

Impact of Intraoperative Postural Transitions on Internal Carotid Artery Blood Flow During Gynecologic Laparoscopic Surgery

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Objective: Reduced internal carotid artery (ICA) blood flow can cause cerebral hypoperfusion, increasing the risk of intraoperative or postoperative cerebral ischemia. In laparoscopic surgery, postural changes and pneumoperitoneum may further compromise ICA hemodynamics. This study aims to evaluate the effects of intraoperative postural transitions on ICA blood flow in patients undergoing gynecologic laparoscopic surgery.

Methods: A single-center, prospective, non-randomized observational study was performed. Measurements of ICA blood flow, heart rate (HR), and mean arterial pressure (MAP) were obtained at eight intraoperative time points: upon arrival to the operating table while awake (T1), post-induction of anesthesia in the supine position (T2), following pneumoperitoneum in the supine position (T3), immediately after placement in the Trendelenburg position (T4), 10 minutes (T5) and 20 minutes (T6) after Trendelenburg positioning, upon return to the supine position (T7), and at the conclusion of surgery (T8).

Results: A total of 79 patients were enrolled in this study. A significant reduction in ICA blood flow was observed at T2 compared to T1 (263.8 ± 11.4 vs 323.5 ± 12.0 mL/min, $p < 0.001$), with further reduction at T3 (237.2 ± 9.8 vs 323.5 ± 12.0 mL/min [T1], $p < 0.001$, vs T1). No statistically significant changes were observed from T4 to T6. Upon transitioning from the Trendelenburg position to supine (T7), ICA blood flow further decreased (202.1 ± 7.5 vs 237.2 ± 9.8 mL/min, $p = 0.004$), accompanied by reductions in HR (60.0 ± 0.7 vs 66.9 ± 1.0 beats/min, $p < 0.001$) and MAP (82.8 ± 12.4 vs 93.6 ± 13.5 mmHg, $p < 0.001$).

Conclusion: Intraoperative postural transitions during gynecologic laparoscopic surgery are associated with fluctuations in ICA blood flow. The return from the Trendelenburg to the supine position results in a marked decrease in ICA blood flow, HR, and MAP.

Clinical Trial Registration: <https://www.chictr.org.cn/showproj.html?proj=178094>, Identifier: ChiCTR2200065104, Registered October 27, 2022.

Plain Language Summary: This prospective observational study was conducted to enhance the understanding of intraoperative hemodynamic changes associated with postural transitions in gynecologic laparoscopic surgery. Utilizing Doppler ultrasound, fluctuations in internal carotid artery blood flow induced by positional changes were characterized, providing clinically relevant insights for perioperative management and patient safety.

Keywords: gynecologic laparoscopic surgery, internal carotid artery blood flow, intraoperative posture changes, Trendelenburg position

Introduction

In gynecologic laparoscopic surgery, the use of anesthesia, induction of pneumoperitoneum, and intraoperative postural transitions, particularly the rapid transition from Trendelenburg to supine position, may induce significant hemodynamic fluctuations that can compromise cerebral autoregulation and consequently affect cerebral blood flow (CBF) perfusion.

This specific postural transition carries substantial clinical significance, as the rapid redistribution of blood volume following prolonged Trendelenburg positioning may exacerbate the risk of cerebral hypoperfusion. The creation of pneumoperitoneum increases intra-abdominal pressure (IAP), which exerts mechanical compression on abdominal vasculature, thereby impeding venous return, reducing perfusion of abdominal organs, and diminishing cardiac output.^{1,2} In addition, carbon dioxide (CO₂) retention or the onset of hypercapnia may induce cerebral vasodilation, contributing to a secondary elevation in intracranial pressure (ICP).³ However, postural adjustments during surgery can aggravate these physiological changes.⁴ An additional rise in ICP and IAP may increase the risk of cerebral edema, compromise the integrity of the blood-brain barrier, and lead to potential neurological injury through reduced cerebral perfusion and oxygenation.^{5,6}

Direct monitoring of CBF in clinical settings remains limited, with available modalities including near-infrared spectroscopy, jugular venous bulb saturation (SjvO₂), and transcranial Doppler ultrasonography.^{7,8} Given the internal carotid artery (ICA) serves as a primary conduit for cerebral perfusion, changes in its diameter and blood flow velocity may serve as surrogate markers for alterations in CBF.^{9,10} Carotid ultrasonography is commonly used to assess ICA stenosis, evaluate risk of occlusion, and aid in inferring the cause of ischemic stroke.¹¹ Doppler ultrasound, in particular, has demonstrated utility in detecting intraoperative variations in ICA blood flow, providing a feasible method for indirect assessment of CBF.¹¹ The present study aims to investigate intraoperative changes in ICA blood flow among patients undergoing laparoscopic gynecologic surgery, using Doppler ultrasound as a monitoring modality.

Materials and Methods

Participant Selection

This non-randomized, prospective, observational study was approved by the institutional ethics committee (Approval number KY-2022-125) and registered with the Chinese Clinical Trials Registry prior to participant enrollment (<https://www.chictr.org.cn>, registration number: ChiCTR2200065104, October 27, 2022). Written, informed consent was obtained from all participants prior to study inclusion.

Inclusion criteria were as follows: (1) American Society of Anesthesiologists (ASA) physical status classification I or II; (2) Age between 18 and 60 years; (3) Body mass index (BMI) between 18 kg/m² and 30 kg/m²; (4) Scheduled for elective gynecologic laparoscopic surgery at the study hospital.

Exclusion criteria were as follows: (1) Presence of neck skin conditions (eg trauma, scarring, dressings) that precluded adequate acoustic evaluation of the ICA; (2) Known conditions affecting cerebral hemodynamics, such as intracranial tumors, cerebrovascular malformations, aneurysms, moyamoya disease, or arterial dissection; (3) Evidence of carotid artery pathology, including stenosis, occlusion, atherosclerosis, or plaque formation, as detected by preoperative cervical Doppler ultrasonography; (4) History of endovascular procedures involving the ICA, thyroid surgery, or any prior cervical vascular or neck surgeries; (5) History of severe cardiac, hepatic, pulmonary, or renal dysfunction; (6) Untreated or uncontrolled hypertension or diabetes mellitus; (7) Current participation in another clinical study; (8) Any other condition deemed inappropriate for inclusion by the investigator.

Intraoperative Protocols

All anesthetic and surgical procedures were conducted in accordance with institutional protocols. Anesthesia was induced using sufentanil (0.4 µg/kg), propofol (2 mg/kg), and cisatracurium besilate (0.2 mg/kg). Maintenance of anesthesia was achieved with continuous infusions of remifentanyl (0.1–0.2 µg/kg/h), propofol (4–6 mg/kg/h), and cisatracurium besilate (0.2–0.3 mg/kg). Anesthetic depth was adjusted to maintain a bispectral index (BIS) between 40 and 60. Anesthesia monitoring included pulse oximetry, HR, three-lead electrocardiography, and blood pressure (systolic, diastolic, and MAP) at five-minute intervals.

Mechanical ventilation was administered with a tidal volume of 6–8 mL/kg based on ideal body weight, respiratory rate of 12–15 beats/min, and an inspiratory-to-expiratory ratio of 1:2. Airway pressures were maintained between 20–24 cmH₂O, and ventilatory parameters were adjusted to maintain an end-tidal CO₂ partial pressure (P_{ET}CO₂) of 35–40 cmH₂O. Laparoscopic pneumoperitoneum was maintained using CO₂ insufflation at an IAP of 12 mmHg. Fluid management

was achieved using a balanced crystalloid solution containing sodium, potassium, magnesium, calcium, and glucose. Vasopressors, including ephedrine and phenylephrine, were intermittently administered to maintain MAP above 65 mmHg.

Measurements

ICA blood flow was the primary outcome measure. Bilateral ICA blood flow measurements were independently recorded and analyzed using averaged bilateral values. All Doppler ultrasound measurements were performed by a single trained anesthesiologist, with sonographers blinded to intraoperative hemodynamic parameters during image acquisition to minimize measurement bias. Additional cerebrovascular measurements included mean ICA velocity, peak systolic velocity (PSV), end-diastolic velocity (EDV), and ICA diameter. ICA blood flow was calculated by multiplying the ICA beat volume by the heart rate (measured by electrocardiography). Beat volume was calculated from ICA blood velocity and vessel diameter. A Doppler ultrasound system (Mindray, Z6, 7L4A liner probe, 7.5 MHz) was used to assess mean ICA velocity (V_{mean}) approximately 2 cm above the carotid bifurcation, with an insonation angle of 60°. The ICA diameter was measured concurrently at the insonation site. Measurements were obtained at eight predefined intraoperative time points: upon arrival to the operating table while awake (T1), post-induction of anesthesia in the supine position (T2), following pneumoperitoneum in the supine position (T3), immediately after placement in the Trendelenburg position (T4), 10 minutes (T5) and 20 minutes (T6) after Trendelenburg positioning, upon return to the supine position (T7), and at the conclusion of surgery (T8). For each time point, ICA vascular variables were recorded over five consecutive cardiac cycles, and the average value was used for analysis.

The following physiological parameters were monitored concurrently: HR, MAP, P_{ETCO_2} , peak airway pressure, respiratory rate, and BIS using the Bene Vision N12 (Mindray, China). A protractor was affixed to the operating table with the supine position set as the 0° reference to document the Trendelenburg angle accurately.

Statistical Analysis

Pilot data from 16 patients indicated that ICA blood flow following the Trendelenburg position was approximately 25% lower than after returning to the supine position. Based on this finding, a sample size of at least 62 patients was calculated to achieve 90% statistical power with a two-sided $\alpha = 0.05$. To account for an anticipated dropout rate of 20%, a total of 78 patients were enrolled.

Continuous variables are presented as mean \pm standard error of the mean (SEM), and categorical variables are presented as percentages, unless otherwise specified. Changes in ICA blood flow and other variables across eight time points were assessed using one-way repeated measures analysis of variance (ANOVA), followed by the Bonferroni post hoc tests for multiple comparisons. A p -value < 0.05 was considered statistically significant. All statistical analyses were performed using IBM SPSS® Statistics for Windows, version 27.0 (IBM Corp. New York, USA).

Results

From November 2022 to January 2023, a total of 117 patients scheduled for gynecologic laparoscopic surgery at the study institution were screened for eligibility. Following application of the inclusion and exclusion criteria, 85 patients met the eligibility requirements. Of these, 6 patients were excluded during the study period—2 due to intraoperative conversion to laparotomy and 4 due to surgical durations of less than 20 minutes. Procedures shorter than 20 minutes were excluded to ensure adequate assessment of hemodynamic stability across at least two complete surgical phases (eg, pneumoperitoneum establishment and positional transition). Ultimately, 79 patients were included in the final analysis (Figure 1). The mean age of the study cohort was 37.5 ± 1.0 years. The mean duration of anesthesia was 148.2 ± 5.3 minutes, and the mean operation time was 108 ± 5.0 minutes. The average degree of head-down tilt was 14.8 ± 0.4 degrees. Baseline characteristics, including age, weight, height, and BMI, as well as perioperative variables such as anesthesia and operative times are presented in Table 1. Intraoperative cerebrovascular and respiratory measurements across predefined time points are summarized in Table 2.

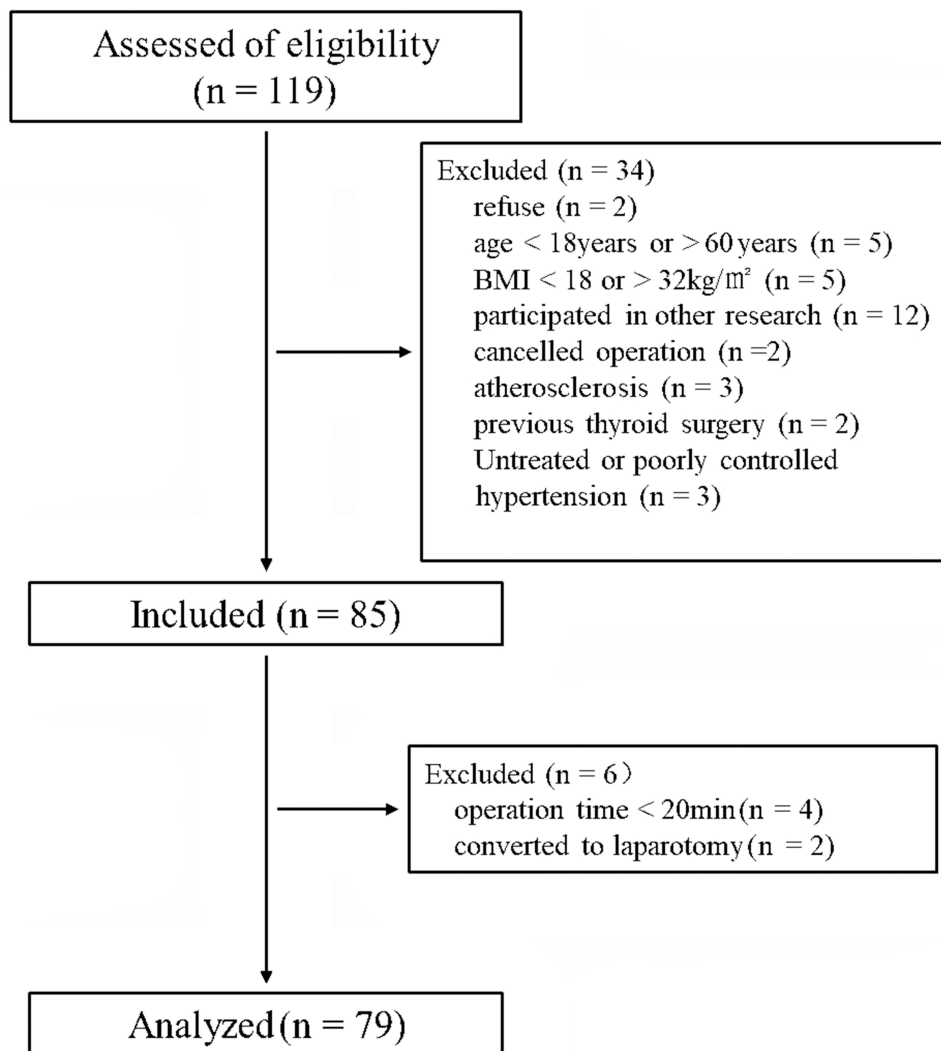


Figure 1 Trial profile of the study.

ICA Blood Flow

ICA blood flow was the primary outcome measure of this study. Repeated measures ANOVA demonstrated a significant reduction in ICA blood flow at all intraoperative time points (T2-T8) compared to the baseline (T1, awake state) ($p < 0.001$). Notably, ICA blood flow decreased further at T3 compared to T1. No significant differences in ICA blood flow were

Table 1 Baseline Characteristics of the Study Participants

Parameter	Data
Age (years)	37.5±9.0
Weight (kg)	56.0±9.6
High (cm)	158.0±6.2
BMI (kg/m ²)	22.6±3.7
ASA	
I	37 (46.8%)
II	42 (53.2%)

(Continued)

Table 1 (Continued).

Parameter	Data
Anesthesia time (min)	148.2±46.7
Operative time (min)	108.2±44.8
Angle of posture change (°)	14.8±3.1

Note: Data were shown in Mean ± SEM or percentage (%).

Abbreviation: ASA, American Society of Anesthesiologists.

Table 2 Intraoperative Cerebrovascular and Respiratory Variables During Gynecologic Laparoscopic Surgery

	T1	T2	T3	T4	T5	T6	T7	T8
ICA mean velocity (cm/s)	18.2±3.1	16.8±4.1	15.4±4.0	16.6±5.4	16.8±4.7	16.6±4.2	15.0±3.6	13.8±3.3
PSV (cm/s)	61.5±12.4	62.9±13.8	57.1±15.2	53.9±14.3	53.9±13.4	56.0±15.8	56.6±16.6	57.3±16.4
EDV (cm/s)	24.7±6.5	24.8±9.4	23.2±12.1	23.0±12.0	21.8±5.7	23.8±9.3	22.3±5.8	21.0±5.3
Diameter (mm)	5.4±0.5	5.2±0.5	5.4±0.5	5.4±0.5	5.4±0.5	5.5±0.5	5.3±0.6	5.3±0.5
Peak airway pressure (cmH ₂ O)	–	14.9±2.2	19.9±2.9	21.5±3.4	21.8±3.2	16.9±2.7	15.8±2.4	–
Respiratory rate (breaths/min)	–	12.6±0.8	12.4±0.6	12.4±0.6	12.5±0.8	12.6±0.8	12.7±1.0	13.0±1.0
P _{ET} CO ₂ (mmHg)	–	31.9±3.2	31.7±2.3	34.1±2.7	36.1±2.4	36.6±2.4	36.4±2.9	22.8±2.7
Bispectral Index	–	48.1±9.6	42.1±10.3	39.2±9.7	39.1±10.8	39.7±10.3	43.9±10.8	51.0±12.1

Notes: T1, awake patient at the operating table; T2, after anesthesia induction with supine position; T3, after pneumoperitoneum with supine position; T4, immediately after the Trendelenburg position; T5, 10min after the Trendelenburg position; T6, 20min after the Trendelenburg position; T7, return to the supine position; T8, at the end of surgery. Data were shown in Mean ± SEM.

Abbreviations: ICA, internal carotid artery; PSV, peak systolic velocity; EDV, end-diastolic velocity; P_{ET}CO₂, end-tidal carbon dioxide partial pressure.

observed between T3 and subsequent Trendelenburg positions (T4–T6). However, a significant reduction was observed upon return to the supine position at T7 (202.1 ± 7.5 vs 237.2 ± 9.8 mL/min, $p < 0.001$), with a further decrease at T8 (166.8 ± 8.0 vs 237.2 ± 9.8 mL/min, $p < 0.001$) (Figure 2).

A subgroup analysis, based on head-down tilt angle ($\leq 15^\circ$ and $> 15^\circ$), indicated no statistically significant difference in ICA blood flow changes between the two groups (Table 3)

Heart Rate (HR)

HR values across intraoperative time points (T2–T8) were significantly lower compared to the awake baseline (T1) ($p < 0.001$). A significant reduction was also noted at T3 compared to T2 (72.8 ± 1.2 vs 66.9 ± 1.0 beats/min, $p < 0.001$). No significant difference in HR were detected during the Trendelenburg phase (T4–T6) relative to T3. HR further declined upon return to the supine position at T7 (60.0 ± 0.7 vs 66.9 ± 1.0 at T3 beats/min, $p < 0.001$), with the lowest HR observed at T8 (57.8 ± 0.6 vs 66.9 ± 1.0 at T3 beats/min, $p < 0.001$) (Figure 2).

Mean Arterial Pressure (MAP)

MAP increased significantly at T2 compared to T1 (100.8 ± 13.6 vs 92.4 ± 11.4 mmHg, $p < 0.001$). A significant decrease occurred at T3 93.6 ± 13.5 mmHg ($p < 0.001$), although the difference from T1 was not statistically significant (Figure 2). Unlike ICA blood flow and HR trends, MAP increased significantly at the onset of the Trendelenburg position (T4) compared to T3 (99.1 ± 12.3 vs 93.6 ± 13.5 mmHg, $p < 0.001$). No significant difference were observed at T5 and T6 relative to T3. MAP decreased significantly upon return to the supine position at T7 (82.8 ± 12.4 vs 93.6±13.5 at T3, $P < 0.001$), reaching its lowest value at T8 (81.3 ± 9.8 mmHg, $p < 0.001$ vs T3) (Figure 2).

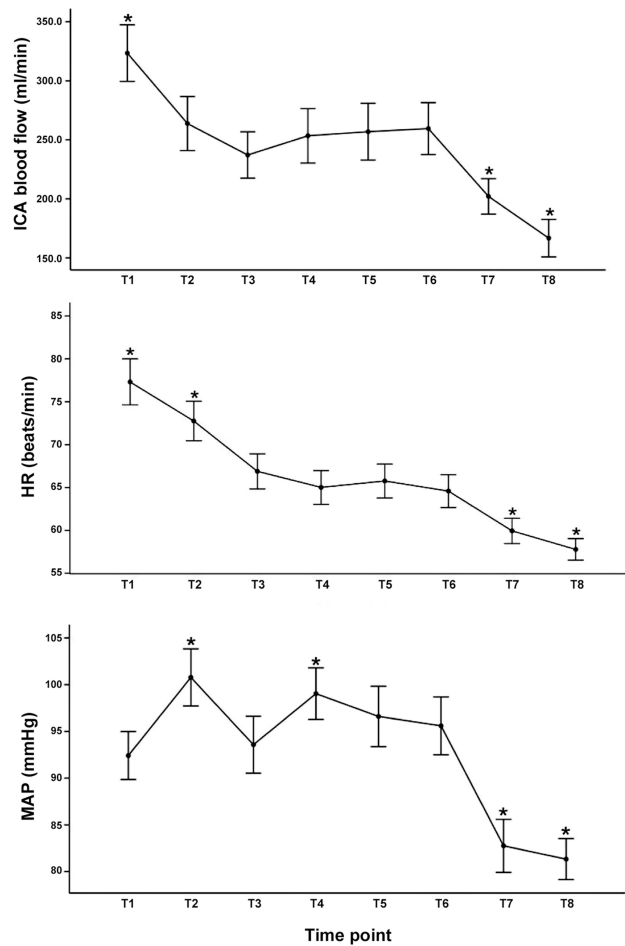


Figure 2 Changes in ICA blood flow, heart rate, and mean arterial pressure during gynecologic laparoscopic surgery. Trends in ICA blood flow, HR, and MAP measured across eight intraoperative time points: T1: Awake, prior to anesthesia induction; T2: Post-anesthesia induction, supine position; T3: Post-pneumoperitoneum, supine position; T4: Immediately after Trendelenburg positioning; T5: 10 minutes after Trendelenburg positioning; T6: 20 minutes after Trendelenburg positioning; T7: Return to supine position; T8: End of surgery. Significant decreases in ICA blood flow, HR, and MAP were observed at T7 compared to T3. Data are presented as mean ± SEM. *p < 0.05 versus T3. **Abbreviations:** ICA, internal carotid artery; HR, heart rate; MAP, mean arterial pressure.

Discussion

The results of this study demonstrated that in patients with ASA physical status I–II undergoing elective gynecologic laparoscopic surgery, ICA blood flow and HR decreased significantly following the induction of anesthesia. After pneumoperitoneum, further reductions in HR and MAP were observed compared to post-induction values. Although no

Table 3 Comparison of Head-Down Tilt Angle and ICA Blood Flow Between T4 and T7

Group	ICA Blood Flow (mL/min)			Repeated Measures Analysis		
	T4	T5	T6	F	P	Partial η^2
≤15°	261.4±18.0	257.9±17.2	253.7±16.0	–	–	–
>15°	243.9±13.4	255.7±16.7	266.6±14.9	–	–	–
Group	–	–	–	0.012	0.914	0.000
Time point	–	–	–	0.348	0.707	0.009
Group×Time point	–	–	–	1.704	0.212	0.020

Notes: T4, immediately after the Trendelenburg position; T5, 10min after the Trendelenburg position; T6, 20min after the Trendelenburg position; T7, return to the supine position. No statistical difference in the effect of the angle of head-down on ICA blood flow.

significant changes in cerebrovascular or hemodynamic variables were noted during the Trendelenburg position (T4–T6), a marked decline in ICA blood flow, HR, and MAP occurred upon returning to the supine position (T7), with the lowest values recorded at the end of surgery (T8). While ICA blood flow during Trendelenburg did not differ significantly from post-pneumoperitoneum levels, it remained lower than values recorded in the awake state. Additionally, variations in the degree of Trendelenburg positioning, did not result in statistically significant differences in ICA blood flow.

A particularly novel finding of this study is the significant reduction in ICA blood flow, HR, and MAP during the transition from the Trendelenburg to supine position. Most existing studies have primarily examined cerebral hemodynamic changes following postural adjustments, with limited attention to the physiological consequences of postural recovery. It is well-established that during abrupt fluctuation in arterial pressure, CBF may more closely parallel MAP, particularly when cerebral autoregulatory capacity is compromised.¹² Kurazumi et al reported that rapid postural changes enhance the synchronization and coherence between arterial pressure and CBF.¹³ Moreover, mild hypercapnia and changes in cerebrospinal fluid dynamics could weaken autoregulatory function.¹⁴

In the present study, ICA blood flow did not significantly decline during 10 minutes of Trendelenburg positioning when compared to post-induction levels, nor was it affected by the degree of head-down tilt within the observed range. However, this finding contrasts with that of Yu et al, who reported significantly lower ICA blood flow in patients undergoing robotic-assisted prostatectomy in a steep Trendelenburg position (45° head-down tilt)¹⁵ Several factors may account for this discrepancy. The current study included a larger cohort of patients with ASA I–II status, likely representing a population with preserved cerebral autoregulatory function. Additionally, the use of refined intraoperative time points allowed for a more detailed characterization of hemodynamic transitions. The anesthetic agents selected—known for minimal effects on CBF—were consistent with standard practice in the study institution and minimized the confounding impact of pharmacologic variation.^{16–18}

Finally, the smaller degree of head-down tilt employed during gynecologic laparoscopic procedures, as compared to that used in robotic prostatectomy, may also contribute to differences in ICA blood flow responses. These findings suggest that postural recovery, particularly the transition from Trendelenburg to the supine position, may represent a critical period of vulnerability for cerebral hemodynamics.

Intraoperative hemodynamic fluctuations represent a crucial factor influencing CBF. According to the Lassen autoregulatory curve, CBF is maintained through autoregulation when MAP is within the range of 50–160 mmHg; however, intraoperative MAP \leq 65 mmHg is commonly defined as intraoperative hypotension (IOH).⁹ In this study, MAP was maintained at \geq 65 mmHg during surgery to preserve adequate perfusion of the brain and vital organs, and to evaluate changes in ICA blood flow under conditions approximating normal physiological function.¹⁹ P_{ET}CO₂ was controlled within the range of 35–40 mmHg to minimize sympathetic stimulation, preserve neurovascular coupling, and stabilize cerebrovascular reactivity.^{20,21} While therapeutic-dose propofol induces systemic hypotension, it preserves both static cerebral autoregulation and cerebrovascular CO₂ reactivity,²² suggesting that drug-specific effects may persist independently of P_{ET}CO₂ regulation. In addition, IAP was maintained at \leq 12mmHg, consistent with current recommendations for minimizing reductions in mesenteric perfusion, avoiding disruption of visceral microcirculation, reducing hemodynamic instability, and lowering the risk of carbon dioxide embolism during laparoscopic surgery.²³ By rigorously controlling anesthetic agents, P_{ET}CO₂, and IAP, this study aimed to minimize confounding variables and better isolate the effects of postural changes on in ICA blood flow. These findings offer a potential reference point for optimizing intraoperative management strategies to support cerebral perfusion during laparoscopic procedures.

Conclusion

The results of this study demonstrate that intraoperative postural changes during gynecologic laparoscopic surgery under general anesthesia significantly influence ICA blood flow. Although CBF is generally maintained through autoregulatory mechanisms such as cerebral autoregulation, neurovascular coupling, and vasomotor responsiveness, the application of these mechanisms may be impaired under general anesthesia. Postural transitions during anesthesia can exacerbate fluctuations in CBF, potentially compromising cerebral perfusion and increasing the risk of perioperative neurological complications. Further large-scale studies are warranted to elucidate the underlying mechanisms by which postural changes and anesthetic factors interact to influence intraoperative CBF, with the goal of improving perioperative cerebral

protection strategies. Future investigations should incorporate standardized neurologic outcome assessments, such as the postoperative Montreal Cognitive Assessment, to correlate intraoperative ICA flow variations with cognitive outcomes. Additionally, advanced neuroimaging (eg, postoperative diffusion-weighted MRI) could help identify subclinical ischemic changes associated with prolonged cerebral hypoperfusion during positional transitions.

In gynecologic laparoscopic surgery, intraoperative postural transitions are associated with fluctuations in ICA blood flow. Notably, repositioning from the Trendelenburg to the supine position results in a significant decrease in ICA blood flow, heart rate, and mean arterial pressure. Additionally, the induction of general anesthesia is associated with a marked reduction in both ICA blood flow and heart rate.

Abbreviations

ICA, internal carotid artery; HR, Heart rate; CBF, cerebral blood flow; IAP, intra-abdominal pressure; CO₂, carbon dioxide; ICP, intracranial pressure; S_{jv}O₂, jugular venous bulb saturation; ASA, American Society of Anesthesiologists; BIS, bispectral index; PETCO₂, end-tidal CO₂ partial pressure; SV, peak systolic velocity; EDV, end-diastolic velocity; BMI, body mass index.

Data Sharing Statement

All data generated or analysed during this study are included in this article. Further enquiries can be directed to the corresponding author.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki (as was revised in 2013). The study was approved by Ethics Committee of the First Affiliated Hospital of Jinan University (Approval number: KY-2022-125). Written informed consent was obtained from all participants.

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Disclosure

The authors declare that they have no competing interests in this work.

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