

Comparison of Different Carbon Dioxide Insufflation Rates and Intra-Abdominal Pressure in Laparoscopic Hysterectomy

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Abstract

Background: Carbon dioxide (CO₂) pneumoperitoneum is essential for laparoscopic hysterectomy but may produce significant hemodynamic alterations depending on the insufflation flow rate and intra-abdominal pressure. Identifying optimal insufflation parameters may improve perioperative safety while maintaining adequate surgical conditions. **Aim:** To compare the effects of different carbon dioxide insufflation flow rates and intra-abdominal pressures on intraoperative hemodynamic parameters and postoperative outcomes during laparoscopic hysterectomies. **Materials and Methods:** This prospective randomized controlled trial was conducted among 90 patients undergoing elective laparoscopic surgeries under general anaesthesia. Patients were randomized into three groups according to the carbon dioxide insufflation flow rate: Group A (5 L/min), Group B (8 L/min), and Group C (10 L/min), with pneumoperitoneum maintained at either 10 mmHg or 12 mmHg. Hemodynamic parameters including heart rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure, and electrocardiographic changes were recorded at predefined intraoperative intervals. Postoperative pain score, desufflation time, opioid requirement, and recovery parameters were also assessed. Data were analysed using repeated-measures ANOVA, one-way ANOVA, Chi-square test, and Fisher's exact test, with $p < 0.05$ considered statistically significant. **Results:** Baseline demographic characteristics were comparable among the three groups. Repeated-measures ANOVA demonstrated no significant overall differences in heart rate ($p = 0.564$), systolic blood pressure ($p = 0.228$), diastolic blood pressure ($p = 0.821$), or mean arterial pressure ($p = 0.882$) between the insufflation flow-rate groups. Although mean arterial pressure changed significantly over time ($F = 3.068$, $p = 0.017$), the temporal pattern was similar across all groups. Intra-abdominal pressure demonstrated significant time-dependent interactions for heart rate ($p = 0.024$) and diastolic blood pressure ($p = 0.044$), while overall group differences remained non-significant. Postoperative pain scores ($p = 0.236$), desufflation time ($p = 0.562$), opioid requirement ($p = 0.056$), and perioperative electrocardiographic changes showed no statistically significant differences among the three insufflation flow-rate groups. **Conclusion:** Carbon dioxide insufflation flow rates of 5, 8, and 10 L/min provide comparable intraoperative hemodynamic stability and postoperative recovery during laparoscopic surgery. Although intra-abdominal pressure influenced the temporal changes in selected hemodynamic variables, varying the insufflation flow rate within the studied range did not significantly affect cardiovascular stability or postoperative outcomes. Lower insufflation flow rates may therefore be considered safe and effective alternatives during elective laparoscopic procedures.

Keywords: Sugar-sweetened beverages; dental caries; body mass index; adolescents; obesity; DMFT index.

Introduction

Laparoscopic surgery has revolutionized modern surgical practice by offering a minimally invasive alternative to conventional open surgery. Since the first laparoscopic cholecystectomy was introduced in the late 1980s, the indications for laparoscopy have expanded to include gastrointestinal, colorectal, bariatric, hepatobiliary, urological, and gynecological procedures. More than 15 million laparoscopic procedures are estimated to be performed worldwide each year, reflecting its widespread acceptance as the standard approach for many elective abdominal operations.[1] Compared with conventional open surgery, laparoscopic procedures are associated with reduced postoperative pain, lower incidence of wound infection, decreased blood loss, shorter duration of hospital stay, faster return to normal activities, and improved cosmetic outcomes.[2]

The success of laparoscopic hysterectomy depends on the creation of an adequate carbon dioxide (CO₂) pneumoperitoneum, which provides sufficient working space and clear visualization of intra-abdominal organs. Carbon dioxide remains the preferred insufflation gas because it is colourless, non-combustible, inexpensive, highly soluble in

blood, and rapidly eliminated through pulmonary ventilation, thereby reducing the risk of gas embolism compared with less soluble gases.[3] Recent advances in laparoscopic surgery have focused on individualized pneumoperitoneum strategies, which tailor insufflation pressure to the patient's physiological characteristics while maintaining adequate surgical exposure.[4]

Despite its advantages, CO₂ pneumoperitoneum produces significant physiological alterations. Increased intra-abdominal pressure compresses the inferior vena cava and abdominal vessels, leading to reduced venous return, increased systemic vascular resistance, elevated mean arterial pressure, and alterations in cardiac output. Simultaneously, absorption of carbon dioxide from the peritoneal cavity may increase arterial carbon dioxide tension (PaCO₂) by approximately 5–10 mmHg and end-tidal carbon dioxide (EtCO₂) by 3–8 mmHg if ventilation is not appropriately adjusted.[5,6] These changes are particularly important in elderly patients and individuals with underlying cardiovascular or respiratory disease.

Standard laparoscopic procedures are commonly performed using an intra-abdominal pressure of 12–15 mmHg, which generally provides satisfactory visualization for surgeons. However, higher insufflation pressures have been associated with increased postoperative shoulder-tip pain, reduced splanchnic perfusion, impaired pulmonary compliance, elevated peak airway pressures, and greater postoperative discomfort.[6] Consequently, several investigators have explored the feasibility of low-pressure pneumoperitoneum, usually maintained between 8 and 10 mmHg, to minimize these physiological disturbances without compromising the quality of the operative field.[4]

Apart from intra-abdominal pressure, the rate of carbon dioxide insufflation has also emerged as an important determinant of intraoperative hemodynamic stability. Rapid insufflation produces sudden stretching of the peritoneum and abrupt elevation of intra-abdominal pressure, which may trigger vagally mediated bradycardia, hypotension, or transient cardiac arrhythmias. Conversely, gradual insufflation allows slower adaptation to these physiological changes and may reduce the incidence of adverse cardiovascular events.[7,8] Modifications in insufflation techniques, including warmed and humidified carbon dioxide, have also demonstrated improvements in postoperative pain, maintenance of core body temperature, and patient comfort compared with conventional cold, dry carbon dioxide insufflation.[9]

Although several studies have independently evaluated low-pressure pneumoperitoneum and different carbon dioxide insufflation techniques, there remains no universal consensus regarding the optimal combination of insufflation rate and intra-abdominal pressure that provides adequate surgical exposure while minimizing hemodynamic disturbances and postoperative morbidity. Establishing an evidence-based pneumoperitoneum strategy is particularly relevant for patients with limited cardiopulmonary reserve, in whom even minor physiological changes may have significant clinical consequences. Therefore, the present study aims to compare different carbon dioxide insufflation rates and intra-abdominal pressures during laparoscopic surgeries and evaluate their effects on intraoperative hemodynamic parameters and perioperative outcomes.

Materials And Methods

This prospective, randomized, single-blinded controlled trial will be conducted in the Department of Anaesthesiology in collaboration with the Department of Obstetrics and Gynaecology, SRM Medical College Hospital and Research Centre, Kattankulathur, Tamil Nadu, over a period of three months after obtaining approval from the Institutional Ethics Committee. The study will be registered with the Clinical Trials Registry–India (CTRI) prior to patient enrolment. Female patients aged 30–60 years scheduled for elective laparoscopic hysterectomy for benign gynaecological conditions under general anaesthesia will be screened for eligibility. Patients belonging to the American Society of Anesthesiologists (ASA) physical status I or II and willing to provide written informed consent will be included in the study. Patients with significant cardiovascular, respiratory, hepatic, renal or neuromuscular disorders, previous major abdominal surgery with dense adhesions, malignant gynaecological disease, pregnancy, body mass index greater than 30 kg/m², conversion to open surgery, or major intraoperative complications unrelated to pneumoperitoneum will be excluded from the study.

A total of 60 eligible patients will be enrolled and randomized equally into three groups using a computer-generated randomization sequence with allocation concealment by sequentially numbered opaque sealed envelopes (SNOSE). Group A will receive carbon dioxide insufflation at a flow rate of 5 L/min, Group B at 8 L/min, and Group C at 10 L/min. Within each study group, pneumoperitoneum will be maintained at either 8 mmHg or 10 mmHg intra-abdominal pressure according to the predetermined randomization schedule. Patients and the investigator assessing postoperative outcomes will remain blinded to the study allocation, whereas the operating surgeon and attending anaesthesiologist will not be blinded because of the nature of the intervention.

All patients will undergo a comprehensive pre-anaesthetic evaluation including detailed medical history, physical examination, airway assessment, routine laboratory investigations, electrocardiography, and additional investigations

wherever clinically indicated. Patients will be kept nil per oral for at least eight hours before surgery. After shifting to the operating room, standard ASA monitoring comprising continuous electrocardiography, non-invasive blood pressure, pulse oximetry, capnography, and temperature monitoring will be instituted. An 18-gauge intravenous cannula will be secured, and intravenous Ringer's lactate solution will be administered according to institutional protocol. General anaesthesia will be induced using intravenous midazolam (0.03 mg/kg), fentanyl (2 µg/kg), propofol (2 mg/kg), and rocuronium (0.6 mg/kg) to facilitate endotracheal intubation. Anaesthesia will subsequently be maintained with oxygen-air mixture, sevoflurane, and intermittent doses of rocuronium. Mechanical ventilation will be adjusted to maintain an end-tidal carbon dioxide concentration between 35 and 40 mmHg throughout the surgical procedure.

Following induction of anaesthesia, carbon dioxide pneumoperitoneum will be established using either the Veress needle or open Hasson technique according to the surgeon's preference. Patients will receive the allocated carbon dioxide insufflation flow rate of 5 L/min, 8 L/min, or 10 L/min, while the intra-abdominal pressure will be maintained at either 8 mmHg or 10 mmHg throughout the procedure using an electronic laparoscopic insufflator. All laparoscopic hysterectomies will be performed by experienced consultant gynaecological surgeons following a standardized surgical technique to minimize operator-related variability. Any deviation from the allocated insufflation parameters due to intraoperative safety concerns will be documented.

Hemodynamic variables including heart rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure, oxygen saturation, end-tidal carbon dioxide, peak airway pressure, and electrocardiographic changes will be recorded at baseline before induction, immediately after induction, following creation of pneumoperitoneum, at 5 minutes, 15 minutes, 30 minutes, 60 minutes, and every 15 minutes thereafter until completion of surgery, immediately after carbon dioxide desufflation, at extubation, and 30 minutes postoperatively. Operative duration, duration of pneumoperitoneum, and any intraoperative complications will also be documented. Postoperative pain will be assessed using the 10-cm Visual Analogue Scale (VAS) at 2, 6, 12, and 24 hours after surgery. The incidence of shoulder-tip pain, postoperative nausea and vomiting, rescue analgesic requirement, time to ambulation, and duration of postoperative hospital stay will also be recorded.

The primary outcome measure will be the comparison of intraoperative hemodynamic changes among different carbon dioxide insufflation flow rates and intra-abdominal pressures. Secondary outcome measures will include changes in end-tidal carbon dioxide, peak airway pressure, operative duration, postoperative pain scores, incidence of shoulder-tip pain, postoperative nausea and vomiting, rescue analgesic consumption, and length of hospital stay.

All data will be entered into Microsoft Excel and analysed using IBM SPSS Statistics version 29.0. Continuous variables will be expressed as mean $\pm$ standard deviation, while categorical variables will be expressed as frequency and percentage. Normality of distribution will be assessed using the Shapiro-Wilk test. Baseline demographic variables among study groups will be compared using one-way analysis of variance (ANOVA) for normally distributed variables and the Kruskal-Wallis test for non-parametric variables. Repeated intraoperative hemodynamic measurements will be analysed using repeated-measures ANOVA with Bonferroni post hoc correction. Categorical variables will be analysed using the Chi-square test or Fisher's exact test wherever appropriate. A two-tailed p-value of less than 0.05 will be considered statistically significant.

Results :

Table 1. Baseline Demographic and Clinical Characteristics of Participants According to Oxygen Flow Rate (N = 90)

Variable	Flow Rate 5 L/min (n = 30)	Flow Rate 8 L/min (n = 30)	Flow Rate 10 L/min (n = 30)	p valu e
Age (years), Mean $\pm$ SD	47.90 $\pm$ 6.96	44.97 $\pm$ 4.39	48.03 $\pm$ 5.18	0.06 3
Procedure Done, n (%)				
TLH	1 (3.3)	0 (0.0)	2 (6.7)	0.77 8
TLH with BS	22 (73.3)	25 (83.3)	22 (73.3)	
TLH with BSO	6 (20.0)	4 (13.3)	6 (20.0)	

Other (Cholecystectomy/Appendicectomy)	1 (3.3)	1 (3.3)	0 (0.0)	
Intra-abdominal Pressure, n (%)				
10 mmHg	17 (56.7)	30 (100.0)	0 (0.0)	<0.001
12 mmHg	13 (43.3)	0 (0.0)	30 (100.0)	

The baseline characteristics of participants according to oxygen flow rate are presented in Table 1. The mean age of participants was comparable across the three groups (Flow Rate 5 L/min: 47.90 ±6.96 years, Flow Rate 8 L/min: 44.97 ±4.39 years, and Flow Rate 10 L/min: 48.03 ±5.18 years), with no statistically significant difference ($p = 0.063$). Similarly, the distribution of the surgical procedures performed was comparable among the groups ($p = 0.778$), indicating that the types of procedures were evenly distributed.

However, the distribution of intra-abdominal pressure differed significantly across the groups ($p < 0.001$). All participants in the 8 L/min group underwent surgery at 10 mmHg, whereas all participants in the 10 L/min group underwent surgery at 12 mmHg. In the 5 L/min group, both pressure levels were used (56.7% at 10 mmHg and 43.3% at 12 mmHg). This significant difference reflects the predefined allocation of intra-abdominal pressure rather than a baseline imbalance.

Table 2. Comparison of Hemodynamic Parameters at Different Time Points According to Oxygen Flow Rate (N = 90)

Parameter	Flow Rate 5 L/min (n = 30)	Flow Rate 8 L/min (n = 30)	Flow Rate 10 L/min (n = 30)
Baseline (0 min)			
Heart Rate (beats/min)	83.63 ± 8.32	81.40 ± 9.13	80.77 ± 7.62
Systolic Blood Pressure (mmHg)	128.53 ± 9.50	130.23 ± 8.22	127.80 ± 12.49
Diastolic Blood Pressure (mmHg)	79.10 ± 7.49	75.40 ± 6.67	79.43 ± 8.19
Mean Arterial Pressure (mmHg)	95.53 ± 5.37	93.67 ± 4.71	95.50 ± 8.02
30 Minutes			
Heart Rate (beats/min)	86.07 ± 9.42	82.37 ± 9.35	84.03 ± 9.66
Systolic Blood Pressure (mmHg)	128.10 ± 10.22	126.17 ± 8.46	126.47 ± 10.28
Diastolic Blood Pressure (mmHg)	73.43 ± 8.95	74.73 ± 8.08	76.23 ± 9.93
Mean Arterial Pressure (mmHg)	91.70 ± 6.35	91.80 ± 6.73	93.03 ± 7.95
1 Hour			
Heart Rate (beats/min)	85.00 ± 8.19	85.33 ± 10.42	85.57 ± 8.86
Systolic Blood Pressure (mmHg)	126.27 ± 9.77	125.97 ± 10.66	124.60 ± 9.98
Diastolic Blood Pressure (mmHg)	76.17 ± 9.12	74.70 ± 9.42	73.47 ± 8.44
Mean Arterial Pressure (mmHg)	92.97 ± 7.15	91.70 ± 7.34	90.43 ± 6.79
1.5 Hours			

Heart Rate (beats/min)	83.83 ± 7.58	87.10 ± 9.36	83.80 ± 8.24
Systolic Blood Pressure (mmHg)	126.90 ± 10.23	130.00 ± 12.33	125.80 ± 10.76
Diastolic Blood Pressure (mmHg)	73.37 ± 8.60	75.90 ± 8.96	75.03 ± 9.28
Mean Arterial Pressure (mmHg)	91.17 ± 6.89	93.90 ± 6.74	91.77 ± 6.85
2 Hours			
Heart Rate (beats/min)	85.47 ± 9.12	82.07 ± 9.77	86.50 ± 9.04
Systolic Blood Pressure (mmHg)	130.80 ± 10.75	126.00 ± 8.97	125.63 ± 11.82
Diastolic Blood Pressure (mmHg)	74.90 ± 9.67	78.33 ± 8.92	75.97 ± 11.32
Mean Arterial Pressure (mmHg)	93.53 ± 6.88	94.20 ± 7.21	92.57 ± 9.28

Table 2 presents the mean heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure measured at baseline, 30 minutes, 1 hour, 1.5 hours, and 2 hours among the three oxygen flow rate groups.

At baseline, the hemodynamic parameters were generally comparable across the three groups, with only small differences in mean values. Throughout the observation period, heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure showed only modest fluctuations within each group. Overall, the mean values remained within clinically acceptable ranges across all time points.

Participants in the 5 L/min group demonstrated a slight increase in heart rate at 30 minutes followed by stabilization over time. The 8 L/min group showed relatively stable heart rate values with a transient increase at 1.5 hours, while the 10 L/min group exhibited minimal variation across the study period. Similar patterns were observed for systolic and diastolic blood pressure, with only minor temporal changes and no obvious differences between the oxygen flow rate groups. Mean arterial pressure also remained relatively stable, showing small fluctuations over time without any marked divergence among the groups.

Table 3. Repeated Measures ANOVA Comparing Hemodynamic Parameters Across Five Time Points Among Three Flow Rate Groups (N = 90)

Outcome	Mauchly's W	p (Sphericity)	Time Effect F(df)	p-value	Time × Group F(df)	p-value	Group Effect F(df)	p-value
Heart Rate	0.842	0.099	F(4,348)=2.014	0.092	F(8,348)=1.242	0.274	F(2,87)=0.577	0.564
Systolic Blood Pressure	0.886	0.325	F(4,348)=1.184	0.318	F(8,348)=0.758	0.640	F(2,87)=1.502	0.228
Diastolic Blood Pressure	0.894	0.385	F(4,348)=2.307	0.058	F(8,348)=1.222	0.285	F(2,87)=0.197	0.821
Mean Arterial Pressure	0.891	0.360	F(4,348)=3.068	0.017	F(8,348)=0.897	0.519	F(2,87)=0.125	0.882

Fig 1,

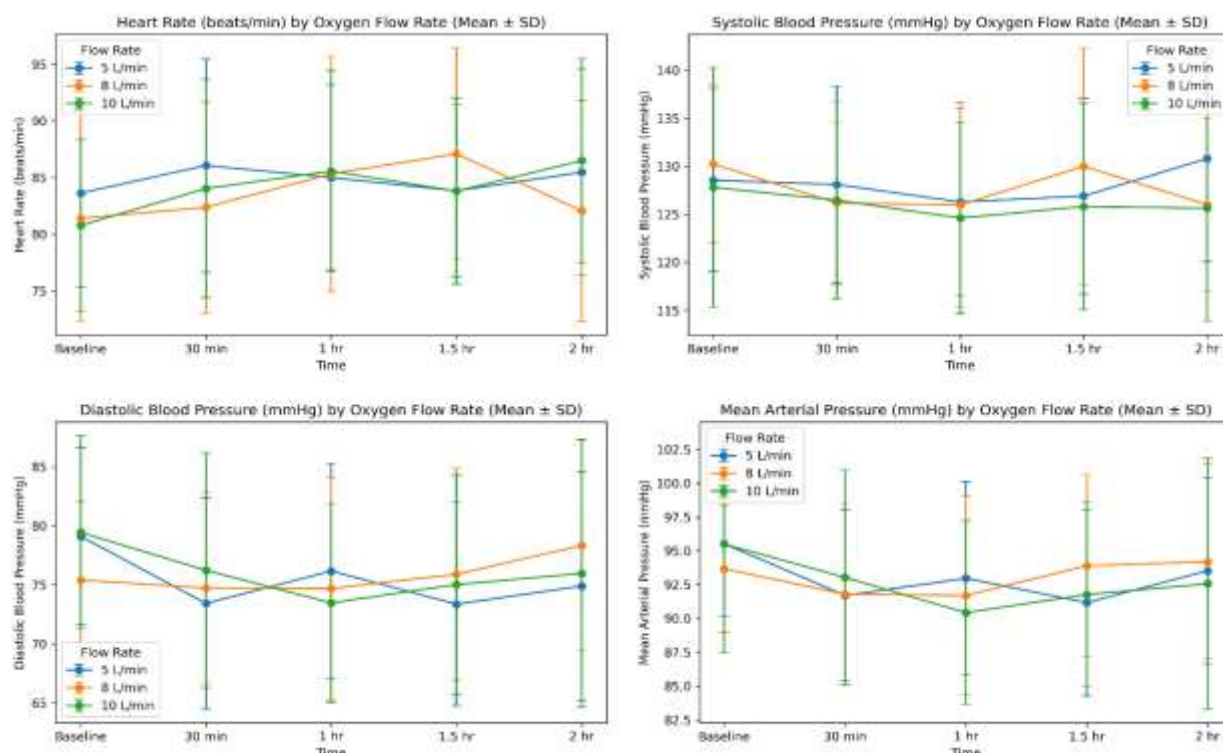


Table 3 presents the results of the repeated measures ANOVA evaluating changes in hemodynamic parameters over five time points among the three oxygen flow rate groups. Mauchly's test of sphericity was not significant for any of the hemodynamic variables (all $p > 0.05$), indicating that the assumption of sphericity was satisfied and the sphericity-assumed results were appropriate for interpretation.

There was no significant overall effect of time on heart rate ($F(4,348) = 2.014$, $p = 0.092$), systolic blood pressure ($F(4,348) = 1.184$, $p = 0.318$), or diastolic blood pressure ($F(4,348) = 2.307$, $p = 0.058$), indicating that these parameters remained relatively stable throughout the observation period. In contrast, mean arterial pressure demonstrated a significant change over time ($F(4,348) = 3.068$, $p = 0.017$).

The time $\times$ group interaction was not statistically significant for heart rate ($p = 0.274$), systolic blood pressure ($p = 0.640$), diastolic blood pressure ($p = 0.285$), or mean arterial pressure ($p = 0.519$). This indicates that the pattern of change in hemodynamic parameters over time was similar across the three oxygen flow rate groups.

Furthermore, there were no significant overall differences between the oxygen flow rate groups for heart rate ($p = 0.564$), systolic blood pressure ($p = 0.228$), diastolic blood pressure ($p = 0.821$), or mean arterial pressure ($p = 0.882$).

Overall, repeated measures ANOVA demonstrated that oxygen flow rate did not significantly influence heart rate, systolic blood pressure, diastolic blood pressure, or mean arterial pressure over time. Although mean arterial pressure changed significantly across the five time points, this temporal change was consistent across all three oxygen flow rate groups and was not attributable to the oxygen flow rate used.

Table 4: Repeated Measures ANOVA Comparing Hemodynamic Parameters Across Five Time Points by Intra-abdominal Pressure (IAP) Group (N = 90)

Outcome	Mauchly's W (p-value)	Time Effect F(df)	p-value	Time $\times$ IAP F(df)	p-value	IAP Group Effect F(df)	p-value
Heart Rate	0.847 (0.110)	$F(4,352)=2.044$	0.088	$F(4,352)=2.840$	0.024	$F(1,88)=0.385$	0.537
Systolic Blood Pressure	0.888 (0.330)	$F(4,352)=1.133$	0.341	$F(4,352)=0.991$	0.412	$F(1,88)=0.594$	0.443

Diastolic Blood Pressure	0.898 (0.413)	F(4,352)=2.485	0.043	F(4,352)=2.474	0.044	F(1,88)=0.810	0.371
Mean Arterial Pressure	0.888 (0.326)	F(4,352)=3.220	0.013	F(4,352)=1.697	0.150	F(1,88)=1.259	0.265

Table 4 presents the repeated measures ANOVA comparing changes in hemodynamic parameters over five time points according to intra-abdominal pressure (IAP) groups (10 mmHg vs. 12 mmHg). Mauchly's test of sphericity was not significant for all hemodynamic parameters (all $p > 0.05$), indicating that the assumption of sphericity was satisfied and the sphericity-assumed results were appropriate for interpretation.

There was no significant overall effect of time on heart rate ($F(4,352) = 2.044$, $p = 0.088$) or systolic blood pressure ($F(4,352) = 1.133$, $p = 0.341$). However, diastolic blood pressure ($F(4,352) = 2.485$, $p = 0.043$) and mean arterial pressure ($F(4,352) = 3.220$, $p = 0.013$) demonstrated significant changes over the study period.

A significant time $\times$ IAP interaction was observed for heart rate ($F(4,352) = 2.840$, $p = 0.024$) and diastolic blood pressure ($F(4,352) = 2.474$, $p = 0.044$), indicating that the pattern of change in these parameters over time differed significantly between the 10 mmHg and 12 mmHg intra-abdominal pressure groups. In contrast, no significant interaction was found for systolic blood pressure ($p = 0.412$) or mean arterial pressure ($p = 0.150$).

The overall effect of intra-abdominal pressure group was not statistically significant for heart rate ($p = 0.537$), systolic blood pressure ($p = 0.443$), diastolic blood pressure ($p = 0.371$), or mean arterial pressure ($p = 0.265$), indicating that the average hemodynamic values did not differ significantly between the two IAP groups across the study period.

Overall, while intra-abdominal pressure did not influence the overall mean hemodynamic parameters, significant time-dependent differences were observed for heart rate and diastolic blood pressure, suggesting that the temporal response of these parameters varied according to the level of intra-abdominal pressure. Additionally, diastolic blood pressure and mean arterial pressure exhibited significant changes over time irrespective of the IAP group.

Table 5. Comparison of Postoperative Outcomes Among Oxygen Flow Rate Groups (N = 90)

Variable	Flow Rate 5 L/min (n = 30)	Flow Rate 8 L/min (n = 30)	Flow Rate 10 L/min (n = 30)	Test Statistic	p-value
Desufflation time	74.10 $\pm$ 9.05	76.43 $\pm$ 10.18	76.27 $\pm$ 8.81	F = 0.580	0.562
Post-surgery (30 min)	78.90 $\pm$ 11.48	72.87 $\pm$ 10.32	76.00 $\pm$ 9.26	F = 2.529	0.086
Postoperative pain score	3.17 $\pm$ 1.68	3.73 $\pm$ 1.55	3.87 $\pm$ 1.80	F = 1.469	0.236
Opioid Usage					
Yes	22 (73.3%)	14 (46.7%)	14 (46.7%)	$\chi^2 = 5.760$	0.056
No	8 (26.7%)	16 (53.3%)	16 (53.3%)		

Table 5 compares the postoperative outcomes among the three oxygen flow rate groups. The mean desufflation time was similar across the 5 L/min (74.10 $\pm$ 9.05), 8 L/min (76.43 $\pm$ 10.18), and 10 L/min (76.27 $\pm$ 8.81) groups, with no statistically significant difference ($F = 0.580$, $p = 0.562$).

The post-surgery score at 30 minutes was numerically lower in the 8 L/min group (72.87 $\pm$ 10.32) compared with the 5 L/min (78.90 $\pm$ 11.48) and 10 L/min (76.00 $\pm$ 9.26) groups; however, this difference did not reach statistical significance ($F = 2.529$, $p = 0.086$).

Similarly, the postoperative pain score did not differ significantly among the three groups (5 L/min: 3.17 $\pm$ 1.68; 8 L/min: 3.73 $\pm$ 1.55; 10 L/min: 3.87 $\pm$ 1.80; $F = 1.469$, $p = 0.236$).

With respect to opioid usage, a higher proportion of participants in the 5 L/min group required opioids (73.3%) compared with the 8 L/min and 10 L/min groups (both 46.7%). However, the difference was not statistically significant ($\chi^2 = 5.760$, $p = 0.056$), although it approached the threshold for significance.

Overall, postoperative outcomes, including desufflation time, post-surgery score at 30 minutes, postoperative pain score, and opioid usage, were comparable among the three oxygen flow rate groups, with no statistically significant differences observed.

Table 6. Comparison of ECG Changes Among Oxygen Flow Rate Groups at Different Time Points (N = 90)

ECG Findings	Flow Rate 5 L/min (n=30)	Flow Rate 8 L/min (n=30)	Flow Rate 10 L/min (n=30)	χ^2 (df)	p-value
Baseline					
Junctional Rhythm	8 (26.7)	8 (26.7)	10 (33.3)	4.631 (6)	0.592
Mild Sinus Bradycardia	7 (23.3)	4 (13.3)	7 (23.3)		
Normal Sinus Rhythm	9 (30.0)	15 (50.0)	10 (33.3)		
Transient Sinus Bradycardia	6 (20.0)	3 (10.0)	3 (10.0)		
30 minutes					
Sinus Tachycardia	21 (70.0)	15 (50.0)	20 (66.7)	2.931 (2)	0.231
Stable Sinus Rhythm	9 (30.0)	15 (50.0)	10 (33.3)		
1 hour					
Isolated PVCs	5 (16.7)	3 (10.0)	5 (16.7)	5.636 (6)	0.465
Left Axis Deviation	7 (23.3)	9 (30.0)	8 (26.7)		
Normal Sinus Rhythm	9 (30.0)	15 (50.0)	10 (33.3)		
Stable Tachycardia	9 (30.0)	3 (10.0)	7 (23.3)		
1.5 hours					
Left Axis Deviation	5 (16.7)	6 (20.0)	12 (40.0)	8.884 (4)	0.064
Normal Sinus Rhythm	10 (33.3)	16 (53.3)	9 (30.0)		
Stable Sinus Rhythm	15 (50.0)	8 (26.7)	9 (30.0)		
2 hours					
Return to Baseline NSR	30 (100.0)	29 (96.7)	30 (100.0)	2.022 (2)	0.364
Persistent ECG Change	0 (0.0)	1 (3.3)	0 (0.0)		

Table 6 compares the distribution of ECG findings among the three oxygen flow rate groups at different perioperative time points. At baseline, the distribution of ECG findings, including junctional rhythm, mild sinus bradycardia, normal sinus rhythm, and transient sinus bradycardia, was comparable across the groups, with no statistically significant difference ($\chi^2 = 4.631$, $p = 0.592$).

At 30 minutes, sinus tachycardia was the most common ECG finding in all three groups, while the remaining participants maintained stable sinus rhythm. The distribution of ECG findings did not differ significantly among the groups ($\chi^2 = 2.931$, $p = 0.231$).

At 1 hour, participants exhibited a mixture of isolated premature ventricular contractions (PVCs), left axis deviation, normal sinus rhythm, and stable tachycardia. However, there was no significant difference in the pattern of ECG changes between the oxygen flow rate groups ($\chi^2 = 5.636$, $p = 0.465$).

At 1.5 hours, although the 10 L/min group showed a relatively higher proportion of left axis deviation (40.0%) compared with the other groups, the overall distribution of ECG findings remained statistically comparable ($\chi^2 = 8.884$, $p = 0.064$). By 2 hours, nearly all participants in each group had returned to normal sinus rhythm, with only one participant (3.3%) in the 8 L/min group exhibiting a persistent ECG change. This difference was not statistically significant ($\chi^2 = 2.022$, $p = 0.364$).

Overall, ECG changes observed during the perioperative period were transient and resolved in most participants by 2 hours. No statistically significant differences in ECG findings were observed among the three oxygen flow rate groups at any assessment time point, suggesting that oxygen flow rate did not have a significant impact on perioperative ECG changes.

Discussion

The present prospective randomized controlled study compared the effects of three different carbon dioxide insufflation flow rates (5 L/min, 8 L/min, and 10 L/min) and two intra-abdominal pressures (10 mmHg and 12 mmHg) on intraoperative hemodynamic parameters and postoperative outcomes during laparoscopic surgeries. The baseline demographic characteristics were comparable among the study groups, indicating that the observed perioperative findings were unlikely to be influenced by differences in age or type of surgical procedure. Although repeated-measures analysis demonstrated a significant change in mean arterial pressure over time ($F=3.068$, $p=0.017$), no significant overall differences were observed between the three insufflation flow-rate groups with respect to heart rate ($p=0.564$), systolic blood pressure ($p=0.228$), diastolic blood pressure ($p=0.821$), or mean arterial pressure ($p=0.882$). Likewise, postoperative pain scores, desufflation time, opioid requirement, and perioperative ECG changes were comparable across all three groups. However, intra-abdominal pressure demonstrated significant time-dependent interactions for heart rate ($p=0.024$) and diastolic blood pressure ($p=0.044$), suggesting that temporal hemodynamic responses were influenced more by pneumoperitoneum pressure than by insufflation flow rate alone.

Carbon dioxide pneumoperitoneum induces hemodynamic alterations through increased intra-abdominal pressure, sympathetic activation, and carbon dioxide absorption. Jung et al. reported that rapid high-flow insufflation could precipitate vagally mediated bradycardia immediately after pneumoperitoneum creation, particularly during rapid abdominal distension.[10] In contrast, our study demonstrated stable hemodynamic responses across all three insufflation flow rates. Heart rate remained comparable between the 5 L/min (83.63 ± 8.32 to 85.47 ± 9.12 beats/min), 8 L/min (81.40 ± 9.13 to 82.07 ± 9.77 beats/min), and 10 L/min (80.77 ± 7.62 to 86.50 ± 9.04 beats/min) groups, with no significant overall group effect ($p=0.564$). Similarly, no clinically significant bradycardia or persistent ECG abnormalities were observed, suggesting that all three insufflation rates were well tolerated under standardized anaesthetic management.

Cho et al. described two cases of cardiac arrest immediately following carbon dioxide insufflation, attributing the events to abrupt vagal stimulation caused by rapid pneumoperitoneum formation.[11] Unlike these isolated reports, no patient in our study experienced severe bradyarrhythmia, cardiac arrest, or hemodynamic collapse. ECG abnormalities observed during surgery were transient and resolved spontaneously, with nearly all patients returning to normal sinus rhythm by two hours, indicating that the selected insufflation rates were safe in appropriately monitored elective laparoscopic procedures.

Similarly, Myles et al. demonstrated that transient bradyarrhythmias may occur during laparoscopic surgery, particularly during initial insufflation, but most episodes resolve without long-term consequences.[12] Our findings support these observations. Although minor variations in heart rate occurred over time, repeated-measures ANOVA showed no significant time effect ($F=2.014$, $p=0.092$), no significant time $\times$ group interaction ($p=0.274$), and no significant overall difference between the three flow-rate groups ($p=0.564$), confirming that varying insufflation flow rates between 5 and 10 L/min did not significantly influence intraoperative heart rate.

Gurusamy et al. reported that reducing pneumoperitoneum pressure could improve patient comfort without adversely affecting intraoperative safety.[13] In the present study, although heart rate and diastolic blood pressure demonstrated significant time $\times$ intra-abdominal pressure interactions ($p=0.024$ and $p=0.044$, respectively), the overall mean values

remained comparable between the 10 mmHg and 12 mmHg groups, indicating that both pressure levels maintained satisfactory hemodynamic stability throughout surgery.

Hua et al., in their meta-analysis, concluded that low-pressure pneumoperitoneum reduces physiological stress while maintaining acceptable surgical conditions in most patients.[14] Our results are consistent with these findings, as systolic blood pressure, diastolic blood pressure, and mean arterial pressure remained within clinically acceptable ranges throughout the perioperative period. Although mean arterial pressure showed a significant change over time ($F=3.068$, $p=0.017$), no significant differences were observed between the three insufflation flow-rate groups ($p=0.882$), indicating that the observed temporal variation was unrelated to insufflation flow rate.

Özdemir-van Brunschot et al. concluded that low-pressure pneumoperitoneum is safe and may improve postoperative recovery without compromising operative performance.[15] Likewise, the present study demonstrated no significant differences in systolic blood pressure ($p=0.228$), diastolic blood pressure ($p=0.821$), or heart rate ($p=0.564$) between the three insufflation flow-rate groups, suggesting that lower insufflation rates can provide adequate cardiovascular stability comparable to higher flow rates.

Matsuzaki et al. demonstrated that optimized pneumoperitoneum using lower pressure and warmed, humidified carbon dioxide improved perioperative physiological responses and postoperative recovery.[16] Although warmed and humidified gas was not evaluated in the present study, our findings similarly indicate that modifying pneumoperitoneum parameters can be achieved without clinically significant adverse hemodynamic consequences. Stable heart rate, blood pressure, and mean arterial pressure were maintained irrespective of the insufflation flow rate used.

Singh et al. compared low-pressure and standard-pressure pneumoperitoneum during laparoscopic cholecystectomy and observed comparable intraoperative hemodynamic profiles between groups.[17] Our results closely parallel these observations. Heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure remained comparable across the three insufflation flow-rate groups throughout the observation period, further supporting the hemodynamic safety of lower insufflation strategies during laparoscopic surgery.

Hsu et al. demonstrated that optimizing carbon dioxide insufflation techniques significantly reduced postoperative shoulder pain and improved patient comfort following laparoscopic surgery.[18] In the present study, postoperative recovery parameters were comparable across all three insufflation flow-rate groups. The mean postoperative pain score was 3.17 ± 1.68 in the 5 L/min group, 3.73 ± 1.55 in the 8 L/min group, and 3.87 ± 1.80 in the 10 L/min group, with no statistically significant difference ($F = 1.469$, $p = 0.236$). Similarly, desufflation time remained comparable (74.10 ± 9.05 , 76.43 ± 10.18 , and 76.27 ± 8.81 minutes, respectively; $p = 0.562$), indicating that lower insufflation flow rates did not prolong operative completion or adversely affect recovery.

Venkatraman et al. compared different carbon dioxide insufflation flow rates during laparoscopic surgery and reported that lower insufflation rates were associated with improved hemodynamic stability without compromising surgical outcomes.[19] Our findings are largely consistent with their observations. Although the 8 L/min group demonstrated the lowest mean post-surgery score at 30 minutes (72.87 ± 10.32) compared with the 5 L/min (78.90 ± 11.48) and 10 L/min (76.00 ± 9.26) groups, this difference was not statistically significant ($F = 2.529$, $p = 0.086$). Furthermore, postoperative pain scores, desufflation time, and overall perioperative recovery remained comparable among all study groups, suggesting that insufflation flow rates between 5 and 10 L/min provide similar clinical outcomes under standardized anaesthetic care.

Venkatraman et al., in their randomized study evaluating regional analgesic techniques for laparoscopic cholecystectomy, emphasized that effective perioperative pain management contributes substantially to enhanced postoperative recovery and reduced analgesic consumption.[20] In the present study, although postoperative pain scores were comparable across groups, opioid requirement was numerically higher in the 5 L/min group (73.3%) than in the 8 L/min (46.7%) and 10 L/min (46.7%) groups. However, this difference did not achieve statistical significance ($\chi^2 = 5.760$, $p = 0.056$), indicating that the observed variation may not be clinically meaningful.

Similarly, Venkatraman et al. reported that adequate perioperative analgesia improves patient comfort and facilitates recovery following surgery.[21] Consistent with these findings, postoperative pain remained mild across all three study groups, with mean Visual Analogue Scale scores below 4, suggesting satisfactory analgesia irrespective of the insufflation flow rate used. The absence of statistically significant differences further supports that variations in carbon dioxide insufflation flow between 5 and 10 L/min have minimal influence on immediate postoperative pain under standardized multimodal analgesic protocols.

Donatsky et al. concluded that postoperative shoulder pain after laparoscopy is multifactorial and is influenced not only by pneumoperitoneum characteristics but also by surgical technique, residual intraperitoneal gas, and perioperative analgesic strategies.[22] In agreement with these observations, our study demonstrated comparable postoperative recovery across all insufflation flow-rate groups without clinically important differences in pain scores, recovery profile,

or analgesic requirements. Collectively, these findings suggest that within the evaluated range of **5–10 L/min**, carbon dioxide insufflation flow rate has little impact on postoperative outcomes when contemporary anaesthetic and surgical protocols are followed.

Conclusion

The present prospective randomized controlled study demonstrated that carbon dioxide insufflation flow rates of 5 L/min, 8 L/min, and 10 L/min produced comparable intraoperative hemodynamic and postoperative outcomes during laparoscopic hysterectomy. Heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure remained within clinically acceptable limits throughout the procedure, with no significant overall differences between the three insufflation flow-rate groups. Although mean arterial pressure showed a significant temporal change, this variation was independent of the insufflation flow rate. Similarly, postoperative pain scores, desufflation time, opioid requirement, and perioperative ECG changes did not differ significantly among the study groups.

Intra-abdominal pressure influenced the temporal pattern of heart rate and diastolic blood pressure; however, no significant differences were observed in the overall hemodynamic profile between the 10 mmHg and 12 mmHg pressure groups. These findings suggest that both pressure levels can be used safely in appropriately selected patients undergoing elective laparoscopic surgery.

Overall, carbon dioxide insufflation flow rates ranging from 5 to 10 L/min are safe and provide comparable perioperative outcomes when standardized anaesthetic and surgical protocols are followed. As no clear clinical advantage was demonstrated for higher insufflation flow rates, the use of lower or moderate flow rates may be considered a safe and effective alternative, particularly in patients where minimizing abrupt hemodynamic fluctuations is desirable. Larger multicentre randomized studies are warranted to establish the optimal combination of insufflation flow rate and intra-abdominal pressure for improving perioperative outcomes across different laparoscopic hysterectomies.

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