ş.T.; Design – L.K., H.Ş.T., S.C.; Supervision – S.C., M.D.; Resources – L.K., P.S.; Materials – P.S., M.D., S.İ.; Data Collection and/or Processing – L.K., P.S.; Analysis and/or Interpretation – L.K., H.Ş.T., S.İ.; Literature Search – L.K., H.Ş.T., M.D.; Writing Manuscript – L.K., H.Ş.T., S.C.; Critical Review – S.C., M.D.

Conflict of Interest: The authors have no conflicts of interest to declare.

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References

1. Wedgewood J, Doyle E. Anaesthesia and laparoscopic surgery in children. Paediatr Anaesth 2001; 11: 391-9. [Crossref]
2. Truchon R. Anesthetic considerations for laparoscopic surgery in neonates and infants: a practical review. Best Pract Res Clin Anaesthesiol 2004; 18: 343-55. [Crossref]
3. Rosin D, Brasesco O, Varela J, Saber AA, You S, Rosenthal RJ, et al. Low-pressure laparoscopy may ameliorate intracranial hypertension and renal hypoperfusion. J Laparoendosc Adv Surg Tech A 2001; 12: 15-9. [Crossref]
4. Párraga Ros E, Correa-Martín L, Sánchez-Margallo FM, Candanosa-Aranda IE, Malbrain MLNG, Wise R. Intestinal histopathological changes in a porcine model of pneumoperitoneum-induced intra-abdominal hypertension. Surg Endosc 2018; 32: 3989-4002. [Crossref]
5. Diebel LN, Wilson RF, Dulchavsky SA, Saxe J. Effectof increased intra-abdominal pressure on hepatic arterial, portal venous, and hepatic microcirculatory blood flow. J Trauma 1992; 33: 279-82. [Crossref]
6. Ho HS, Saunders CJ, Corso FA, Wolfe BM. The effects of CO2 pneumoperitoneum on hemodynamics in hemorrhaged animals. Surgery 1993; 114: 381-7.
7. Clark CH, Gutierrez G. Gastric intramucosal pH: a non-invasive method for the indirect measurement of tissue oxygenation. Am J Crit Care 1992; 1: 53-60. [Crossref]
8. Zhang X, Xuan W, Yin P, Wang L, Wu X, Wu Q. Gastric tonometry guided therapy in critical care patients: a systematic review and meta-analysis. Crit Care 2015; 27: 19-22. [Crossref]
9. Dantzker DR. Monitoring tissue oxygenation: The quest continues. Chest 2001; 20: 701-2. [Crossref]
10. Casati A, Spreafico E, Putzu M, Fanelli G. New technology for noninvasive brain monitoring: continuous cerebral oximetry. Minerva Anesthesiol 2006; 72: 605-25.
11. Pelizzo G, Bernardi L, Carlini V, Pasqua N, Mencherini S, Maggio G, et al. Laparoscopy in children and its impact on brain oxygenation during routine inguinal hernia repair. J Minim Access Surg 2017; 13: 51-6. [Crossref]
12. Jo YY, Lee JY, Lee MG, Kwak HJ. Effects of high positive end-expiratory pressure on haemodynamics and cerebral oxygenation during pneumoperitoneum in the Trendelenburg position. Anaesthesia 2013; 68: 938-43. [Crossref]
13. Bailey SM, Hendricks-Muñoz KD, Wells JT, MallyP. Packedred blood cell transfusion increases regional cerebral and splanchnic tissueoxygen saturation in anemic symptomatic preterminfants. Am J Perinatol 2010; 27: 445-53. [Crossref]
14. Braski K, Weaver-Lewis K, Loertscher M, Ding Q, Sheng X, Baserga M. Splanchnic-Cerebral Oxygenation Ratio Decreases during Enteral Feedings in Anemic Preterm Infants: Observations under Near-Infrared Spectroscopy Neonatology. Neonatology 2018; 113: 75-80. [Crossref]
15. Ferrari M, Mottola L, Quaresima V. Principles, techniques, and limitations of near infrared spectroscopy. Can J Appl Physiol 2004; 29: 463-87. [Crossref]
16. Kuratani N. Anesthetic Management of Laparoscopic Surgery for Infants and Children. J Japan Socie Clin Anesth 2008; 28: 573-7. [Crossref]
17. Gentili A, Iannettone CM, Pigna A, Landuzzi V, Lima M, Baroncini S. Cardiocirculatory changes during videolaparoscopy in children: echocardiographic study. Paed Anaesth 2000; 10: 399-406. [Crossref]

18. Pelizzo G, Carlini V, Iacob G, Pasqua N, Maggio G, Brunero M, et al. Pediatric Laparoscopy and Adaptive Oxygenation and Hemodynamic Changes. Pediatr Rep 2017; 9: 21-5. [Crossref]
19. Moka E. Cerebral oximetry and laparoscopic surgery. J Minim Access Surg 2006; 2: 47-8. [Crossref]
20. de Waal EE, de Vries JW, Kruitwagen CL, Kalkman CJ. The effects of low-pressure carbon dioxide pneumoperitoneum on cerebral oxygenation and cerebral blood volume in children. Anesth Analg 2002; 94: 500-5. [Crossref]
21. Westgarth-Taylor C, de Lijster L, van Bogerijen G, Millar AJ, Karpelowsky J. A. prospective assessment of renal oxygenation in children undergoing laparoscopy using near-infrared spectroscopy. Surg Endosc 2013; 27: 3696-704. [Crossref]
22. Tuna AT, Akkoyun I, Darcin S, Palabiyik O. Effects of carbon dioxide insufflation on regional cerebral oxygenation during laparoscopic surgery in children: A prospective study. Rev Bras Anestesiol 2016; 66: 249-53. [Crossref]
23. Tytgat SH, Stolwijk LJ, Keunen K, Milstein DM, Lemmers PM, van der Zee DC. Brain oxygenation during laparoscopic correction of hypertrophic pyloric stenosis. J Laparoendosc Adv Surg Tech A 2015; 25: 352-7. [Crossref]
24. Tsypin LE, Mikhel'son VA, Chusov KP, Kazharskaia E Iu, Lazarev VV, Prokop'ev GG, et al. Central and cerebral hemodynamics during gynecological laparoscopic interventions in children. Anesteziol Reanimatol 2007; 1: 30-2.
25. Bailey SM, Hendricks-Munoz KD, Mally P. Cerebral, renal, and splanchnic tissue oxygen saturation values in healthy term newborns. Am J Perinatol 2014; 31: 339-44. [Crossref]
26. Gillam-Krakauer M, Cochran CM, Slaughter JC, Polavarapu S, McElroy SJ, Hernanz-Schulman M, et al. Correlation of abdominal rSO2 with superior mesenteric arteryvelocities in preterm infants. J Perinatol 2013; 33: 609-12. [Crossref]
27. Sood BG, McLaughlin K, Cortez J. Near-infrared spectroscopy: applications in neonates. Semin Fetal Neonatal Med 2015; 20: 164-72. [Crossref]
28. Bailey SM, Hendricks-Muñoz KD, Mally P. Splanchnic-cerebral oxygenation ratio (SCOR) values in healthy term infants as measured by near-infrared spectroscopy (NIRS). P Pediatr Surg Int 2013; 29: 591-5. [Crossref]
29. Bhalala US, Nishisaki A, McQueen D, Bird GL, Morrison WE, Nadkarni VM, et al. Change in regional (somatic) near-infrared spectroscopy is not a useful indicator of clinically detectable low cardiac output in children after surgery for congenital heart defects. Pediatr Crit Care Med 2012; 13: 529-34. [Crossref]
30. Dave V, Brion LP, Campbell DE, Scheiner M, Raab C, Nafday SM. Splanchnic tissue oxygenation, but not brain tissue oxygenation, increases after feeds in stable preterm neonates tolerating full bolus orogastric feeding. J Perinatol 2009; 29: 213-8. [Crossref]
31. Petros AJ, Heys R, Tasker RC, Fortune PM, Roberts I, Kiely E. Near infrared spectroscopy can detect changes in splanchnic oxygen delivery in neonates during apnoeic episodes. Eur J Pediatr 1999; 158: 173-4. [Crossref]
32. Banerjee J, Leung T, Aladangady N. Effect of blood transfusion on intestinal blood flow and oxygenation in extremely preterm infants during first week of life. Transfusion 2016; 56: 808-15. [Crossref]
33. Kaufman J, Almodovar MC, Zuk J, Friesen RH. Correlation of abdominal site near-infrared spectroscopy with gastric tonometry in infants following surgery for congenital heart disease. Pediatr Crit Care Med 2008; 9: 62-8. [Crossref]
34. Hatipoglu S, Akbulut S, Hatipoglu F, Abdullayev R. Effect of laparoscopic abdominal surgery on splanchnic circulation: Historical developments. World J Gastroenterol 2014; 20: 18165-76. [Crossref]
35. Gueugniaud PY, Abisseror M, Moussa M, Godard J, Foussat C, Petit P, et al. The hemodynamic effects of pneumoperitoneum during laparoscopic surgery in healthy infants: assessment by continuous esophageal aortic blood flow echo-Doppler. Anesth Analg 1998; 86: 290-3. [Crossref]
36. Eleftheriadis E, Kotzampassi K, Botsios D, Tzartinoglou E, Farmakis H, Dadoukis J. Splanchnic ischemia during laparoscopic cholecystectomy. Surg Endosc 1996; 10: 324-6. [Crossref]