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Research Paper

Cerebral and hemodynamic responses in elderly patients during laparoscopic cholecystectomy: A cross-sectional study

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ABSTRACT

Laparoscopic cholecystectomy is among the most frequently performed abdominal surgeries in the elderly population. However, the physiological changes in hemodynamic and cerebral parameters induced by pneumoperitoneum and the head-up (reverse Trendelenburg) position present notable clinical challenges in this age group. This cross-sectional study aimed to evaluate alterations in cerebral oxygenation and hemodynamic status in elderly patients undergoing laparoscopic cholecystectomy. The study was conducted on 50 elderly patients scheduled for laparoscopic cholecystectomy at Razi Hospital, Rasht, between March 20, 2023, and March 19, 2024. Hemodynamic parameters and cerebral oxygen saturation were recorded at baseline (prior to anesthesia induction), 5 and 15 minutes after abdominal gas insufflation, immediately following gas desufflation, and 15 minutes post-desufflation. The mean patient age was 66.9 ± 7.1 years, with 58% being female. Systolic, diastolic, and mean arterial pressures significantly increased following gas insufflation ($P < 0.001$), whereas heart rate changes were not statistically significant ($P = 0.443$). End-tidal carbon dioxide ($EtCO_2$) levels significantly rose during pneumoperitoneum. Cerebral oxygen saturation initially increased after anesthesia induction, declined post-insufflation, and subsequently recovered in the later stages. Peripheral oxygen saturation (SpO_2) remained stable throughout the procedure. The most commonly observed side effects included hypertension (16%), nausea and vomiting (16%), and bradycardia (8%). The findings indicate that anesthesia induction, pneumoperitoneum, and the reverse Trendelenburg position influence both cardiac function and cerebral perfusion in elderly patients. Specifically, carbon dioxide insufflation into the abdominal cavity is associated with elevated hemodynamic parameters, increased $EtCO_2$, and transient reductions in cerebral oxygenation across both hemispheres.

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1. Introduction

Cholecystectomy is the most common surgical abdominal condition in the elderly. Old age is one of the critical factors that affects morbidity and mortality after cholecystectomy. For this purpose, laparoscopic surgery has become a popular alternative to open cholecystectomy due to its favorable short-term outcomes such as less pain, reduced blood loss, and faster recovery time [1-4]. However, the combined effects of anesthesia, pneumoperitoneum, the systemic effects of absorbed carbon dioxide, and the patient's body position during laparoscopy can alter the cardiovascular, respiratory, and cerebral physiology of the patient [5,6].

These factors together lead to increased systemic and pulmonary vascular resistance, while simultaneously decreasing cardiac index, reducing pulmonary compliance and functional residual capacity, increasing peak airway pressure, respiratory acidosis accompanied by hypercarbia, and enhancing stress and inflammatory responses [5-7]. Although carbon dioxide has been accepted as the ideal gas for insufflation into the abdomen during laparoscopy due to its low flammability and high solubility in blood [4-6,8], an increase in arterial carbon dioxide pressure and subsequent changes in cerebral blood flow may occur, leading to prolonged recovery and cognitive dysfunction [9,10]. Cerebral oximetry with near-infrared spectroscopy (NIRS) allows for continuous and non-invasive monitoring of regional cerebral oxygenation (rSO2). Cerebral oximetry shows the ratio of oxygenated and deoxygenated hemoglobin in the area of the brain cortex beneath the sensors, which is usually located in the frontal region [10,11] . Despite the interventions performed, the use of necessary monitoring, and adherence to anesthesia and surgical considerations, studies continue to show degrees of pathophysiological changes during this procedure, resulting in complications and adverse outcomes of hemodynamic instability during and after the operation, which can be challenging for the anesthesiologist [12,13]. Significant alterations in cerebral oxygenation have been described in certain patients during carbon dioxide insufflation and the reverse Trendelenburg position during laparoscopic surgery, resulting in cognitive problems and other consequences [14-16]. Understanding these alterations and regulating cardiovascular and cerebral components during laparoscopic procedures, particularly in older patients, is critical for the surgeon and anesthesiologist. And if the surgeon and anesthesiologist lack appropriate expertise dealing with these changes, they will occur more often, as will the difficulties that arise. However, research on the link between laparoscopic surgery and hemodynamic changes and regional cerebral oxygenation in older individuals is sparse. Given the relevance of the issue and the high frequency of cholecystectomy in the elderly, this research was designed to look at hemodynamic changes and cerebral oxygenation changes during laparoscopic cholecystectomy.

2. Materials and Methods

2.1 Study design

This analytical cross-sectional study was conducted in 2023 at Razi Educational and Therapeutic Hospital in Rasht, northern Iran, on patients eligible for laparoscopic cholecystectomy. The sample size of 50 patients was determined based on the study by Banerjee et al. [1].

2.2 Inclusion and exclusion criteria

The inclusion criteria were patients eligible for elective laparoscopic cholecystectomy in the head-up position, aged above 60 years, and classified as American Society of Anesthesiologists (ASA) class one or two. The exclusion criteria encompassed a history of chronic lung disease, valvular and ischemic heart disease, patient refusal to participate, alterations in surgical technique, a body mass index exceeding 35 or falling below 18, and any unforeseen occurrences during surgery, including severe hemorrhage or unexpected complications necessitating conversion to open laparotomy.

2.3 Preoperative preparation and monitoring

Prior to surgery, the study's objective and procedures were explained to all patients, and informed consent was obtained. After positioning each patient in the supine position on the operating table, standard monitoring was initiated, including a 3-lead electrocardiogram (ECG), non-invasive blood pressure, pulse oximetry, and cerebral oximetry using bilateral frontal probes.

2.4 Anesthesia induction and maintenance

Following the establishment of suitable venous access, hydration commenced with normal saline. Following pre-oxygenation of the patient with 100% oxygen, anesthesia was initiated using midazolam at 0.2 mg/kg, fentanyl at 2 mcg/kg, propofol at 1 mg/kg, and atracurium at 0.5 mg/kg. Following the intubation of the patient with a suitably sized endotracheal tube, end-tidal carbon dioxide monitoring was implemented. Patients were ventilated in a controlled manner, using a tidal volume of 8 mL/kg of body weight and a respiratory rate of 12 breaths/min. The inhalational anesthetic isoflurane, with a minimum alveolar concentration of 0.8, was used to sustain anesthesia throughout the surgery.

2.5 Surgical procedure and positioning

Pneumoperitoneum was achieved by insufflating carbon dioxide into the peritoneal cavity, maintaining intra-abdominal pressure between 12–14 mmHg. Shortly thereafter, patients were placed in the reverse Trendelenburg position. All surgeries were performed by the same surgical and anesthesia team, using a STORZ laparoscopic system (IMAGE 1 S model, Germany).

2.6 *Data collection*

Patients' vital signs, encompassing systolic blood pressure, diastolic blood pressure (BP), mean arterial pressure, heart rate (HR), end-tidal carbon dioxide ($EtCO_2$), oxygen saturation percentage, and cerebral oxygenation levels, were documented at baseline (T0), 5 minutes post-anesthesia induction and intubation prior to abdominal gas insufflation (T1), and subsequently at 5 minutes after insufflation (T2), 15 minutes after insufflation (T3), immediately following gas release and horizontal positioning (T4), and 15 minutes post-gas release (T5).

2.7 *Postoperative care and complication monitoring*

At the end of the procedure, atropine (0.02 mg/kg) and neostigmine (0.04 mg/kg) were administered to reverse neuromuscular blockade. Patients were extubated and transferred to the recovery room. During the procedure, any cases requiring pharmacologic interventions such as inotropes for hypotension (BP drop >20% from baseline), atropine for bradycardia (HR <60 bpm), nitroglycerin for hypertension (BP increase >20% from baseline), or management of cerebral desaturation (rSO_2 <75% of baseline for >15 seconds) were documented. Postoperative adverse events including pneumothorax, nausea and vomiting, bleeding, and oxygen saturation (SpO_2) <90% in recovery were also recorded.

2.8 *Statistical Analysis*

Quantitative data were described using mean, standard deviation, median, range (min–max), and 95% confidence intervals. Hemodynamic and cerebral oxygenation changes over time were assessed using repeated-measures analysis of variance (ANOVA). Statistical analyses were performed using SPSS version 19 (IBM Corp., Armonk, NY, USA). A p-value < 0.05 was considered statistically significant.

3. Results

This research examined 50 patients eligible for laparoscopic cholecystectomy. The majority of the patients (58%) in the study were female. The average age of the research participants was 66.92 ± 7.14 years, with the majority falling within the 60-70 age bracket. The oldest and youngest subjects were 61 and 90 years old, respectively. The average body mass index (BMI) was 27.62 ± 3.57 kg/m², with 48% of patients categorized as overweight (BMI 25–30). The minimum and maximum recorded BMIs were 20.57 and 34.5 kg/m², respectively. Sixty-six percent of patients were classified as ASA class II. The mean duration of surgery was 64.1 ± 20.3 minutes, with the shortest and longest durations being 40 and 120 minutes, respectively. The average recovery time was 32.2 ± 4.5 minutes, ranging from 30 to 45 minutes (Table 1). Analysis of hemodynamic parameters across intraoperative time points revealed a statistically significant variation in systolic blood pressure, diastolic blood pressure, and mean arterial pressure (MAP) ($p < 0.001$). These values increased following gas insufflation and subsequently decreased after gas deflation, although they remained elevated compared to baseline in most cases. However, changes in heart rate were not statistically significant across the studied intervals ($p = 0.443$) (Table 2).

Assessment of arterial SpO_2 across all timepoints showed no statistically significant changes, and the values remained within clinically acceptable ranges throughout the procedure (Figure 1).

Evaluation of $EtCO_2$ demonstrated a statistically significant increase following gas insufflation, which persisted during pneumoperitoneum and began to decline after deflation of the gas (Figure 2).

Analysis of rSO_2 revealed statistically significant differences across the six timepoints ($p < 0.001$). Following anesthesia induction, cerebral oxygenation increased, then showed a temporary decrease after insufflation, and later resumed an upward trend toward recovery levels (Table 3). Assessment of intraoperative and recovery complications revealed that the most frequently reported complications were hypertension and nausea and vomiting, each occurring in 8 patients (16%). Bradycardia was observed in 4 patients (8%), while hypoxia and hypotension were recorded in 3 (6%) and 2 (4%) patients, respectively. All cases were managed without the need for escalation of care.

Table 1. Demographic and clinical characteristics of patients

Variable	Value
Female patients (%)	58% (n=29)
Male patients (%)	42% (n=21)
Age (years), mean ± SD	66.92 ± 7.14 (range: 61–90)
BMI (kg/m²), mean ± SD	27.62 ± 3.57 (range: 20.57–34.5)
BMI 25–30 (%)	48% (n=24)
ASA Class II (%)	66% (n=33)
Surgery duration (min), mean ± SD	64.1 ± 20.3 (range: 40–120)
Recovery duration (min), mean ± SD	32.2 ± 4.5 (range: 30–45)

Table 2. Hemodynamic and clinical index changes during different time intervals

Time interval	Heart rate (Rate/min) Mean ± SD	Systolic blood pressure (mmHg) Mean ± SD	Diastolic blood pressure (mmHg) Mean ± SD	Mean arterial pressure (mmHg) Mean ± SD
Awake	78.14 ± 68.28	155.22 ± 36.23	92.12 ± 16.14	113.14 ± 22.19
5 min after anesthesia induction	74.15 ± 72.22	127.19 ± 72.41	80.12 ± 66.64	96.14 ± 34.06
5 min after pneumoperitoneum	75.18 ± 92.71	140.24 ± 24.27	93.7 ± 14	108.17 ± 9.26
15 min after pneumoperitoneum	78.14 ± 64.17	132.2 ± 2.32	85.11 ± 22.43	100.13 ± 88.18
Immediately after gas release and repositioning	77.14 ± 52.39	136.17 ± 4.01	83.10 ± 42.66	101.11 ± 08.86
15 min after gas release	76.17 ± 18.06	137.17 ± 82.94	84.11 ± 08.3	101.13 ± 99.01
Statistical Significance (P-value)	P = 0.443	P <0.001	P <0.001	P <0.001

Table 3. Regional cerebral oxygenation trends

Time interval	Right hemisphere oxygen saturation Mean ± SD	Left hemisphere oxygen saturation Mean ± SD
Awake	65.62 ± 8.94	64.88 ± 9.67
5 min after anesthesia induction	73.36 ± 8.89	72.76 ± 9.14
5 min after pneumoperitoneum	70.64 ± 8.53	70.94 ± 8.86
15 min after pneumoperitoneum	72.38 ± 9.38	72.28 ± 10.1
Immediately after gas release and repositioning	75.10 ± 8.72	75.16 ± 9.83
15 min after gas release	74.36 ± 8.87	74.26 ± 9.73
Statistical Significance (P-value)	P <0.001	P <0.001

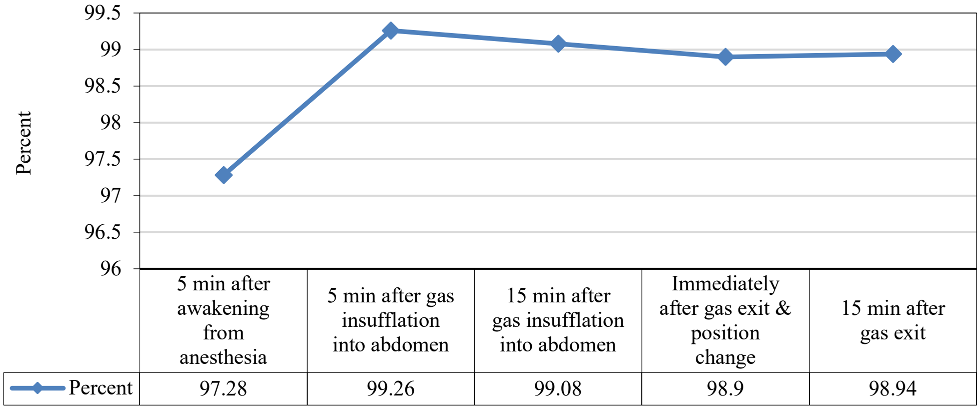

Figure 1. Monitoring of SpO_2 variations throughout the investigated time intervals

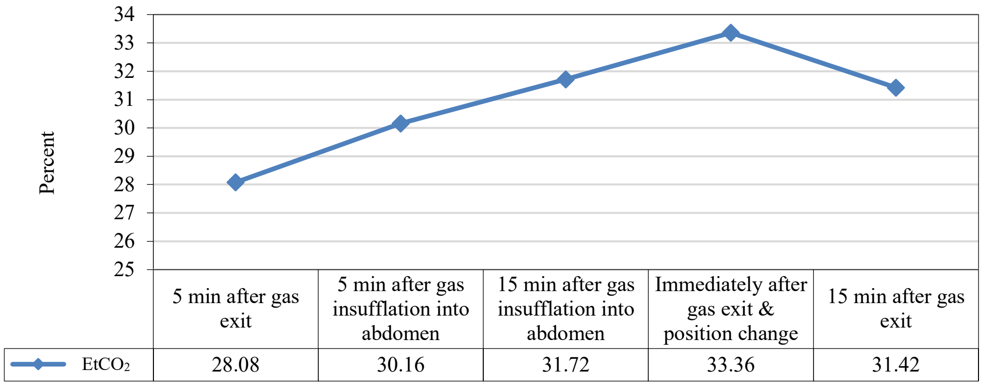

Figure 2. Monitoring of $EtCO_2$ variations over the course of the study

4. Discussion

This study investigated hemodynamic and cerebral oxygenation alterations in elderly patients undergoing laparoscopic cholecystectomy. The findings demonstrated that the insufflation of carbon dioxide into the abdominal cavity significantly increased systolic blood pressure, diastolic blood pressure, and MAP, with these elevations persisting until desufflation. These results align with established literature indicating that physiological changes during laparoscopy are driven by patient positioning, external gas insufflation, and elevated intra-abdominal pressure associated with pneumoperitoneum .The cardiovascular consequences of pneumoperitoneum, including reduced cardiac output, increased vascular resistance, and elevated arterial pressure, are well recognized [17]. Conversely, substantial declines in cerebral oxygenation during CO_2 insufflation and reverse Trendelenburg positioning have been reported, with potential cognitive and neurologic implications [14-16]. Although laparoscopic surgery typically carries lower mortality than open procedures, elderly patients present a unique challenge due to age-related comorbidities, which increase the risk of complications and conversion to open surgery. The pathophysiologic complexity of these cases underscores the importance of anticipating hemodynamic and ventilatory disturbances that may elevate cardiovascular risk. The rise in systolic blood pressure observed post-insufflation in our study can be attributed to reflex systemic vasoconstriction due to peritoneal distension, increased cardiac afterload, and sympathetic activation triggered by absorbed CO_2 [17]. Prior studies have documented elevated levels of catecholamines, cortisol, vasopressin, renin, and aldosterone during laparoscopy, which contribute to transient hemodynamic shifts [17,18]. Similar trends of MAP elevation following insufflation have been confirmed in studies by Banerjee et al. and Naghdipour et al. [1,17], as well as in Umar et al.'s work, where blood pressure increased at varying intra-abdominal pressures [19]. Notably, our study differed in showing a transient decline in BP 15 minutes post-insufflation-still higher than baseline-likely reflecting an age-related decline in cardiac reserve, as all our subjects were elderly.

These observations are supported by other studies in elderly patients showing reduced cardiac output and elevated blood pressure post-insufflation, followed by improvement after gas evacuation [2].

In contrast to these, Kim et al. noted a modest BP reduction in the reverse Trendelenburg position, highlighting its impact on preload and cardiac performance in elderly patients with cardiac risk [8]. Similarly, Jain D et al. observed an initial BP rise followed by a decline during Trendelenburg positioning in older adults, contrasting with findings in younger cohorts [4]. Heart rate trends in our cohort showed a mild increase after insufflation, although this increase was not statistically significant. This may be explained by reduced venous return and compensatory sympathetic activity in response to hypercapnia, which stimulates the release of catecholamines. Ramos et al. and Umar et al. also reported mild HR elevations [2,19]. While Naghdipour et al. found statistically significant HR increases likely influenced by different surgical types, younger age, and Trendelenburg positioning in their sample [17]. In contrast, Banerjee et al. reported decreased HR under remifentanil-based anesthesia, highlighting the influence of anesthetic regimens [1].

CO_2 insufflation also impacted respiratory parameters. Rising $EtCO_2$ levels were observed from the point of insufflation until gas evacuation, followed by a decline. This trend is consistent with previous findings, reflecting CO_2 absorption due to high-pressure gradients across the peritoneum [1,8,17]. Although SpO_2 remained stable and within safe limits throughout the procedure, its pattern was similar to that observed in prior studies. Naghdipour et al. observed a statistically significant change in SpO_2 trends, possibly due to differences in surgical type, younger age, and patient positioning [1,7,8,18].

Cerebral oxygenation (rSO_2) exhibited a biphasic trend initially rising after anesthesia induction, then declining after insufflation, followed by gradual recovery. These changes were statistically significant and varied between hemispheres. The observed decline in rSO_2 may stem from reduced cerebral perfusion pressure and PaO_2 due to CO_2 effects and head-up positioning [22]. Though these reductions did not cross critical thresholds, they may hold clinical relevance for vulnerable groups such as the elderly, obese, or those with impaired cardiovascular function [23,24]. The mechanism of cerebral oxygenation during laparoscopy remains complex, involving cerebral metabolic rate, hemoglobin concentration, and blood flow regulation [20]. $PaCO_2$ is a key determinant of rSO_2, with studies showing that increased $EtCO_2$ levels can enhance cerebral oxygenation [20,21].

Azizoğlu et al. demonstrated a significant correlation between $PaCO_2$ and rSO_2 during pneumoperitoneum [20]. Supporting our observation that rSO_2 recovered in tandem with rising $EtCO_2$. Postoperative nausea and vomiting (PONV) occurred in 16% of our cohort, lower than the 27.7% pooled rate from a recent meta-analysis [27]. This discrepancy may be due to anesthetic differences, shorter recovery monitoring, and older patient age. Factors such as obesity, PONV history, surgical technique, and postoperative pain also influence this outcome [17,28].

Patients in our study were evaluated only during recovery. Pulmonary dysfunction, independent of general anesthesia, is a known complication of upper abdominal surgery. In our study, three patients had transient desaturation (SpO_2 <90%) in recovery, managed successfully with supplemental oxygen. This mirrors the findings of Barnett et al., who reported immediate postoperative declines in FVC and FEV1 after laparoscopic cholecystectomy, though without major complications [30].

Although this study provides valuable insights into hemodynamic and cerebral oxygenation changes in elderly patients undergoing laparoscopic cholecystectomy in the reverse Trendelenburg position, several limitations should be acknowledged. The study included only ASA class I–II patients, limiting generalizability to higher-risk populations. Advanced monitoring tools such as transthoracic echocardiography and central venous pressure measurements were not utilized due to procedural constraints. Additionally, the effects of varying intra-abdominal pressures were not assessed. Future studies should include broader patient populations, incorporate advanced hemodynamic monitoring, and evaluate the impact of different insufflation pressures.

Our findings indicate that anesthesia, pneumoperitoneum, and the reverse Trendelenburg position affect cardiac function and cerebral perfusion in elderly patients. Such that insufflating carbon dioxide gas into the abdomen is associated with an increase in hemodynamic parameters including blood pressure, heart rate, and end-tidal carbon dioxide, and a decrease in cerebral oxygenation in both cerebral hemispheres. Although all the aforementioned parameters were maintained within acceptable limits and none of the patients experienced any significant complications during the procedure.

Authors' contributions

Study concept, design and supervision: PS, SGT. Acquisition, analysis, or interpretation of data: ZA, TG. Drafting and critical revision of the manuscript: PS, SGT, ZA, TG . All authors read and approved the final version of manuscript.

Conflict of interest

No potential conflict of interest was reported by the authors.

Ethical declarations

This study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Ethics Committee of Guilan University of Medical Sciences (Approval ID: IR.GUMS.REC.1402.225). Written informed consent was obtained from all participants prior to their enrollment in the study.

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