Mohammed, Babcock Univ. Med. J.2026 9(1):277-285
https://doi.org/10.38029/babcockuniv.med.j..v9i1.1383
eISSN: 2756-4657

RESEARCH ARTICLE OPEN ACCESS

Systemic physiological changes induced by CO_2 pneumoperitoneum in laparoscopic cholecystectomy

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Submitted: 9th November 2026
Accepted: 13th February 2026
Published: 31st March 2026
ID: Orcid ID

Abstract

Objective: Carbon dioxide pneumoperitoneum is crucial for laparoscopic surgery but has adverse cardiorespiratory effects due to raised intra-abdominal pressure, diaphragmatic displacement, and systemic CO_2 resorption. We aimed to investigate intraoperative variations in respiratory and cardiovascular parameters induced by CO_2 pneumoperitoneum and to determine the factors contributing to this effect, including BMI and anaesthetic techniques.

Methods: A total of 150 adult ASA I–II patients undergoing laparoscopic cholecystectomy were monitored prospectively in this clinical study. Respiratory (EtCO2, PIP) and hemodynamic (MAP, HR, SpO2, temperature) parameters were measured at six time points during anaesthesia. Repeated-measures ANOVA and subgroup comparisons were performed in statistical analysis.

Results: $EtCO_2$ and PIP increased significantly after CO_2 insufflation ($p < 0.001$). Both MAP and HR initially decreased transiently and then took a stabilised course. Respiratory variations were higher in obese patients. The longer the pneumoperitoneum time, the higher the $EtCO_2$ concentration.

Conclusions: CO_2 pneumoperitoneum induces a predictable but clinically important depressor effect that must be closely followed and managed accordingly, including the need for respiratory strategies to enable the control of its effects, particularly in high-risk patients.

Keywords: Pneumoperitoneum, $EtCO_2$, Peak airway pressure, Haemodynamics

Plain English Summary

This study examined how carbon dioxide used during laparoscopic surgery affects breathing and heart function. In 150 patients, the researchers found that airway pressure and carbon dioxide levels increased during surgery, while blood pressure and heart rate changed temporarily. These effects were more noticeable in obese patients and during longer procedures. The findings highlight the importance of close monitoring and proper ventilation to maintain patient safety.

Introduction

The gold standard of treatment for symptomatic gallbladder disease is laparoscopic cholecystectomy. Compared with open surgery, the laparoscopic approach provides patients with a reduced amount of postoperative pain, shorter hospital stay and recovery time, and better cosmetic results. The efficacy of such minimally invasive procedure involves producing an inflated abdominal cavity, pneumoperitoneum usually achieved with carbon dioxide (CO_2), providing a clear view and access for the operation. Yet, CO_2 insufflation is associated with demonstrable physiological changes in both the respiratory and circulatory systems (1, 2).

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Because of its high solubility, rapid pulmonary removal and non-flammability, carbon dioxide is used for pneumoperitoneum. However, as the IAP also mechanically raises the diaphragm and affects thoraco-abdominal compliance, lung volumes are reduced, leading to decreased FRC and increased airway resistance. These mechanical effects may lead to high-peak inspiratory pressure and ventilation–perfusion mismatch, particularly when general anaesthesia is administered, and compensatory respiratory mechanisms are depressed (3, 4).

Systemic effects on metabolism and ventilation

Systemic absorption of CO_2, in addition to mechanical effects influences both metabolic process and ventilatory activity. If ventilation is not adjusted properly, elevated arterial CO_2 can raise end-tidal CO_2 ($EtCO_2$) and the patient may be predisposed to hypercapnia. It is recommended to monitor intraoperatively vigilantly during such modifications, which maintain the sufficient gas exchange and acid–base balance. These effects may be exaggerated in obese patients or those with limited respiratory reserve (5, 6).

Pneumoperitoneum also induces cardiovascular responses. Increased intra-abdominal pressure (IAP) can temporarily decrease venous return and cardiac output by compressing the major abdominal vessels, whereas autonomic reflexes might affect the heart rate and arterial pressure. While such changes are usually well-tolerated in healthy individuals, they could be clinically significant during longer procedures or in subjects with poor cardiovascular reserve (7, 8).

General anaesthetics also modify these physiologic responses. Controlled ventilation facilitates CO_2 accumulation correction, but anaesthetics may also have intrinsic effects on hemodynamic stability. Thus, monitoring of the ventilatory parameters, such as $EtCO_2$ and airway pressures, and hemodynamic variables like blood pressure and heart rate is important for maintenance of perioperative patient safety (4, 9).

Despite widespread clinical application of laparoscopic cholecystectomy, it is unknown how specific patient and operative factors determine the physiologic response to pneumoperitoneum. Furthermore, data are scarce on BMI-subgroup respiratory consequences and pneumoperitoneum duration-CO_2 retention correlation. Filling these gaps is important to enhance strategies for anaesthetic and perioperative management.

The goal of this study was to assess the cardiopulmonary responses associated with CO_2 pneumoperitoneum for laparoscopic cholecystectomy, and to examine whether these responses are modulated by patient BMI and duration of pneumoperitoneum. Our assumption was that the respiratory and hemodynamic effects of CO_2 insufflation would be influenced by these circumstances (3, 10).

Materials and Methods

Study Design and Setting

This was a prospective observational study done at Rezgary Teaching Hospital in Erbil, Iraq. It is the aim of this study to assess the perioperative respiratory and cardiovascular alterations related to CO_2 pneumoperitoneum in elective laparoscopic cholecystectomy. It resulted in a homogenization of intraoperative monitoring with no redundancy, in relation to basic physiological principles stated in the Introduction.

Study Population

Only adult patients were eligible and all consecutive adult patients scheduled for elective laparoscopic cholecystectomy were included to reduce selection bias.

Sample size determination

This study included a consecutive sample of 150 eligible patients during the study period. No formal a priori power calculation was performed, as the sample size was determined by the number of eligible patients presenting within the predefined study timeframe.

Version of the narrative Inclusion and Exclusion Criteria

Enrolment was open to adults aged 18–65 with American Society of Anaesthesiologists (ASA) physical status I or II and scheduled for elective posterior laparoscopic cholecystectomy able to give informed consent. Patients with severe cardiopulmonary disease, morbid obesity (body mass index ≥ 40 kg/m^2), pregnancy and emergency surgery were excluded. Further exclusion criteria were a priori knowledge of a difficult airway, and patients requiring conversion to open cholecystectomy were excluded from the final analysis

Preoperative Assessment

All patients underwent an identical preoperative work-up, including medical history, physical examination, baseline vital signs, and standard laboratory tests. Body mass index (BMI) was measured. Preoperative fasting was in accordance with standardised recommendations of anaesthesia.

Anaesthesia Protocol

Standard intraoperative monitoring was performed in all patients, which included ECG, non-invasive blood pressure monitoring, pulse oximetry and capnography. Intravenous access was secured, and preoxygenation with 100% oxygen for 3–5 minutes was performed prior to induction.

Anaesthesia was administered using a combination of IV propofol (2 mg/kg) and fentanyl (1–2 μg/kg), and injection of rocuronium (0.6 mg/kg) or a comparable non-depolarising neuromuscular blocking agent to aid intubation. The insertion of the endotracheal tube was confirmed by capnography and bilateral point chest in oscillation.

Patients were ventilated in volume-controlled ventilation mode with tidal volumes of 6–8 mL/kg of predicted body weight. Ventilation was controlled to achieve normocapnia with an inspiratory to expiratory ratio of 1:2 and positive end-expiratory pressure of 5 cmH_2O, whereas oxygen/air mixtures (FiO2=0.6) were delivered using inhalational agents throughout the experiment to maintain hemodynamic stability.

Surgical Protocol

Routine multiport laparoscopic cholecystectomy was carried out. The intra-abdominal pressure was maintained at 10–14 mmHg by carbon dioxide insufflation for creating pneumoperitoneum. Patients were placed in reverse Trendelenburg when necessary. The operative procedure was the same in all of the cases.

Anaesthesia, ventilation and surgical procedure

All patients received standardised general anaesthesia. After routine monitoring (non-invasive blood pressure, continuous ECG, pulse oximetry and capnography) and intravenous access, anaesthesia was induced with propofol (2 $mg\cdot kg^{-1}$), fentanyl (2 $\mu g\cdot kg^{-1}$) and rocuronium (0.6 $mg\cdot kg^{-1}$). Anaesthesia was maintained with sevoflurane at an end-tidal concentration of 1.0–1.5% (≈0.8–1.0 MAC). No nitrous oxide was used. Additional intraoperative analgesia consisted of intermittent intravenous fentanyl boluses as required.

Mechanical ventilation was delivered with a Dräger Fabius GS ventilator (or equivalent) in volume-controlled mode. Predicted body weight (PBW) was calculated using standard formulae: male PBW (kg) = 50.0 + 0.91 × (height in cm − 152.4); female PBW (kg) = 45.5 + 0.91 × (height in cm − 152.4). Initial tidal volume was targeted to 6–8 $mL\cdot kg^{-1}$ PBW (typical initial setting 7 $mL\cdot kg^{-1}$ PBW) with an initial respiratory rate of 12 $breaths\cdot min^{-1}$. Minute ventilation was adjusted by the attending anaesthetist to maintain end-tidal CO_2 ($EtCO_2$) between 35–45 mmHg. The adjustment protocol used was stepwise changes in respiratory rate of ±2 $breaths\cdot min^{-1}$; if $EtCO_2$ remained outside the target after a ±4 $breaths\cdot min^{-1}$ change, tidal volume was adjusted within the 6–8 $mL\cdot kg^{-1}$ PBW range. All ventilator settings and adjustments were recorded.

CO_2 pneumoperitoneum was established using an automated insufflator and maintained at 12 mmHg in all cases. Pneumoperitoneum duration (minutes) was recorded from insufflation start to the beginning of desufflation. Patient positioning was standardised to supine with a ~15° reverse-Trendelenburg tilt during gallbladder dissection unless the surgeon requested otherwise; any changes in tilt were recorded.

Intraoperative interventions were prospectively recorded and included vasopressor administration (any bolus/infusion of phenylephrine, ephedrine or norepinephrine), additional fluid boluses (>500 mL crystalloid), bronchodilator therapy, and conversion to open cholecystectomy (defined as any unplanned laparotomy). Cases converted to open were handled as specified in the Statistical Analysis section.

Data Collection

Demographic and clinical data were collected using a structured data collection form. Recorded variables included age, sex, body mass index (BMI), American Society of Anaesthesiologists (ASA) physical status classification, and relevant comorbidities. Intraoperative variables recorded were pneumoperitoneum pressure (mmHg), duration of pneumoperitoneum (minutes), ventilatory parameters (tidal volume, respiratory rate, peak inspiratory pressure), and hemodynamic parameters (mean arterial pressure and heart rate). End-tidal carbon dioxide ($EtCO_2$) was continuously monitored, and values were recorded at predefined time points.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were assessed for normality using visual inspection of histograms and Q–Q plots, supplemented by the Shapiro–Wilk test. Normally distributed variables are presented as mean ± standard deviation (SD), and non-normally distributed variables as median (interquartile range, IQR). Categorical variables are presented as frequencies and percentages.

Changes in physiological parameters ($EtCO_2$, peak inspiratory pressure [PIP], mean arterial pressure [MAP], and heart rate [HR]) across predefined intraoperative time points were analysed using repeated-measures analysis of variance (ANOVA). The assumption of sphericity was evaluated using Mauchly's test. When sphericity was violated, the Greenhouse–Geisser correction was applied. Effect sizes are reported as partial eta-squared (partial η^2). Where the overall ANOVA was significant, pairwise comparisons between time points were performed using Bonferroni-adjusted post-hoc tests.

The association between duration of pneumoperitoneum and peak $EtCO_2$ was evaluated using Pearson's correlation coefficient (r), with 95% confidence intervals (CI). If normality assumptions were not met, Spearman's rank correlation coefficient (ρ) was used.

Between-group comparisons were performed using independent-samples t-tests or Mann–Whitney U tests as appropriate. Bonferroni correction was applied for multiple subgroup comparisons.

Complete case analysis was performed. Of 150 enrolled patients, complete intraoperative measurements across all predefined time points were available for 150 (100%) for $EtCO_2$ and PIP, and 148 (98.7%) for MAP and HR. Missing MAP/HR values (n = 2) were due to transient monitor artefact and were not imputed.

A multivariable linear regression model was constructed to identify independent predictors of peak $EtCO_2$. Variables entered into the model were BMI (continuous, kg/m²), pneumoperitoneum duration (minutes), age (years), and baseline $EtCO_2$ (mmHg). Assumptions of linearity, homoscedasticity and absence of multicollinearity were verified. Regression coefficients (β), 95% confidence intervals (CI), and p-values are reported.

Body Mass Index (BMI) Classification

Body mass index (BMI) was calculated as weight (kg) divided by height squared (m²). Patients were categorised according to World Health Organisation (WHO) criteria as normal weight (<25.0 kg/m²), overweight (25.0–29.9 kg/m²), and obese (≥30.0 kg/m²).

Results

Participant Characteristics (Table 1)

One hundred fifty patients scheduled for laparoscopic cholecystectomy were included in the study. Of the 150 patients, 68 (45.3%) were normal weight, 52 (34.7%) were overweight, and 30 (20.0%) were obese according to WHO criteria. There were 62 (41.3%) males and 88 (58.7%) females, with a mean age of 42.6 ± 11.8 years in this study population. The mean BMI was 27·4 ± 4.6 kg/m². Patients were ASA I or II. No perioperative complications requiring exclusion were recorded.

Table 1: Demographic Characteristics

Variable	Value
Age (years), mean ± SD	44.8 ± 12.1
Female sex, n (%)	88 (58.7%)
BMI (kg/m²), mean ± SD	27.4 ± 4.6
BMI Category (WHO), n (%)	
– Normal (<25 kg/m²)	68 (45.3%)
– Overweight (25–29.9 kg/m²)	52 (34.7%)
– Obese (≥30 kg/m²)	30 (20.0%)
ASA I, n (%)	91 (60.7%)
ASA II, n (%)	59 (39.3%)
Pneumoperitoneum duration (min), median (IQR)	40 (32–52)
Pneumoperitoneum pressure (mmHg)	12 (fixed)

BMI = body mass index; ASA = American Society of Anaesthesiologists; IQR = interquartile range

Respiratory Parameters

End-Tidal Carbon Dioxide ($EtCO_2$) (Table 2)

Repeated-measures ANOVA demonstrated a significant effect of time on $EtCO_2$ levels (F (3.8, 562.4) = 92.6, $p < 0.001$, partial $\eta^2 = 0.38$; Greenhouse–Geisser correction applied due to violation of sphericity, Mauchly's p = 0.012). Mean $EtCO_2$ increased from 33.2 ± 4.1 mmHg at baseline to 41.0 ± 5.8 mmHg during dissection (mean difference 7.8 mmHg; 95% CI 6.9–8.7). Bonferroni-adjusted pairwise comparisons showed significant increases between baseline and post-insufflation ($p < 0.001$) and between baseline and dissection ($p < 0.001$), with levels returning toward baseline after desufflation (p = 0.08 compared with baseline).

Table 2: $EtCO_2$ Changes Across Surgical Stages

Stage	$EtCO_2$ (mmHg)
Baseline	33.2 ± 4.1
Post-intubation	34.5 ± 4.3
Post-insufflation	39.1 ± 5.0

Dissection	41.0 ± 5.8
Pre-exsufflation	40.2 ± 5.3
Recovery	36.0 ± 4.4

Repeated-measures ANOVA demonstrated a statistically significant increase in $EtCO_2$ during pneumoperitoneum ($p < 0.001$).

Peak Inspiratory Pressure (PIP)

A significant time effect was observed for PIP ($F (4.1, 610.3) = 74.2$, $p < 0.001$, partial $\eta^2 = 0.31$; Greenhouse–Geisser correction applied). Mean PIP increased from 15.8 ± 3.2 cmH_2O at baseline to 23.0 ± 4.3 cmH_2O during pneumoperitoneum. Bonferroni-adjusted comparisons confirmed significant differences between baseline and all pneumoperitoneum stages (all adjusted $p < 0.001$) (Table 3).

PIP had a rapid increase after insufflation, suggesting an elevation of airway resistance and a decrease in lung compliance. The maximum pressures were registered under dynamic surgical manipulation.

Table 3: PIP Changes

Stage	PIP (cmH_2O)
Baseline	15.8 ± 3.2
Post-intubation	17.4 ± 3.5
Post-insufflation	22.3 ± 4.1
Dissection	23.0 ± 4.3
Pre-exsufflation	21.6 ± 3.8
Recovery	18.1 ± 3.1

Cardiovascular Parameters

Mean Arterial Pressure (MAP)

MAP demonstrated a transient reduction immediately after insufflation, followed by gradual stabilisation during the remainder of surgery. Statistical analysis showed significant variation between stages ($p < 0.01$) (Table 4).

Table 4: MAP Changes

Stage	MAP (mmHg)
Baseline	96.4 ± 12.1
Post-intubation	94.8 ± 11.6
Post-insufflation	88.7 ± 13.0
Dissection	90.5 ± 11.2
Recovery	94.2 ± 10.4

Heart Rate (HR)

Heart rate followed the MAP changes, exhibiting a slight transient decrease following insufflation, and recovery during the post-insufflation period.

Oxygen Saturation and Temperature

Peripheral oxygen saturation (SpO_2) and core temperature remained within clinically acceptable ranges throughout the procedure, with no statistically significant variations across measured time points ($p > 0.05$) (Table 5). Body temperature did not change significantly during the procedure (<0.5°C), providing a minimum amount of thermal protection.

Table 5: Peripheral Oxygen Saturation Across Surgical Stages

Stage	SpO_2 (%) Mean ± SD
Baseline	98.6 ± 0.8
Post-intubation	98.4 ± 0.9
Post-insufflation	98.2 ± 1.0
Dissection	98.1 ± 1.1
Pre-exsufflation	98.3 ± 0.9
Recovery	98.7 ± 0.7

Influence of BMI (Table 6)

Peak $EtCO_2$ differed significantly across WHO BMI categories (one-way ANOVA $p < 0.001$). Obese patients demonstrated higher peak $EtCO_2$ values (43.8 ± 5.6 mmHg) compared with overweight (41.5 ± 5.2 mmHg) and normal-weight patients (38.9 ± 4.8 mmHg). Bonferroni-adjusted pairwise comparisons showed significant differences between obese and normal-weight groups (adjusted $p < 0.001$) and between overweight and normal-weight groups (adjusted $p = 0.012$), while the difference between obese and overweight groups was not statistically significant (adjusted $p = 0.08$). The subgroup analysis was pre-specified, and no additional exploratory subgroup comparisons were performed.

Table 6: BMI Subgroup Analysis

Variable	Normal (<25 kg/m²) (n = 68)	Overweight (25–29.9 kg/m²) (n = 52)	Obese (≥30 kg/m²) (n = 30)	p-value (ANOVA)
Peak $EtCO_2$ (mmHg)	38.9 ± 4.8	41.5 ± 5.2	43.8 ± 5.6	<0.001
Peak PIP (cmH_2O)	21.6 ± 3.1	23.4 ± 3.5	25.1 ± 3.8	<0.001
Lowest MAP (mmHg)	76.8 ± 8.9	74.2 ± 9.4	72.9 ± 10.1	0.18
Lowest HR (beats/min)	69.4 ± 9.7	67.2 ± 10.3	65.8 ± 11.1	0.24

Values presented as mean ± SD; ANOVA = one-way analysis of variance across BMI categories; Post-hoc Bonferroni comparisons showed significant differences between obese and normal-weight groups for peak $EtCO_2$ and PIP (adjusted $p < 0.01$)

Significant differences across BMI categories were observed for peak $EtCO_2$ and PIP, with progressively higher values in overweight and obese patients. No statistically significant differences were observed in the lowest MAP or HR across BMI categories.

Duration of Pneumoperitoneum

Duration of pneumoperitoneum was moderately correlated with peak $EtCO_2$ (Pearson $r = 0.42$, 95% CI 0.27–0.55, $p < 0.001$), indicating that longer insufflation times were associated with greater CO_2 retention (Figure 1).

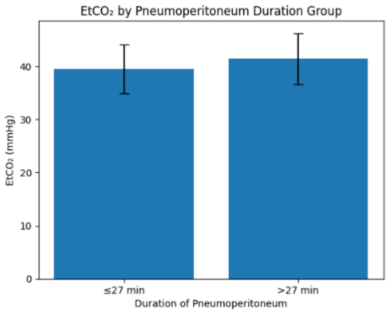

Figure 1: Mean $EtCO_2$ Levels According to Pneumoperitoneum Duration

Ventilation and pneumoperitoneum summary

Median predicted body weight (PBW) was 68 kg (IQR 62–74 kg). Mean delivered tidal volume was 476 ± 38 mL (equivalent to 7.0 ± 0.6 $mL \cdot kg^{-1}$ PBW). The initial respiratory rate was 12 $breaths \cdot min^{-1}$; in 35 (23%) patients, it was adjusted during the procedure to maintain $EtCO_2$ within the 35–45 mmHg target range.

Pneumoperitoneum pressure was 12 mmHg in all cases. Median duration of pneumoperitoneum was 40 minutes (IQR 32–52 minutes).

Intraoperative interventions

Vasopressors were administered to 12 (8.0%) patients (phenylephrine in 9 patients, ephedrine in 3 patients). Additional fluid boluses (>500 mL) were given to 9 (6.0%) patients. Bronchodilator therapy was required in 2 (1.3%) patients. There were no conversions to open cholecystectomy (n = 0).

Multivariable Analysis

In multivariable linear regression analysis, BMI remained an independent predictor of peak $EtCO_2$ after adjustment for pneumoperitoneum duration, baseline $EtCO_2$, and age ($\beta = 0.38$ mmHg per 1 kg/m² increase; 95% CI 0.21–0.55; $p < 0.001$). Pneumoperitoneum duration was also independently associated with peak $EtCO_2$ ($\beta = 0.12$ mmHg per minute; 95% CI 0.06–0.18; $p < 0.001$). Baseline $EtCO_2$ was a strong predictor ($\beta = 0.45$; $p < 0.001$), while age was not significantly associated ($p = 0.31$). The overall model explained 41% of the variance in peak $EtCO_2$ (adjusted $R^2 = 0.39$) (Table 7).

Table 7: Multivariable Linear Regression Predicting Peak $EtCO_2$ (n = 150)

Predictor	β Coefficient (SE)	95% CI	p-value
BMI (per 1 kg/m² increase)	0.38 (0.09)	0.21 – 0.55	<0.001
Pneumoperitoneum duration (per min)	0.12 (0.03)	0.06 – 0.18	<0.001
Baseline $EtCO_2$ (per mmHg)	0.45 (0.07)	0.31 – 0.59	<0.001
Age (per year)	0.02 (0.02)	−0.02 – 0.06	0.31

Model statistics: $R^2 = 0.41$; Adjusted $R^2 = 0.39$; Overall model $p < 0.001$

Dependent variable = Peak $EtCO_2$ (mmHg); β = unstandardized regression coefficient

In multivariable analysis, BMI and pneumoperitoneum duration remained independent predictors of peak $EtCO_2$ after adjustment for baseline $EtCO_2$ and age (Table 7).

Discussion

CO_2 pneumoperitoneum in laparoscopic cholecystectomy induced demonstrable cardiopulmonary changes due to both mechanical and systemic physiological responses. The increases in airway pressure, EtCO 2, and the transient hemodynamic changes demonstrate that both elevation of intra-abdominal pressure and CO 2 absorption have a direct impact on mechanical ventilation and cardiovascular stability. These results support that pneumoperitoneum exerts a predictable physiologic demand necessitating careful anaesthetic control (1, 10).

The increase in peak inspiratory pressure after insufflation is attributable to elevation of the diaphragm and decreased compliance. As airway resistance increases, greater work of breathing is required to achieve and maintain adequate gas exchange. Similar increments in airway opening pressures have been described to occur during laparoscopic procedures and are assumed to result from a mechanical impediment between external extraneous pressure applied on the abdomen and gravity. Clinically, these results suggest that lung-protective ventilation strategies which tailor tidal volume and PEEP could be beneficial for the prevention of excessive airway pressure (11, 12).

The marked increase in $EtCO_2$ during pneumoperitoneum is consistent with increased peritoneal CO_2 absorption and/or reduced elimination. However, because arterial blood gases were not obtained, we cannot quantify the arterial $PaCO_2$ response or the arterial-to-end-tidal CO_2 gradient in this cohort. Healthy people can tolerate short episodes of hypercapnea; however, intraoperative monitoring is required to avoid an escalating CO_2 underexcretion if the same condition occurs repeatedly. The progressive normalisation of $EtCO_2$ after desufflation noted in the present study is consistent with previous studies showing that these changes are reversible when ventilation is correctly adjusted (7, 13).

Hemodynamic changes were defined by brief decreases in mean arterial pressure and heart rate after insufflation, with subsequent stabilisation. These alterations are probably secondary to transient decreases in venous return due to high intra-abdominal pressure. Comparable hemodynamic responses have been demonstrated in low-risk surgical populations, highlighting that while changes are generally well tolerated, ongoing monitoring is still required to identify instability (7).

The BMI-dependent effect was also observed, which revealed that the obese group experienced more of an increase in airway pressure and $EtCO_2$. Decreased baseline thoracic compliance and diaphragmatic restriction could accentuate the hemodynamic effects of pneumoperitoneum when applied in these individuals. These findings are consistent with prior evidence that individuals with obesity may benefit from customizing ventilatory settings, such as precise monitoring of airway pressures and ventilation parameters (3, 12). The use of BMI as a continuous variable in multivariable analysis confirmed that increasing body mass independently contributes to greater intraoperative CO_2 retention, even after accounting for pneumoperitoneum duration and baseline ventilatory status.

A modest correlation was found between pneumoperitoneum time and the elevation of $EtCO_2$, suggesting that an extended period of insufflation leads to higher systemic CO_2 levels. The haemodynamic effects, however, were well within acceptable normal limits throughout, but could be further minimised by reducing the insufflation time. that similar time-dependent effects were observed in laparoscopic anaesthesia studies (2, 10).

Taken together, these observations provide evidence for dynamic yet controllable cardiovascular and pulmonary responses to pneumoperitoneum when adequate monitoring of anaesthetic depth and controlled ventilation are used. Customised anaesthetic plans are of special interest in obese patients and patients with restricted cardiopulmonary reserve.

Although $EtCO_2$ is widely used as a surrogate for arterial CO_2 ($PaCO_2$) in intraoperative monitoring, the relationship between $EtCO_2$ and $PaCO_2$ may vary during pneumoperitoneum due to changes in ventilation–perfusion matching and increased dead space. Because arterial blood gases were not obtained in this study, the exact magnitude of arterial hypercapnia cannot be determined. Therefore, our findings should be interpreted as reflecting changes in $EtCO_2$ rather than directly measured systemic $PaCO_2$.

Study limitations

We recognise several limitations in this study that are important to consider when interpreting our findings.

First, this was a single-centre study, which may limit the generalizability of our results to broader populations or different clinical settings.

Second, we did not perform arterial blood gas analysis. Instead, we relied on end-tidal CO_2 ($EtCO_2$) as a non-invasive surrogate for arterial CO_2. While $EtCO_2$ is a useful bedside tool, the arterial-to-end-tidal CO_2 gradient can widen during pneumoperitoneum, meaning we cannot directly quantify the true extent of arterial hypercapnia from our data. This limits the precision of our assessment of systemic CO_2 retention. Future studies that include serial arterial blood gas measurements would allow for a more accurate and dynamic characterisation of CO_2 changes under these conditions.

Third, we did not conduct a subject-by-subject analysis of ventilatory response variability. As individual physiological responses to pneumoperitoneum can differ considerably, this level of analysis could have uncovered important patterns not visible at the group level. Incorporating more advanced respiratory monitoring in future work, such as continuous volumetric capnography or transcutaneous CO_2 monitoring, would offer clearer physiological insights and help tailor ventilatory strategies on a more individualised basis (10).

Together, these limitations highlight the need for future multi-centre studies that combine more precise CO_2 monitoring with personalised analyses. Despite these constraints, we believe our findings contribute meaningfully to the growing understanding of respiratory physiology during laparoscopic surgery.

Conclusion

Predictable respiratory and cardiovascular changes, such as increased airway pressure and $EtCO_2$, occur in CO_2 pneumoperitoneum during laparoscopic cholecystectomy. These effects are short-lived but more intense in the obese patient and after extended insufflation.

These physiological effects are controllable with proper ventilatory adaptation and monitoring. Knowledge of these changes enables anaesthesia to be tailored and improves patient safety in the peri-operative period.

List of Abbreviations

CO_2:	Carbon Dioxide
$EtCO_2$:	End-tidal Carbon Dioxide
PIP:	Peak Inspiratory Pressure
MAP:	Mean Arterial Pressure
HR:	Heart Rate
SpO_2:	Peripheral Oxygen Saturation
BMI:	Body Mass Index
ASA:	American Society of Anaesthesiologists Classification
ECG:	Electrocardiography
PEEP:	Positive End-Expiratory Pressure
IV:	Intravenous

Declarations

Ethics Approval and Consent to Participate

This prospective observational study was conducted at Rezgary Teaching Hospital, Erbil. Ethical approval was provided by the Scientific and Ethical Committee of Gilgamesh University, Baghdad (Approval No. 21/2025, dated 23rd January 2025). The ethical approval covered clinical research activities performed by Gilgamesh University investigators at collaborating clinical sites, including Rezgary Teaching Hospital. All participants gave written informed consent before enrolment. A copy of the ethical approval letter is available from the corresponding author on request.

All research involving human participants was in accordance with the ethical standards of the institutional committee and with the 1964 Helsinki Declaration and its later amendments.

Consent for publication

All authors gave consent for publication of the work under the Creative Commons Attribution-Non-Commercial 4.0 license.

Data Availability

Data for this work is available from the authors and may be provided upon reasonable request.

Competing Interests

None.

Funding Sources

None.

Author Contributions

MHN conceived and designed the study; developed the study protocol; obtained ethical approval; collected and curated the data; performed statistical analysis; interpreted the results; drafted the manuscript; critically revised the manuscript for important intellectual content; and approved the final version for publication. MHN agrees to be accountable for all aspects of the work.

Acknowledgments
Not Applicable.

References

1. Cunningham AJ. Laparoscopic surgery—anesthetic implications. Surgical endoscopy. 1994 Nov;8(11):1272-84. https://doi.org/10.1007/BF00188282
2. Joris JL, Noirot DP, Legrand MJ, Jacquet NJ, Lamy ML. Hemodynamic changes during laparoscopic cholecystectomy. Anesthesia & Analgesia. 1993 May;76(5):1067-71. https://doi.org/10.1213/00000539-199305000-00027
3. Nguyen NT, Wolfe BM. The physiologic effects of pneumoperitoneum in the morbidly obese. Annals of surgery. 2005 Feb 1;241(2):219-26. https://doi.org/10.1097/01.sla.0000151791.93571.70
4. Miller RD, Eriksson LI, Fleisher LA, Wiener-Kronish JP, Cohen NH, Young WL. Miller's anesthesia e-book. Elsevier Health Sciences; 2014 Oct 20.
5. Pelosi P, Croci M, Ravagnan I, Tredici S, Pedoto A, Lissoni A, Gattinoni L. The effects of body mass on lung volumes, respiratory mechanics, and gas exchange during general anesthesia. Anesthesia & Analgesia. 1998 Sep 1;87(3):654-60. https://doi.org/10.1213/00000539-199809000-00031
6. Kadhm A, Al-Galebi A. Analysis of IL-6 and IL-8 gene polymorphisms and their association with cytokine levels in sinus infections. Babcock University Medical Journal. 2025 Dec 31;8(2):60-75. https://doi.org/10.38029/babcockuniv.med.j..v8i2.961
7. Joris JL, Chiche JD, Canivet JL, Jacquet NJ, Legros JJ, Lamy ML. Hemodynamic changes induced by laparoscopy and their endocrine correlates: effects of clonidine. Journal of the American College of Cardiology. 1998 Nov 1;32(5):1389-96. https://doi.org/10.1016/S0735-1097(98)00406-9
8. Rajeb RA, Hamadi SI. Distribution and prevalence of Periplaneta Americana in urban households of Ramadi, Iraq. Babcock University Medical Journal. 2025 Dec 31;8(2):54-9. https://doi.org/10.38029/babcockuniv.med.j..v8i2.960
9. ZAnderson JA. Respiratory monitoring for anesthesia and sedation. Anesthesia Progress. 2024 Jan 15;70(4):198-201. https://doi.org/10.2344/862700
10. Bablekos GD, Michaelides SA, Analitis A, Charalabopoulos KA. Effects of laparoscopic cholecystectomy on lung function: a systematic review. World Journal of Gastroenterology: WJG. 2014 Dec 14;20(46):17603. https://doi.org/10.3748/wjg.v20.i46.17603
11. Safran DB, Orlando III R. Physiologic effects of pneumoperitoneum. The american journal of surgery. 1994 Feb 1;167(2):281-6. https://doi.org/10.1016/0002-9610(94)90094-9
12. Pelosi P, Croci M, Ravagnan I, Vicardi P, Gattinoni L. Total respiratory system, lung, and chest wall mechanics in sedated-paralyzed postoperative morbidly obese patients. Chest. 1996 Jan 1;109(1):144-51. https://doi.org/10.1378/chest.109.1.144
13. Cove ME, Pinsky MR. Perioperative hemodynamic monitoring. Best practice & research Clinical anaesthesiology. 2012 Dec 1;26(4):453-62. https://doi.org/10.1016/j.bpa.2012.10.003