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Effect of Low-flow CO_2 Insufflation on Hemodynamics in Gynecological Laparoscopic Surgery: A USCOM-based Randomized Controlled Trial

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Abstract

Objective

This study aimed to investigate whether a low CO_2 insufflation rate (1 L/min) could better preserve cardiac output and systemic hemodynamics compared to a standard rate (5 L/min) at equivalent pneumoperitoneal pressures, thereby providing evidence for optimizing intraoperative parameters and enhancing perioperative safety.

Methods

A total of 50 patients scheduled for gynecological laparoscopic surgery under general anesthesia were enrolled and randomized into two groups: the low insufflation rate group (Group A, 1 L/min) and the normal insufflation rate group (Group B, 5 L/min). The pneumoperitoneal pressure was maintained at 15 mmHg in both groups. USCOM non-invasive ultrasonic monitoring was used to record changes in cardiac output (CO), stroke volume (SV), systemic vascular resistance (SVR), and heart rate (HR) at different time points.

Results

Compared to the standard rate (5 L/min), the low rate (1 L/min) maintained significantly higher CO and SV, with lower SVR at IAP 9–15 mmHg (T4–T7; all $p < 0.05$). At surgery end (T9), CO remained higher in the low-rate group ($p = 0.043$). All parameters in the low-rate group remained stable relative to baseline, whereas the standard-rate group showed significant declines in CO and SV and increased SVR at multiple time points ($p < 0.05$).

Conclusion

A low CO_2 insufflation rate of 1 L/min attenuates hemodynamic fluctuations during pneumoperitoneum establishment without affecting surgical efficiency, supporting individualized optimization of pneumoperitoneal parameters.

Trial Registration:

This trial was registered at the Chinese Clinical Trial Registry on November 17, 2025 (Registration No.: ChiCTR2500112583).

1. Introduction

In modern gynecological clinical practice, laparoscopic surgery has developed into the mainstream approach for various common gynecological procedures such as hysterectomy, ovarian cystectomy, and ectopic pregnancy lesion resection, due to its significant advantages including minimal invasiveness, rapid

postoperative recovery, and low complication rate, and is widely used in clinical diagnosis and treatment [1]. The key to the successful implementation of laparoscopic surgery is insufflating CO_2 into the abdominal cavity to establish a pneumoperitoneum, thereby creating sufficient operating space in the abdomen. However, this process inevitably leads to an increase in intra-abdominal pressure (IAP), which in turn triggers a series of chain reactions. At the cardiovascular system level, the elevated IAP directly exerts mechanical compression on large blood vessels such as the inferior vena cava and aorta, resulting in impaired venous return and reduced visceral and renal blood perfusion [2–4]. These effects may delay the patient's postoperative recovery process and are not conducive to the implementation of the Enhanced Recovery After Surgery (ERAS) concept.

In current clinical practice, to shorten the time for pneumoperitoneum establishment, a high insufflation rate of 3–5 L/min is generally adopted, but the safety of this protocol lacks systematic verification. Especially for patients with weak cardiovascular reserve function, high-rate insufflation may cause severe circulatory fluctuations due to the sudden rise in IAP, increasing the risk of adverse events [5]. Numerous studies have explored the effects of different pneumoperitoneal pressures on hemodynamics, but there is no clear conclusion on key issues such as whether different insufflation rates can further exacerbate or alleviate hemodynamic fluctuations, and whether there is a synergistic effect between insufflation rate and pneumoperitoneal pressure [6–9]. Relevant clinical evidence is relatively scarce. Although traditional invasive hemodynamic monitoring techniques (such as arterial puncture and catheterization, central venous pressure monitoring) can provide accurate data, they carry risks such as bleeding, infection, and vascular injury, which limit their application in low-risk patients undergoing gynecological laparoscopic surgery [10, 11].

As a non-invasive monitoring tool based on suprasternal fossa Doppler ultrasound, the Ultrasonic Cardiac Output Monitor (USCOM) can measure core hemodynamic indicators in real time and continuously including cardiac output (CO), heart rate (HR), stroke volume (SV), and systemic vascular resistance (SVR) without additional trauma. Its high sensitivity and specificity make it an ideal tool for capturing dynamic hemodynamic changes during pneumoperitoneum establishment [12].

Based on the above-mentioned clinical status and research gaps, this study used USCOM as the monitoring tool, focusing on two core parameters of CO_2 pneumoperitoneum—insufflation rate and pressure. It systematically explored the influence of different insufflation rates (1 L/min and 5 L/min) on patients' hemodynamic indicators under the same pneumoperitoneal pressure, clarified the association between insufflation rate and hemodynamic disturbances, and provided scientific evidence for clinically optimizing pneumoperitoneal parameter settings, reducing intraoperative hemodynamic risks, and improving patients' perioperative safety.

2. Methods

This was a prospective randomized double-blind study, approved by the Research Ethics Committee of Obstetrics and Gynecology Hospital of Fudan University and registered at the Chinese Clinical Trial Registry on November 17, 2025 (Registration No.: ChiCTR2500112583). This study was designed, conducted, and reported in accordance with the CONSORT guidelines. All patients meeting the inclusion criteria were

informed of the study-related information in the preoperative preparation room, and informed consent was obtained with signed consent forms. The study was conducted at the Obstetrics and Gynecology Hospital of Fudan University. A total of 54 patients were assessed for eligibility, of whom 4 were excluded and 50 were randomly assigned to the two groups (25 per group).

Inclusion criteria

American Society of Anesthesiologists (ASA) physical status □-□; age between 18 and 45 years; scheduled for routine gynecological laparoscopic surgery (such as hysterectomy, oophorectomy, ectopic pregnancy surgery, etc.) under general anesthesia.

Exclusion criteria

Body mass index (BMI) > 30 kg/m²; history of gynecological malignant tumors; coagulation disorders; complicated with severe cardiovascular diseases.

Randomization and Blinding

In this study, a computer-generated random number table was used for grouping with a block randomization method. The enrolled patients were divided into two groups at a 1:1 ratio: the 1 L/min insufflation rate group (Group A) and the 5 L/min insufflation rate group (Group B). The pneumoperitoneal pressure in both groups was finally set to 15 mmHg. The double-blind method was adopted throughout the study. The random allocation sequence was kept by a statistician in opaque sealed envelopes, which were opened by an anesthetic nurse not involved in data collection to set the pneumoperitoneal insufflation rate on the CO_2 insufflator.

Anesthetic procedures

All patients fasted for 8 hours and abstained from water for 4 hours preoperatively. After entering the operating room, the patients were placed in supine position, pre-oxygenated with a face mask at 6 L/min for 3 minutes, and a peripheral venous access was established in the upper limb for intravenous infusion of lactated Ringer's solution. A pre-infusion of 3 mL/kg was administered for volume expansion before anesthesia induction. Routine monitoring devices including non-invasive blood pressure measurement, pulse oxygen saturation (SpO_2) monitoring, and electrocardiography were connected. Blood pressure was recorded every 5 minutes, and HR and SpO_2 were continuously monitored intraoperatively.

All patients received a standardized anesthesia protocol. Induction agents included etomidate (0.3 mg/kg), sufentanil (0.5 μg/kg), and cisatracurium (0.15 mg/kg). Endotracheal intubation was performed 2 minutes after the administration of the muscle relaxant. Anesthesia maintenance was achieved with 1.5% sevoflurane inhalation combined with intravenous infusion of propofol (4 mg/kg/h) and remifentanil (0.1 μg/kg/min). Cisatracurium was intermittently injected intravenously as needed to maintain muscle relaxation, and the bispectral index (BIS) was maintained between 40 and 60.

Intraoperative Operation and Monitoring

All surgeries were performed using the standard 4-port laparoscopic approach, with CO_2 as the insufflation gas. A single experienced anesthesiologist used USCOM for non-invasive monitoring of cardiac output (CO) and HR at the following time points: before anesthesia induction (T0), intra-abdominal pressure (IAP) of 3 mmHg (T1), 5 mmHg (T2), 7 mmHg (T3), 9 mmHg (T4), 11 mmHg (T5), 13 mmHg (T6), 15 mmHg (T7), when the position was changed to the Trendelenburg position at the start of surgery (T8), and at the end of surgery (T9).

Volume-controlled mechanical ventilation was used intraoperatively, with oxygen flow rate adjusted to 2 L/min, inspiratory-expiratory ratio of 1:2, tidal volume of 6–8 mL/kg, and respiratory rate of 12–14 breaths/min. The partial pressure of end-tidal carbon dioxide was maintained between 30 and 45 mmHg, and airway pressure between 12 and 20 cm H_2O. When the mean arterial pressure (MAP) was 30% lower than the baseline value, phenylephrine (40 μg) was administered intravenously; when HR was < 50 beats/min, atropine (0.5 mg) was given intravenously; when MAP or HR was 30% higher than the baseline value, sedative-analgesic or vasoactive drugs were administered for treatment.

Primary and secondary endpoints

The primary outcomes were changes in CO, HR, SV, and SVR at different time points. We also documented secondary outcome measures including flow time corrected (FTC) and aortic flow velocity index (INO) at various time points.

Intraoperative adverse reactions included intraoperative hypotension, hypertension, tachycardia, and bradycardia. Postoperative adverse events included the following: admission to the intensive care unit postoperatively; occurrence of severe adverse events within 24 hours after surgery (such as reoperation, severe infection, severe intraoperative hemorrhage with blood loss > 1000 ml, etc.); surgical duration > 3 hours; and intraoperative occurrence of severe hypertension, hypotension, or arrhythmia.

Data Analysis

Data analysis was performed using SPSS 22.0 software (SPSS, Inc., Chicago, IL, USA). The sample size was estimated based on the primary outcome of CO. Referring to previous studies investigating hemodynamic changes during laparoscopic pneumoperitoneum [13], we anticipated a mean difference in CO of approximately 0.5 L/min between the two insufflation rates, with a pooled standard deviation of 0.8 L/min. Assuming a two-sided significance level of 0.05 and a statistical power of 80%, a minimum of 21 participants per group was required. To allow for potential exclusions during screening, we planned to assess 54 participants. Baseline characteristics were compared using independent samples t-test or chi-square test as appropriate. Hemodynamic parameters measured repeatedly over time (T0–T9) were analyzed using a two-way repeated-measures ANOVA with group as the between-subjects factor and time as the within-subjects factor. Mauchly's test of sphericity was applied, and Greenhouse-Geisser correction was used when the assumption of sphericity was violated. Following a significant group-by-time interaction, simple effects analyses with Holm–Šídák correction were used to compare groups at each time point and to assess changes from baseline within each group. A p value < 0.05 was considered statistically significant.

3. Results

This study was conducted at the Obstetrics and Gynecology Hospital of Fudan University from October 2025 to December 2025. Patient enrollment and data collection commenced after trial registration (November 17, 2025). A total of 54 patients were assessed for eligibility between October 2025 and December 2025. Of these, 4 were excluded (2 declined to participate and 2 did not meet inclusion criteria), and the remaining 50 were randomly assigned to Group A (1 L/min, n = 25) or Group B (5 L/min, n = 25). All randomized participants completed the study and were included in the final analysis. The participant flow throughout the trial is presented in Fig. 1.

The demographic characteristics and surgical information of the two groups were comparable (Table 1). The mean surgical duration, average pneumoperitoneum duration, and mean intravenous fluid volume of patients in both groups were 96.5 ± 5.8 minutes, 77.3 ± 5.0 minutes, and 1010 ± 117 mL, respectively, with no statistically significant differences between the groups ($p > 0.05$). Additionally, the two groups were similar in terms of age, height, weight, and American Society of Anesthesiologists (ASA) physical status classification.

Table 1
General data and surgery-related information of the two groups.

Characteristics	**Group A (n = 25)**	**Group B (n = 25)**	***p***
Age (year)	41.48 ± 6.26	38.84 ± 6.73	0.961
Height (cm)	161.00 ± 3.80	160.44 ± 4.16	0.651
Weight (kg)	58.52 ± 8.18	54.85 ± 6.08	0.194
Operative duration (min)	96.84 ± 5.43	96.16 ± 6.12	0.535
Pneumoperitoneum duration (min)	77.52 ± 5.18	77.08 ± 4.88	0.758
Intraoperative fluid replacement volume (mL)	991.60 ± 130.38	1030.00 ± 104.23	0.387
Values are presented as mean ± standard deviation			

Two-way repeated-measures ANOVA revealed significant group-by-time interactions for CO, SV, and SVR ($p_{group \times time} < 0.001$). Between-group comparisons showed that Group A maintained significantly higher CO and SV, along with lower SVR, compared to Group B at multiple time points (T4–T7; $p < 0.05$). Intragroup analysis further showed that Group A maintained stable hemodynamic parameters relative to baseline, whereas Group B exhibited significant declines in CO and SV and increased SVR. The dynamic trajectories of these hemodynamic parameters are illustrated in Fig. 2. Detailed results of between-group and within-group comparisons, along with the overall interaction effects, are summarized in Table 2.

Table 2
Comparison of hemodynamic parameters between groups at each time point and within-group changes from baseline.

Time	CO (L·min^{-1})			SV (mL)			SVR (dyne·s·cm^{-5})		
	Group A	Group B	*p*	Group A	Group B	*p*	Group A	Group B	*p*
T_0	4.3 ± 0.2	4.1 ± 0.1	0.267	70.5 ± 2.4	69.4 ± 1.7	0.628	1430.6 ± 37.7	1480.0 ± 46.7	0.356
T_1	4.3 ± 0.2	4.2 ± 0.1	0.298	70.6 ± 2.4	71.0 ± 1.8	0.876	1450.9 ± 39.0	1464.9 ± 47.5	0.792
T_2	4.4 ± 0.2	4.3 ± 0.1	0.488	72.1 ± 2.0	73.3 ± 2.0	0.604	1425.9 ± 37.4	1439.3 ± 41.6	0.800
T_3	4.3 ± 0.2	4.2 ± 0.1	0.563	69.4 ± 2.2	71.0 ± 1.7	0.511	1501.9 ± 50.6	1470.0 ± 41.6	0.601
T_4	4.2 ± 0.2	3.8 ± 0.2	0.021	69.2 ± 2.0	65.5 ± 1.4	0.108	1488.8 ± 40.8	1601.6 ± 71.7$^{\#}$	0.029
T_5	4.2 ± 0.2	3.7 ± 0.1	< 0.001	68.9 ± 2.0	62.2 ± 1.4	0.004	1490.7 ± 43.2	1678.6 ± 48.8$^{\#}$	< 0.001
T_6	4.1 ± 0.2	3.6 ± 0.1$^{\#}$	< 0.001	67.1 ± 2.3	60.7 ± 1.4$^{\#}$	0.006	1523.8 ± 45.6	1751.9 ± 56.4$^{\#}$	< 0.001
T_7	4.0 ± 0.1	3.4 ± 0.1$^{\#}$	0.001	64.7 ± 2.0	57.8 ± 1.4$^{\#}$	0.003	1565.9 ± 41.8	1831.0 ± 56.3	< 0.001
T_8	4.6 ± 0.2	4.7 ± 0.2$^{\#}$	0.418	71.8 ± 1.9	70.1 ± 2.1	0.467	1587.0 ± 57.3	1621.6 ± 69.9	0.185
T_9	4.6 ± 0.2	4.9 ± 0.1$^{\#}$	0.043	71.1 ± 1.7	73.1 ± 1.9	0.397	1629.0 ± 54.3	1572.1 ± 66.0	0.621
$p_{group\times time}$	< 0.001			< 0.001			< 0.001		

Values were expressed as mean ± SD. *p* between-group comparison at each time point. $p_{group\times time}$: Overall group-by-time interaction. #: Significantly different from baseline (T0) within the same group.

4. Discussion

Laparoscopic surgery is a core minimally invasive approach in gynecology, yet the required CO_2 pneumoperitoneum can induce significant hemodynamic disturbances due to increased intra-abdominal pressure (IAP), which compresses great vessels, impairs venous return, and reduces cardiac output (CO) [13, 14]. While previous studies have predominantly focused on the effects of pneumoperitoneal pressure [15], the role of the insufflation rate remains less understood. This study utilized the USCOM to sensitively capture real-time hemodynamic changes [16], specifically comparing a low insufflation rate (1 L/min, Group A) with a standard rate (5 L/min, Group B) under equivalent pressures. These findings provide direct

evidence for the individualized optimization of pneumoperitoneal parameters to enhance perioperative circulatory stability.

The observed hemodynamic profile aligns with established physiological principles. The increase in intra-abdominal pressure (IAP) during pneumoperitoneum compresses the inferior vena cava, impedes venous return, and reduces cardiac preload, constituting the primary mechanism for decreased CO [2–4]. Our study further reveals that the insufflation rate is a critical modifier of this process. Rapid insufflation leads to an abrupt rise in IAP, potentially provoking an acute circulatory stress response manifested as a more pronounced decrease in SV and a compensatory rise in SVR. In contrast, a low insufflation rate allows for a more gradual increase in IAP, providing the cardiovascular system with valuable time for compensatory adjustments, thereby mitigating the abrupt reduction in preload and the sharp increase in afterload.

These mechanistic insights are supported by the distinct hemodynamic patterns observed between the two groups and are consistent with the conclusion of previous studies [13]. Significant between-group differences emerged as early as T4 (IAP = 9 mmHg) and persisted through T7 (IAP = 15 mmHg), with Group A maintaining significantly higher CO and SV, along with a significantly lower SVR, compared to Group B at all these points ($p < 0.05$). This indicates that the protective effect of low-flow insufflation begins once IAP reaches a moderately elevated level and continues throughout the pressure build-up phase. Notably, even at the end of surgery (T9), Group A exhibited significantly higher CO than Group B ($p = 0.043$), suggesting that the hemodynamic benefits of a gradual pneumoperitoneum establishment may extend beyond the immediate insufflation period.

The differential impact of insufflation rate was also evident in the intragroup comparisons. In Group B, significant declines from baseline in CO and SV were observed starting at T6 (IAP = 13 mmHg) and persisted through T9 ($p < 0.05$), accompanied by a progressive increase in SVR that reached significance at T4–T6. In contrast, Group A maintained hemodynamic parameters comparable to baseline throughout the entire observation period, with no significant changes detected at any time point after Holm–Šidák correction. This finding underscores the remarkable stability afforded by the low-flow protocol, which effectively buffers the cardiovascular system against the cumulative stress of prolonged pneumoperitoneum.

Notably, despite the differing trends in CO between groups, conventional hemodynamic parameters such as heart rate (HR) and mean arterial pressure (MAP) showed no intergroup differences at any time point. This highlights the limitation of traditional monitoring, which may fail to sensitively reflect actual changes in cardiac function and tissue perfusion [5]. The USCOM device, a non-invasive ultrasonic cardiac output monitor used in this study, successfully captured the dynamic changes in core hemodynamic indices like CO and SV, enabling the detection of significant differences between insufflation rates. This not only validates our hypothesis but also demonstrates the practical utility of such non-invasive monitoring in optimizing pneumoperitoneum management.

Unlike previous studies that predominantly focused on pneumoperitoneal pressure [9, 10], our investigation innovatively centers on the insufflation rate—an often-overlooked operative variable. Our results confirm that even at an identical "target pressure," the "speed" at which it is achieved can yield distinct physiological

impacts, deepening the understanding of pneumoperitoneum-induced hemodynamic effects. Crucially, the low-flow protocol achieved hemodynamic benefits without sacrificing surgical efficiency (comparable operative and pneumoperitoneum durations) and demonstrated a good safety profile, significantly enhancing its clinical feasibility for adoption. This approach better aligns the goals of surgeons seeking optimal exposure and anesthesiologists maintaining patient stability, resonating well with the principles of Enhanced Recovery After Surgery (ERAS).

This study has certain limitations. First, the sample size was relatively small, and the enrolled population was restricted to relatively healthy women (ASA I-II, aged 18–45 years). Therefore, caution is warranted when extrapolating the conclusions to high-risk populations, such as the elderly or those with significant cardiovascular comorbidities. Second, the study primarily focused on intraoperative effects, lacking follow-up assessment of long-term recovery quality. Future research should expand the sample size to include patients with varying risk profiles, extend the follow-up period, and incorporate multidimensional recovery metrics to comprehensively evaluate the long-term clinical benefits of the low-flow insufflation strategy.

The results of this study showed that with the gradual increase in IAP, the cardiac output (CO) of patients in both groups showed a progressive downward trend, which is highly consistent with the conclusions of previous studies [4, 13]. The core mechanism lies in the mechanical compression of the inferior vena cava caused by increased IAP, leading to reduced venous return and subsequent decrease in CO. Notably, there was a significant difference in the magnitude of CO reduction under different insufflation rates: when IAP reached 9 mmHg and above (time points T4–T6), the CO value in the low-rate insufflation group (Group A) was significantly higher than that in the standard-rate insufflation group (Group B), indicating that low-rate insufflation can effectively mitigate the degree of CO reduction during pneumoperitoneum establishment.

Further analysis suggested that this difference may stem from two mechanisms: on one hand, low-rate insufflation results in a slow rise in IAP, providing sufficient compensatory adjustment time for the cardiovascular system, avoiding acute impact of sudden IAP elevation on the circulatory system, and reducing circulatory stress response induced by mechanical compression; on the other hand, slow insufflation can slow down the absorption rate of CO_2, reduce its interference with the body's acid-base balance, thereby alleviating the inhibitory effect of CO_2 retention on myocardial function [17, 18]. Meanwhile, this study using USCOM non-invasive ultrasonic monitor found that the SV in the low-rate insufflation group was significantly higher than that in the standard-rate insufflation group. This result may be related to the attenuated increase in SVR observed in the low-rate insufflation group. The relatively smaller rise in SVR likely reduced the overall circulatory load, exerting a protective effect on the cardiovascular system.

In addition, there was no statistically significant difference in HR between the two groups at each time point, suggesting that insufflation rate has little impact on HR. This phenomenon may be related to the inclusion criteria of this study: all subjects were ASA physical status □–□ patients with a concentrated age range and good cardiovascular reserve function, who could maintain HR stability through their own neurohumoral regulation. This result also provides a basis for expanding the scope of included populations in subsequent studies.

In terms of evaluation of surgical efficiency and safety, there were no significant differences in core efficiency indicators such as surgical duration, average pneumoperitoneum time, and intraoperative blood loss between the two groups. This result directly eliminates clinicians' concerns that low-rate insufflation may prolong the surgical process, confirming that the 1 L/min low-rate insufflation protocol will not affect the surgical progress and can better maintain intraoperative hemodynamic stability while ensuring surgical efficiency. At the same time, there was no significant difference in the incidence of adverse events between the two groups, and no serious adverse events occurred, further verifying the safety of the low-rate insufflation protocol, indicating that it does not increase the risk of postoperative complications and is feasible for clinical adoption.

This study used USCOM non-invasive ultrasonic monitor for hemodynamic monitoring. Compared with traditional invasive monitoring techniques, this device has the advantages of simple operation, non-invasiveness, and real-time continuous monitoring. It not only avoids the risk of complications such as bleeding and infection caused by invasive operations like arterial puncture and catheterization but also can accurately capture dynamic changes in hemodynamics. This study successfully identified dynamic differences in CO under different insufflation rates through USCOM, which not only provided reliable data support for the research conclusions but also further verified the applicability and reliability of this monitoring technology in pneumoperitoneum-related hemodynamic research, offering practical evidence for its popularization and application in the field of gynecological anesthesia.

This study has certain limitations that should be addressed in future research *real-time and continuously measure core hemodynamic indicators*: first, the sample size was relatively limited (25 cases in each group), and the included population was restricted to ASA physical status □–□ patients aged 18–45 years, resulting in limited generalizability of the research results, which cannot be directly applied to high-risk populations such as the elderly and patients with underlying cardiovascular diseases; second, the follow-up duration is short, failing to explore the long-term impact of different insufflation rates on patients' postoperative rehabilitation. In the future, the sample size can be expanded to include patients of different ages and different cardiovascular risk levels, the follow-up cycle can be prolonged and combined with multidimensional rehabilitation indicators to more comprehensively evaluate the clinical value of the low-rate insufflation protocol.

5. Conclusion

In conclusion, employing a low CO_2 insufflation rate of 1 L/min during gynecological laparoscopic surgery effectively attenuates hemodynamic fluctuations associated with pneumoperitoneum establishment. Compared to a standard rate of 5 L/min, the low-flow protocol better preserves cardiac output and stroke volume while mitigating the rise in systemic vascular resistance, without compromising surgical efficiency or safety. These findings provide compelling evidence for the individualized optimization of pneumoperitoneal parameters, supporting the integration of low-flow insufflation into clinical practice to enhance perioperative stability and align with Enhanced Recovery After Surgery principles.

Abbreviations

USCOM: Ultrasonic Cardiac Output Monitor;

ANOVA: Analysis of variance; BMI: Body mass index; BIS: Bispectral index; CO: Cardiac output; FTC: Flow time corrected; HR: Heart rate; IAP: intraabdominal pressure; INO: Aortic flow velocity index; MAP: Mean arterial pressure; SpO_2: Pulse oxygen saturation; SV: stroke volume; SVR: Systemic vascular resistance.

Declarations

Ethics approval and consent to participate

The study protocol was reviewed and approved by the Research Ethics Committee of Obstetrics and Gynecology Hospital of Fudan University. All patients meeting the inclusion criteria were informed of the study-related information in the preoperative preparation room, and informed consent was obtained with signed consent forms. Approval was obtained from the Chinese Clinical Trial Registry on November 17, 2025 (Registration No.: ChiCTR2500112583).

Consent for publication

Not applicable.

Data availability

The data that support the findings of this study are available on request from the corresponding author. The data is not publicly available due to privacy or ethical restrictions.

Competing Interests

The authors declare no competing interests.

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Authors' contributions

All authors contributed to the study conception and design. Rui Liu participated in the design, conducted the study, analyzed the data, and prepared the manuscript. Yingcai Song participated in conducting the study and contributed to manuscript preparation. Zhiqiang Liu and Jiang Li led the study design, oversaw its execution, and supervised manuscript preparation. All authors read and approved the final manuscript.

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Figures

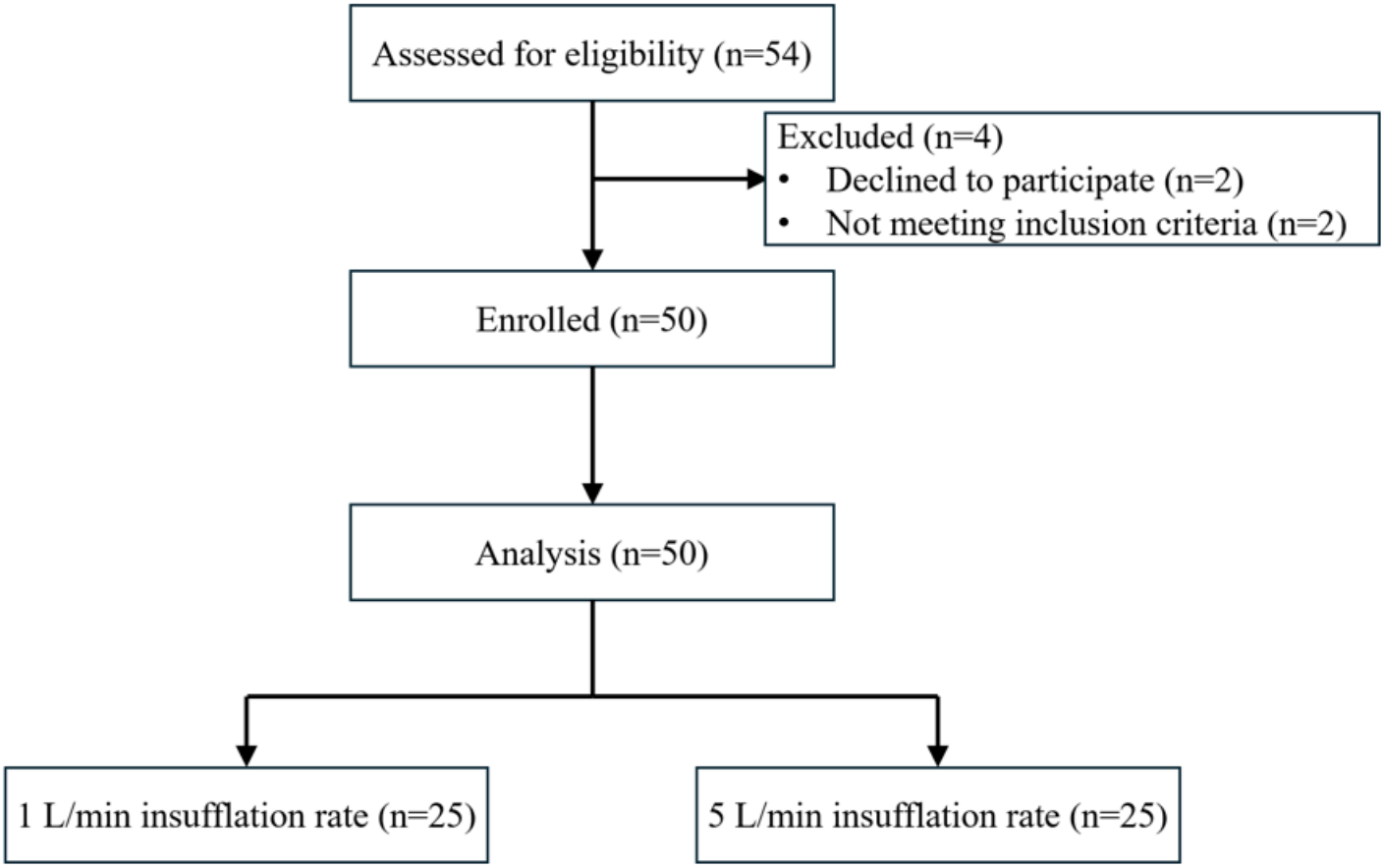


Figure 1

CONSORT flow diagram.

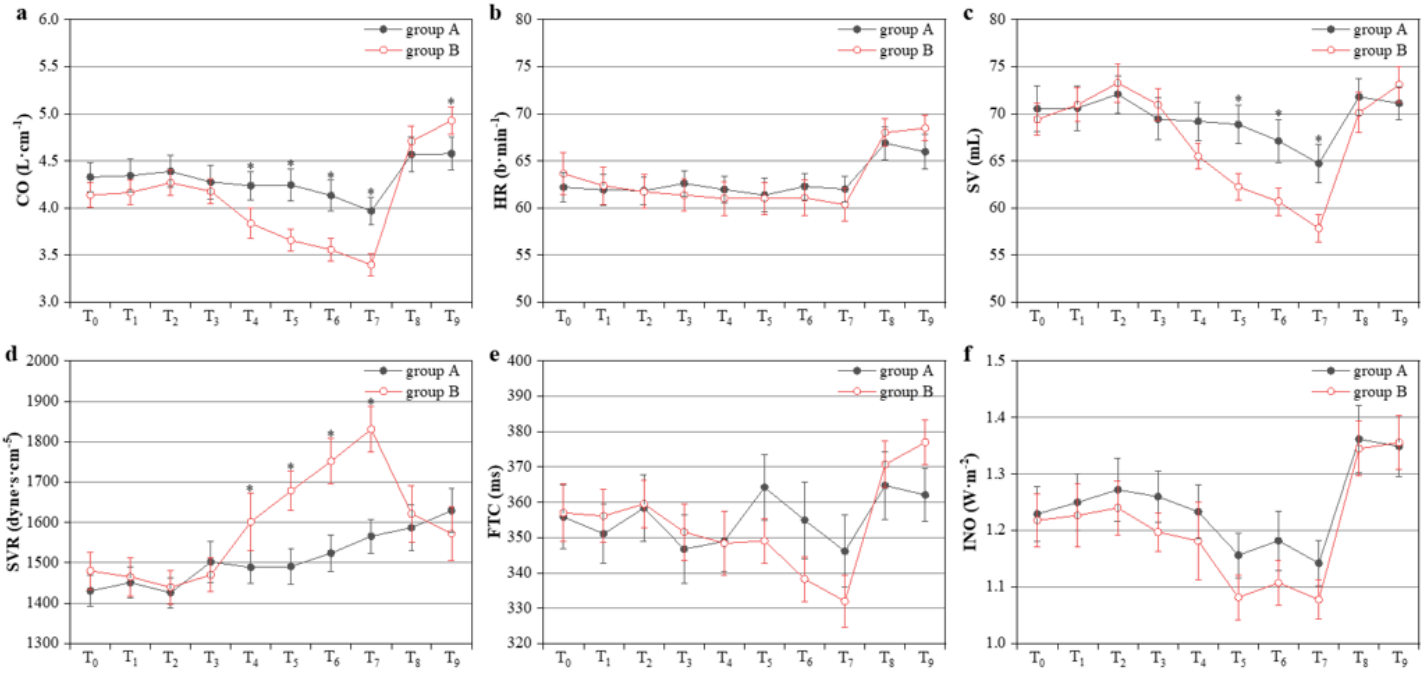


Figure 2

Changes in CO (a), HR (b), SV(c), SVR (d), FTC (e) and INO (f) during pneumoperitoneum establishment and surgery at different time points.