

CO₂ insufflation consequences on respiratory and cardiovascular parameters in laparoscopic cholecystectomy patients: a prospective observational cohort

Received: 16/07/2025

Accepted: 20/08/2025

Shereen Mahmood Noori¹Haidar Nasser Mohammed²

ABSTRACT

Background and objective: Pneumoperitoneum is essential to provide a good surgical view during laparoscopy. Carbon dioxide is the most commonly used gas for pneumoperitoneum, and it induces multiple changes in the mechanics of respiration and cardiovascular function, particularly under general anesthesia. This study aimed to identify the key physiological parameters most likely to deviate from normal during laparoscopic cholecystectomy. Respiratory variables assessed included end-tidal CO₂ (EtCO₂) and peak airway pressure, while cardiovascular parameters encompassed mean blood pressure (MBP), pulse rate, body temperature, and oxygen saturation.

Methods: This prospective observational cohort study evaluated physiological changes in patients classified as American Society of Anesthesiologists (ASA) grade I/II undergoing elective laparoscopic cholecystectomy at Rizgary Teaching Hospital, Iraq, over four months. A sample of 186 patients, aged 18–75 years, meeting inclusion and exclusion criteria were enrolled. Median-split methodology was used to divide patients into two groups based on the median duration of surgery (≤ 27 minutes vs. > 27 minutes).

Results: CO₂ insufflation during laparoscopic surgery led to significant physiological changes. Mean blood pressure decreased from 95.7 ± 13.5 mmHg to 87.4 ± 14.3 mmHg ($p < 0.001$), and heart rate dropped from 95.6 ± 16.2 bpm to 89.3 ± 13.8 bpm ($p < 0.001$). Peak inspiratory pressure (PIP) increased markedly from 15.9 ± 3.7 cmH₂O to 21.2 ± 3.8 cmH₂O ($p < 0.001$), while end-tidal CO₂ declined from 33.7 ± 4.1 mmHg to 31.2 ± 4.9 mmHg ($p < 0.001$). Following CO₂ exsufflation, PIP decreased to 18.7 ± 8.0 cmH₂O, and end-tidal CO₂ increased to 37.5 ± 6.1 mmHg (both $p < 0.001$), reflecting improved respiratory compliance. Intraoperative comparisons revealed higher end-tidal CO₂ levels in procedures lasting more than 27 minutes compared with shorter ones: 32.6 ± 4.8 mmHg vs. 29.8 ± 4.6 mmHg after insufflation, 37.6 ± 5.7 mmHg vs. 33.0 ± 5.4 mmHg after artery clamping, and 39.2 ± 6.0 mmHg vs. 34.5 ± 5.8 mmHg after gallbladder dissection (all $p < 0.001$). These findings emphasize the need for vigilant monitoring and ventilatory adjustments to prevent potential complications associated with CO₂ insufflation.

Conclusion: CO₂ insufflation caused notable fluctuation in most monitored parameters (end-tidal CO₂, peak inspiratory pressure, heart rate, body temperature). Minimizing insufflation time is a key factor in reducing pneumoperitoneum effects.

Keywords: Laparoscopic cholecystectomy, Pneumoperitoneum, Carbon dioxide (CO₂) insufflation, End-tidal CO₂ (EtCO₂), Peak inspiratory pressure (PIP)

¹ Department of Anesthesia Sciences, Erbil Medical Technical Institute, Erbil, Kurdistan Region, Iraq.

² Department of Anesthesia Sciences, Anesthesia and Intensive Care Medicine, College of Health Sciences, University of Duhok, Kurdistan Region, Iraq.

Correspondence: Shereen Mahmood Noori, razaw.sabrm@gmail.com

Copyright © The Author(s) 2026. Open Access. This work is licensed under a [Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License](https://creativecommons.org/licenses/by-nc-sa/4.0/).

INTRODUCTION

Laparoscopic cholecystectomy offers numerous benefits compared with conventional surgery, such as diminished postoperative pain, reduced hospital stays, aesthetic appeal, and a decrease in postoperative ileus, in addition to significant medical and economic advantages (1, 2).

A pneumoperitoneum is essential to laparoscopic cholecystectomy, and carbon dioxide is used due to its high solubility, ease of diffusion through biological membranes, and non-flammability. This gas is insufflated into the abdominal cavity to ensure operative safety and space. Insufflation can significantly affect the respiratory and cardiovascular systems, especially under general anesthesia, so it must be carefully calculated based on the operation and the patient (3, 4).

The insufflation of CO₂ causes upward displacement of the diaphragm, reducing thoracic cavity capacity, decreasing lung expansion, and creating the potential for respiratory compromise. It can diminish lung volumes, causing atelectasis, especially in dependent lung areas, and reduce functional residual capacity (5-7).

Increased intra-abdominal pressure compresses the inferior vena cava, reducing cardiac output and venous return. It can also raise peak airway pressures, hinder ventilation, and increase barotrauma risk. Shunting, hypoxia, hypercapnia, and respiratory acidosis result from ventilation-perfusion mismatching. These effects may cause respiratory and cardiovascular instability, especially in people with cardiopulmonary problems (8).

The duration of surgery may also play a role in the severity of cardiopulmonary and respiratory changes, with prolonged exposure possibly linked to increased intra-abdominal pressure and increased systemic absorption of CO₂, leading to

hypercarbia and further elevating end-tidal CO₂ (EtCO₂) levels (9, 10).

This study sought to identify the characteristics most likely to deviate from normal physiology during laparoscopic cholecystectomy. End-tidal CO₂ (EtCO₂) and peak airway pressure were the respiratory variables assessed; mean blood pressure, pulse rate, body temperature, and oxygen saturation were the cardiovascular variables.

METHODS

Study Design

This study was a prospective observational cohort with repeated intraoperative measurements, using a convenience sample collection method at a single center, with 186 patients scheduled for elective laparoscopic cholecystectomy.

Ethical Approval

Ethical clearance was obtained from the Research Ethics Committee of the Ministry of Health–Duhok Directorate General of Health and the University of Duhok, reference number 30102024-9-18, dated 30 October 2024. Written informed consent was obtained from each patient prior to surgery after detailed explanation of the study's aim and scope.

Study Setting

The study was carried out at Rizgary Teaching Hospital, Erbil, Iraq, over a four-month period from 31 October 2024 to 28 February 2025.

Inclusion Criteria

The study included adult patients of either gender, aged between 18 and 75 years, classified as ASA grade I or II, and scheduled for elective (non-urgent) laparoscopic cholecystectomy. Only patients who provided written informed consent were enrolled.

Exclusion Criteria

Patients were excluded if they had chronic respiratory conditions (particularly COPD), chronic cardiovascular disease such as heart failure or arrhythmia, or a history of anesthetic or surgical complications. During the study, two cases were converted to open cholecystectomy due to surgical complications; these were excluded entirely from the analysis because intraoperative monitoring data were incomplete and not comparable to laparoscopic procedures, giving a final sample size of $n=186$. Intention-to-treat analysis was not applied, as the study specifically focused on physiological changes associated with laparoscopic CO₂ insufflation; no cases were missed due to complications other than the monitored variables.

Study Variables

The main variables recorded included two respiratory variables (end-tidal CO₂ [EtCO₂] and peak inspiratory pressure [PIP]) and cardiovascular variables (pulse rate, mean arterial pressure, oxygen saturation [SpO₂], and body temperature). These variables were measured at six operation events: E1, before intubation; E2, immediately after intubation; E3, after CO₂ insufflation; E4, after clamping the artery; E5, after dissecting the gallbladder; and E6, after CO₂ exsufflation. Demographic data (age, gender, BMI, etc.) and intraoperative complications were also collected preoperatively for comprehensive analysis.

Anesthesia Protocols

Clinical assessments and measurements were made using standard hospital anesthesia equipment and protocols: capnography, ventilator monitors, pulse oximetry, non-invasive blood pressure, and thermometers (mercury and electrical probe) were used during anesthesia. All patients underwent a standardized general anesthesia protocol,

beginning with IV access and fluid administration, followed by pre-medications (e.g., metoclopramide, metronidazole, ceftriaxone) and ASA monitoring (blood pressure, SpO₂, ECG). Patients were pre-oxygenated with 100% oxygen for 3–5 minutes before anesthesia induction using propofol, fentanyl, and atracurium, followed by endotracheal intubation confirmed by capnography and auscultation. Ventilation was volume-controlled, with adjusted tidal volume, respiratory rate, and I:E ratio (1:2). Anesthesia was maintained with sevoflurane (67 patients) or isoflurane (117 patients), supplemented with atracurium, remifentanyl, or fentanyl as deemed necessary by the attending anesthesiologist. Additional medications (dexamethasone, aminophylline, hydrocortisone, etc.) were given based on patient condition.

Surgical Protocols

Laparoscopic cholecystectomy was performed using a standard three- or four-port technique, creating a pneumoperitoneum (8–15 mmHg CO₂). Patients were placed in reverse Trendelenburg position to optimize surgical access. The gallbladder was dissected, with clipping and cutting of the cystic duct and artery, followed by retrograde removal and hemostasis. Bile or stone spills were irrigated, and a drain was placed if needed. Residual CO₂ was vented, ports were closed, and the abdomen was checked. Anesthesia was reversed with neostigmine and atropine, and patients were extubated upon meeting criteria.

Monitoring of Study Parameters

At E1 (before intubation), pulse rate, mean arterial pressure, and SpO₂ were recorded once patients were connected to the anesthetic machine monitor. Peak airway pressure and EtCO₂ were recorded during pre-oxygenation when switching to mechanical ventilation, since patients were not yet

intubated; body temperature was taken orally with a mercury thermometer.

At E2 (immediately after intubation), once intubation was confirmed and the patient was on mechanical ventilation, variables were collected through the anesthetic machine monitor, including peak airway pressure; EtCO₂ was measured by capnograph, and body temperature through an electrical probe.

E3 (after CO₂ insufflation) followed achievement of insufflation and regulation of CO₂ flow rate and pressure; E4 (after clamping the artery) followed identification and clamping of the artery; and E5 (after dissecting the gallbladder) followed separation of the gallbladder from the liver bed — variables at these three events were recorded using the same methods and equipment as at E2.

E6 (after CO₂ exsufflation) was the final event in the examination period; once the specimen was removed, all ports were vented to eliminate residual intra-abdominal CO₂, and the final recording of variables occurred using the same methods and equipment as at E2 and subsequent events.

Statistical Analysis

Data were analyzed using SPSS version 25. Mean±SD was used for continuous variables, and the Shapiro-Wilk test was used to check normality. To categorize patients for comparative analysis,

median-split methodology was employed: based on the median operative duration of 27 minutes, patients were divided into two groups (≤27 minutes vs. >27 minutes), allowing a balanced distribution across groups and facilitating evaluation of surgical duration as a potential factor influencing perioperative outcomes. Paired-sample t-tests were used to compare means between two events. A p-value <0.05 was considered statistically significant.

RESULTS

Table 1 summarizes the monitored parameters before and after CO₂ insufflation at different intraoperative stages. Immediately after intubation, mean blood pressure was 91.7±17.1 mmHg and heart rate was 95.5±16.6 bpm; after insufflation, these decreased to 87.4±14.3 mmHg (p=0.001) and 89.3±13.8 bpm (p <0.001), respectively. Peak inspiratory pressure increased significantly, from 16.6±3.6 to 21.2±3.8 cmH₂O (p <0.001), while end-tidal CO₂ declined from 33.7±4.1 to 31.2±4.9 mmHg (p <0.001). Following exsufflation, peak inspiratory pressure decreased to 18.7±8.0 cmH₂O (p <0.001), end-tidal CO₂ increased to 37.5±6.1 mmHg (p <0.001), and heart rate changed to 89.3±13.8 bpm (p <0.001). Hemodynamic fluctuations were also recorded at key operative steps, including intubation, artery clamping, and gallbladder dissection.

Table 1. Comparison of monitored parameters before and after CO₂ insufflation at different intraoperative stages

Parameter	Stage	After CO ₂ Insufflation	p*
MBP, mmHg	95.7±13.5	87.4±14.3	<0.001
HR, bpm	95.6±16.2	89.3±13.8	<0.001
SpO ₂ , %	99.6±0.7	99.7±0.7	0.570
Temp, °C	36.7±0.4	36.6±0.4	<0.001
PIP, cmH ₂ O	15.9±3.7	21.2±3.8	<0.001
EtCO ₂ , mmHg	32.1±4.2	31.2±4.9	0.008
<i>Above: before intubation vs. after CO₂ insufflation.</i>			
Parameter	Immed. after intubation	After CO ₂ Insufflation	p*
MBP, mmHg	91.7±17.1	87.4±14.3	0.001
HR, bpm	95.5±16.6	89.3±13.8	<0.001
SpO ₂ , %	99.7±0.7	99.7±0.7	0.740
Temp, °C	36.6±0.4	36.6±0.4	0.03
PIP, cmH ₂ O	16.6±3.6	21.2±3.8	<0.001
EtCO ₂ , mmHg	33.7±4.1	31.2±4.9	<0.001
Parameter	After clamping artery	After CO ₂ Insufflation	p*
MBP, mmHg	91.1±15.9	87.4±14.3	0.01
HR, bpm	86.4±14.5	89.3±13.8	0.012
SpO ₂ , %	99.5±0.8	99.7±0.7	<0.001
Temp, °C	36.5±0.4	36.6±0.4	<0.001
PIP, cmH ₂ O	21.8±3.3	21.2±3.8	0.001
EtCO ₂ , mmHg	35.2±5.9	31.2±4.9	<0.001
Parameter	After dissecting GB	After CO ₂ Insufflation	p*
MBP, mmHg	89.7±14.9	87.4±14.3	0.07
HR, bpm	86.9±14.8	89.3±13.8	0.067
SpO ₂ , %	99.5±0.9	99.7±0.7	0.001
Temp, °C	36.4±0.4	36.6±0.4	<0.001
PIP, cmH ₂ O	21.4±3.4	21.2±3.8	0.410
EtCO ₂ , mmHg	36.8±6.3	31.2±4.9	<0.001
Parameter	After CO ₂ exsufflation	After CO ₂ Insufflation	p*
MBP, mmHg	88±15.6	87.4±14.3	0.668
HR, bpm	84.8±14.6	89.3±13.8	<0.001
SpO ₂ , %	99.5±0.9	99.7±0.7	0.001
Temp, °C	36.3±1	36.6±0.4	<0.001
PIP, cmH ₂ O	18.7±8	21.2±3.8	<0.001
EtCO ₂ , mmHg	37.5±6.1	31.2±4.9	<0.001

*Calculated by paired-sample t-test. Note: the Abstract and Results narrative describe the change in EtCO₂ as “from 33.7±4.1 to 31.2±4.9 mmHg,” matching the “immediately after intubation” comparison row above, while the accompanying PIP, MBP, and HR starting values quoted in the same sentence (15.9, 95.7, 95.6) come from the “before intubation” row instead (where EtCO₂ is 32.1±4.2, not 33.7). We have reproduced both rows as supplied; we recommend confirming which baseline (before intubation or immediately after intubation) the narrative summary is intended to describe, so that a single consistent comparison can be quoted throughout.

Table 2 compares monitored parameters between two groups stratified by duration from intubation to gallbladder dissection (≤ 27 minutes vs. > 27 minutes). Across all four time points, there were no statistically significant differences in mean blood pressure, heart rate, oxygen saturation, or body temperature (all $p > 0.05$). However, peak

inspiratory pressure was significantly higher immediately after intubation in the ≤ 27 -minute group ($p < 0.05$). In contrast, end-tidal CO_2 was consistently higher in the > 27 -minute group after insufflation, artery clamping, and gallbladder dissection (all $p < 0.001$).

Table 2. Comparison of monitored parameters by surgical duration (≤ 27 min vs. > 27 min, intubation to GB dissection)

Parameter	≤ 27 min	> 27 min	p*
MBP (immed. post-intub.)	91.88 $\pm$ 14.84	91.71 $\pm$ 19.24	0.945
HR (immed. post-intub.)	96.44 $\pm$ 16.90	94.59 $\pm$ 16.35	0.450
SpO ₂ (immed. post-intub.)	99.71 $\pm$ 0.67	99.66 $\pm$ 0.75	0.634
Temp (immed. post-intub.)	36.61 $\pm$ 0.36	36.59 $\pm$ 0.38	0.678
PIP (immed. post-intub.)	16.71 $\pm$ 3.46	16.57 $\pm$ 3.82	0.017
EtCO ₂ (immed. post-intub.)	33.05 $\pm$ 3.51	34.47 $\pm$ 4.48	0.796
MBP (post-insufflation)	85.66 $\pm$ 14.55	89.43 $\pm$ 13.77	0.072
HR (post-insufflation)	88.96 $\pm$ 14.31	89.17 $\pm$ 13.72	0.920
SpO ₂ (post-insufflation)	99.60 $\pm$ 0.76	99.73 $\pm$ 0.54	0.173
Temp (post-insufflation)	36.56 $\pm$ 0.35	35.57 $\pm$ 0.40	0.827
PIP (post-insufflation)	21.34 $\pm$ 3.56	21.07 $\pm$ 4.03	0.629
EtCO ₂ (post-insufflation)	29.80 $\pm$ 4.59	32.62 $\pm$ 4.85	<0.001
MBP (post-clamp)	90.29 $\pm$ 16.05	91.96 $\pm$ 15.71	0.478
HR (post-clamp)	86.28 $\pm$ 13.89	86.53 $\pm$ 15.23	0.908
SpO ₂ (post-clamp)	99.52 $\pm$ 0.82	99.46 $\pm$ 0.82	0.620
Temp (post-clamp)	36.46 $\pm$ 0.39	36.47 $\pm$ 0.40	0.821
PIP (post-clamp)	21.81 $\pm$ 3.33	21.72 $\pm$ 3.28	0.856
EtCO ₂ (post-clamp)	33.00 $\pm$ 5.38	37.60 $\pm$ 5.73	<0.001
MBP (post-dissection)	88.26 $\pm$ 16.09	91.31 $\pm$ 13.57	0.166
HR (post-dissection)	85.93 $\pm$ 14.41	87.94 $\pm$ 15.21	0.356
SpO ₂ (post-dissection)	99.45 $\pm$ 0.98	99.48 $\pm$ 0.74	0.809
Temp (post-dissection)	36.41 $\pm$ 0.43	36.42 $\pm$ 0.41	0.867
PIP (post-dissection)	21.22 $\pm$ 3.07	21.48 $\pm$ 3.81	0.620
EtCO ₂ (post-dissection)	34.46 $\pm$ 5.77	39.22 $\pm$ 5.98	<0.001

*Calculated by independent t-test.

DISCUSSION

Laparoscopic surgery for gallbladder problems is unparalleled. A pneumoperitoneum is necessary to perform this procedure, serving as the initial step for every laparoscopic approach, and has intricate effects on various body systems.

In this study, the monitored parameters showed significant changes after CO₂ insufflation. Mean arterial blood pressure and heart rate significantly decreased, probably due to CO₂ pressure. As stated in previous research, low-pressure CO₂ pneumoperitoneum is optimal for reducing hemodynamic complications (11-13). These findings are not in line with those published by Venkatraman et al., who found significant increases at 60 minutes for mean arterial pressure and at 10 minutes for heart rate during CO₂ insufflation, especially at higher flow rates (14).

This study shows marked changes in body temperature after CO₂ insufflation; prior studies have explained that this may result from cold, dry CO₂ insufflation, and that using humidified insufflation gas during laparoscopy may mitigate the risk of intraoperative hypothermia (15, 16).

This study also found an interesting result: peak inspiratory pressure (PIP) increased significantly with CO₂ insufflation at all study events, which could be due to ventilation strategies and CO₂ insufflation separately or simultaneously. This result is in line with studies by Chandra¹⁷ and Kothari et al. (18), who found that pressure-controlled ventilation and pressure-controlled volume-guaranteed modes are more effective than volume-controlled ventilation, offering sufficient oxygenation at reduced peak inspiratory pressures. They noted significantly higher PIP with volume-controlled ventilation, especially at various time intervals following intubation. This result is also in harmony with Aksakal's study, which established

that elevated intra-abdominal pressure during pneumoperitoneum influences respiratory function, diminishes dynamic compliance, and elevates PIP (19).

This study found that end-tidal CO₂ (EtCO₂) changed significantly after CO₂ insufflation, with elevated values across all monitored events, likely due to insufficient ventilation, CO₂ absorption, or both, necessitating careful monitoring and management, especially for patients with respiratory and cardiovascular insufficiency. This has been noted in previous studies, such as those by Makwana et al. (20) and Uma Maheswari (21), who found that EtCO₂ increased significantly above the pre-insufflation value yet remained within the physiological range. Additionally, oxygen saturation did not significantly change during abdominal insufflation. A prior study by Bachh et al. noted that CO₂ insufflation induces metabolic alterations in pH, PCO₂, EtCO₂, and HCO₃ (22). However, with appropriate monitoring and management, laparoscopic procedures can be conducted safely.

In this study, the period between immediately after intubation and gallbladder dissection had a significant impact on respiratory and cardiovascular parameters. At four events (E2, E3, E4, E5), the time analysis was limited to ≤27 minutes vs. >27 minutes, based on median-split methodology.

There was no significant difference in mean arterial pressure, heart rate, oxygen saturation, or body temperature between the two time groups. In contrast, peak inspiratory pressure was influential, with a slightly higher value in the ≤27-minute group.

In patients whose group time was >27 minutes, the EtCO₂ value was significantly higher, with a continuous rise across four events, which could be due to absorption of CO₂ or respiratory distress. Patients with pre-existing respiratory and

cardiovascular conditions therefore warrant careful monitoring.

No published research appears to provide specific comparisons of respiratory and cardiovascular parameter changes between long and short durations of pneumoperitoneum during laparoscopic cholecystectomy, although research pointing to the impact of surgery duration on complication incidence has been conducted by Patel et al. (23), who found that atelectasis may occur even during brief surgical procedures, including laparoscopic cholecystectomy, and that the duration of pneumoperitoneum and ASA status may influence the occurrence of atelectasis. Prior studies by Maharjan et al. (24) and Wang et al. (10) reported that the duration of the operation notably elevates the risk of complications and extends postoperative hospital stays after elective laparoscopic cholecystectomy.

A limitation of this study was the variation in anesthesia maintenance agents, as both isoflurane and sevoflurane were used during the procedures. The potential influence of these agents on hemodynamic and respiratory parameters was not analyzed, so their differential effects on outcomes cannot be excluded. Future studies with standardized anesthesia protocols are warranted to better control for this variable.

CONCLUSION

This study highlighted that pneumoperitoneum induces significant cardiovascular and respiratory changes even in ASA grade I and II patients. CO₂ insufflation caused notable fluctuation in most monitored parameters (EtCO₂, PIP, heart rate, body temperature), necessitating careful monitoring and ventilation management. Minimizing insufflation time is a key factor in reducing pneumoperitoneum effects.

COMPETING INTEREST

The authors declare that they have no competing interests.

REFERENCES

1. Ismail A, Latef A. Baseline heart rate as a predictor of post spinal hypotension in patients undergoing caesarean section. *Medico Legal Update*. 2023;23(1):1-6. <https://doi.org/10.37506/mlu.v23i1.3353>
2. Ali BA, Khidhir MN, Muhammed SH. Bowel movement changes after laparoscopic cholecystectomy. *Adv Med J*. 2022;7(2):45-51. <https://doi.org/10.56056/amj.2022.177>
3. Michenkova M, Taki S, Blosser MC, Hwang HJ, Kowatz T, Moss FJ, et al. Carbon dioxide transport across membranes. *Interface Focus*. 2021;11(2):20200090. <https://doi.org/10.1098/rsfs.2020.0090>
4. Yıldırım E, Turhan KSC, Güven A, Gökmen D, Özcelik M. Factors influencing abdominal compliance during CO₂ insufflation in patients undergoing laparoscopic abdominal surgery. *Reports (Basel)*. 2024;7(3):52. <https://doi.org/10.3390/reports7030052>
5. Tonetti T, Cavalli I, Ranieri VM, Mascia L. Respiratory consequences of intra-abdominal hypertension. *Minerva Anesthesiol*. 2020;86(8):877-83. <https://doi.org/10.23736/S0375-9393.20.14325-6>
6. Umano GR, Delehay G, Noviello C, Papparella A. The “dark side” of pneumoperitoneum and laparoscopy. *Minim Invasive Surg*. 2021;2021:5564745. <https://doi.org/10.1155/2021/5564745>
7. Yu J, Park JY, Kim DH, Kim S, Hwang JH, Seo H, et al. Incidence and risk factors of pulmonary

- complications after robot-assisted laparoscopic prostatectomy: a retrospective observational analysis of 2208 patients at a large single center. *J Clin Med.* 2019;8(10):1509. <https://doi.org/10.3390/jcm8101509>
8. Bharadwaj A, Gupta S, Gupta A, Singhal S, Matgur V, Vikrant G. Internal carotid artery blood flow response to anaesthesia, pneumoperitoneum and head-up tilt during laparoscopic cholecystectomy: a clinical study. *Sri Lankan J Anaesthesiol.* 2023;31(2):9050. <https://doi.org/10.4038/slja.v31i2.9050>
 9. Banerjee A, Saini S, Lal J. Evaluation of hemodynamic changes during laparoscopic cholecystectomy by transthoracic echocardiography. *J Anaesthesiol Clin Pharmacol.* 2021;37(3):436-42. https://doi.org/10.4103/joacp.JOACP_173_19
 10. Wang DE, Bakshi C, Chung P. Does operative time affect complication rate in laparoscopic cholecystectomy? *Am Surg.* 2023;89(11):4479-84. <https://doi.org/10.1177/00031348221117032>
 11. Al-Dabbagh AA, Ismaeel NH. Randomized, prospective comparison of post-operative pain in low- versus high-pressure pneumoperitoneum in laparoscopic cholecystectomy. *Zanco J Med Sci.* 2010;14(2):35-40.
 12. Abass M, Singh A, Sharma M, Chaudhary S. A prospective randomized controlled study comparing low-pressure versus standard-pressure CO₂ pneumoperitoneum during laparoscopic cholecystectomy. *Int J Surg Sci.* 2022;6(2):40-4. <https://doi.org/10.33545/surgery.2022.v6.i2a.884>
 13. Mohammadzade A, Esmaili F. Comparing hemodynamic symptoms and the level of abdominal pain in high versus low pressure carbon dioxide in patients undergoing laparoscopic cholecystectomy. *Indian J Surg.* 2018;80(1):30-5. <https://doi.org/10.1007/s12262-016-1552-4>
 14. Venkatraman R, Chitrabalam TG, Preethi A. Comparison of different carbon dioxide insufflation rates on hemodynamic changes in laparoscopic surgeries: a randomized controlled trial. *Cureus.* 2023;15(1):e34071. <https://doi.org/10.7759/cureus.34071>
 15. Hughes B, Saxena AK. Monitoring of body temperature during laparoscopic surgery following peritoneal insufflation with warm, humidified carbon dioxide using infrared camera. *J Pediatr Endosc Surg.* 2023;5(3):119-21. <https://doi.org/10.1007/s42804-023-00189-6>
 16. Wittenborn J, Clausen A, Zeppernick F, Stickeler E, Meinhold-Heerlein I. Prevention of intraoperative hypothermia in laparoscopy by the use of body temperature and humidified CO₂: a pilot study. *Geburtshilfe Frauenheilkd.* 2019;79(9):969-75. <https://doi.org/10.1055/a-0903-2638>
 17. Chandra A. Evaluation of pressure-controlled ventilation versus volume-controlled ventilation with PEEP on respiratory mechanics and hemodynamics in patients undergoing laparoscopic cholecystectomy. *Ain Shams J Anesthesiol.* 2024;16(1):25.
 18. Kothari A, Baskaran D. Pressure-controlled volume guaranteed mode improves respiratory dynamics during laparoscopic cholecystectomy: a comparison with conventional modes.

Anesth Essays Res. 2018;12(1):206-12.
https://doi.org/10.4103/aer.AER_96_17

19. Aksakal N. The effects of pneumoperitoneum pressure on blood gases, respiratory and venous systems during laparoscopic cholecystectomy: a prospective randomized trial. *Laparoendosc Surg Sci*. 2017;24(3):115-21.
<https://doi.org/10.14744/less.2017.25744>
20. Makwana DS, Patil PN, Kerketta CS, Ghogari D, Patel B. A comparison of EtCO₂ and PaCO₂ in laparoscopic surgery during general anesthesia. *GCSMC J Med Sci*. 2014;3(1):1-9.
21. Uma Maheswari P. A prospective randomized study to assess the effect of pneumoperitoneum on arterial and end tidal carbon dioxide pressure gradient during laparoscopic surgery in adults [dissertation]. Chennai: Madras Medical College; 2016.
22. Bachh MD, Farooq N, Gillani YM. Metabolic effects of carbon dioxide insufflation during laparoscopic surgery: changes in pH, arterial partial pressure of carbon dioxide (PaCO₂) and end tidal carbon dioxide (ETCO₂). *Natl J Med Res*. 2022;12(1):23-7.
<https://doi.org/10.55489/njmr.12012022893>
23. Patel SK, Bansal S, Puri A, Taneja R, Sood N. Correlation of perioperative atelectasis with duration of anesthesia, pneumoperitoneum, and length of surgery in patients undergoing laparoscopic cholecystectomy. *Cureus*. 2022;14(4):e24261.
<https://doi.org/10.7759/cureus.24261>
24. Maharjan S, Paudel P, Pradhan GBN, Shrestha S. Does the operative time have an influence on postoperative outcome in elective laparoscopic cholecystectomy? *HPB (Oxford)*. 2022;24(Suppl 2):S511.
<https://doi.org/10.1016/j.hpb.2022.05.1100>