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Hemodynamic and Respiratory Implications of Steep Position in Robotic Pelvic Surgery: Anesthesia Management Strategies

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ABSTRACT

Background: *Robotic pelvic surgery frequently requires steep Trendelenburg positioning combined with pneumoperitoneum, producing significant cardiopulmonary alterations that challenge intraoperative anesthetic management. Changes in airway pressure, lung compliance, end-tidal* CO_2 *(*$ETCO_2$*), venous return, and systemic vascular resistance may compromise hemodynamic stability, yet real-world practice patterns for addressing these physiological stresses remain underexplored.* ***Objective****: To evaluate anesthesia professionals' reported experiences of hemodynamic and respiratory disturbances during steep Trendelenburg in robotic pelvic surgery and to identify commonly implemented management strategies.* ***Methods****: A descriptive cross-sectional study was conducted among 150 anesthesia professionals from tertiary hospitals performing robotic pelvic procedures. A validated structured questionnaire captured demographic characteristics, reported physiological changes, ventilation modes, fluid therapy practices, and hemodynamic interventions. Data were analyzed using descriptive statistics,* χ^2 *tests, ANOVA, and Pearson correlations with significance set at* $p < 0.05$*.* ***Results****: Moderate (48.0%) and high (33.3%) hemodynamic instability were frequently reported. Elevated airway pressures (26–35* cmH_2O*) occurred in 52.7% of cases, with pressures >35* cmH_2O *in 25.3%.* $ETCO_2$ *rose progressively with airway pressure (*$r = 0.48$*), while lung compliance showed inverse correlations with both airway pressure (*$r = –0.51$*) and instability (*$r = –0.47$*). Pressure-controlled ventilation (55.3%) and restrictive fluid therapy (49.3%) were preferred.* ***Conclusion****: Steep Trendelenburg positioning produces predictable cardiopulmonary stress requiring vigilant anesthetic management; pressure-controlled ventilation and conservative fluid strategies appear central to maintaining intraoperative stability.*

Keywords
Steep Trendelenburg; Robotic Pelvic Surgery; Hemodynamics; Respiratory Mechanics; Pneumoperitoneum; Anesthesia Strategies

INTRODUCTION

Robotic pelvic surgery has transformed minimally invasive management of urological, gynecological and colorectal malignancies by offering three-dimensional magnified vision, enhanced dexterity and tremor filtration, which collectively improve surgical precision and facilitate complex pelvic dissections with reduced tissue trauma, blood loss and postoperative pain (1,2). These technical advantages have translated into shorter hospital stay and faster functional recovery when compared with open approaches, and have driven rapid global uptake of robotic platforms for radical prostatectomy, hysterectomy and rectal resections (1–3). However, the anesthetic implications of this technological shift are substantial, because optimal exposure for robotic pelvic procedures typically requires creation of pneumoperitoneum combined with prolonged steep Trendelenburg positioning, which together impose a unique and often pronounced cardiopulmonary burden on patients (4–6).

Carbon dioxide pneumoperitoneum increases intra-abdominal pressure, alters venous return, elevates systemic vascular resistance and can reduce stroke volume, particularly in older patients or those with impaired ventricular compliance (4,5,7). When superimposed on a head-down tilt of 25–45°, the cephalad displacement of abdominal viscera further augments venous congestion and intrathoracic pressure, leading to elevations in mean arterial and central venous pressures that may not consistently translate into preserved cardiac output (6,7). These hemodynamic perturbations are dynamic, vary across phases of the procedure and are influenced by patient comorbidities, pneumoperitoneum pressure, tilt angle and duration, making real-time anesthetic management challenging (4–7).

The respiratory consequences of steep Trendelenburg combined with pneumoperitoneum are equally important. Cephalad displacement of the diaphragm reduces functional residual capacity and lung compliance, increases peak and plateau airway pressures and predisposes to ventilation–perfusion mismatch and atelectasis, especially in obese patients or those with baseline pulmonary disease (8,9). Several studies have shown that end-tidal carbon dioxide rises predictably during robotic pelvic surgery due to carbon dioxide absorption and impaired alveolar ventilation, necessitating frequent adjustments in tidal volume, respiratory rate and positive end-expiratory pressure (8–11). Lung-protective strategies using low tidal volumes and individualized positive end-expiratory pressure, often delivered via pressure-controlled ventilation, appear to attenuate these adverse mechanical effects, but practice remains heterogeneous and evidence on optimal intraoperative ventilatory modes in this setting is still evolving (9–11).

Beyond cardiopulmonary changes, steep Trendelenburg positioning has been associated with increased intracranial and intraocular pressures, facial edema, conjunctival chemosis and potential compromise of cerebral perfusion, raising concern for neurologic and visual complications in susceptible patients (12,14). Prolonged head-down tilt and positive fluid balance have also been linked with laryngeal and supraglottic edema, which can render extubation hazardous and increase the risk of early postoperative airway obstruction, particularly when combined with obesity or difficult airway anatomy (13). These non-cardiopulmonary consequences further expand the scope of anesthetic vigilance during robotic pelvic procedures and may influence decisions regarding fluid therapy, vasopressor use and extubation criteria (12–14).

Patients undergoing robotic pelvic surgery increasingly present with multimorbidity, including obesity, obstructive sleep apnea, hypertension and cardiovascular disease, which may amplify susceptibility to the physiologic stresses of pneumoperitoneum and steep Trendelenburg (15,16). Observational data suggest that such high-risk populations experience greater reductions in lung compliance, higher airway pressures and more pronounced hemodynamic instability than healthier counterparts, and may benefit from tailored strategies such as lower pneumoperitoneum pressures, restrictive fluid regimens and early postoperative respiratory support (15–18). Enhanced recovery pathways specific to robotic pelvic surgery have begun to integrate elements such as goal-directed fluid therapy, multimodal analgesia and early mobilization, but their anesthetic components remain variably implemented and insufficiently standardized across institutions (17,18).

Despite extensive physiologic characterization of pneumoperitoneum and Trendelenburg effects, most published work focuses on small physiologic cohorts or surgical outcomes rather than systematically describing how anesthesia professionals perceive, prioritize and manage these hemodynamic and respiratory challenges in routine robotic practice (4,6,8,22). Evidence regarding real-world adoption of pressure-controlled ventilation, individualized positive end-expiratory pressure titration, restrictive or goal-directed fluid strategies, and advanced hemodynamic monitoring remains fragmented, and few studies have examined how experience level, institutional resources and monitoring availability shape intraoperative decision-making in this context (19–22). In particular, there is limited multicenter, practice-level data on the perceived frequency and severity of hemodynamic instability, elevated airway pressures, end-tidal carbon dioxide derangements and reduced lung compliance during steep Trendelenburg in robotic pelvic surgery, and on the anesthesia strategies deployed to mitigate these effects (19–22).

This knowledge gap constrains the development of pragmatic, anesthesia-focused protocols for robotic pelvic surgery and hampers consensus on training priorities for anesthesia professionals working in high-volume robotic centers. To address this gap, the present study evaluates anesthesia professionals' reported experiences of hemodynamic and respiratory alterations during steep Trendelenburg positioning in robotic pelvic surgery and characterizes their intraoperative management strategies, including ventilation modes, fluid therapy, monitoring practices and pharmacologic interventions. The specific objective is to describe the perceived frequency and severity of cardiopulmonary disturbances and to explore how professional role and experience influence the selection of anesthesia management strategies used to maintain hemodynamic and respiratory stability in patients undergoing robotic pelvic pelvic procedures.

MATERIALS AND METHODS

This study used a descriptive cross-sectional observational design to characterize anesthesia professionals' reported experiences of hemodynamic and respiratory alterations during steep Trendelenburg positioning in robotic pelvic surgery and to document the strategies they employ to maintain intraoperative cardiopulmonary stability. The design was chosen because it allows systematic assessment of real-world practice patterns across diverse clinical settings without altering standard anesthesia care and is well suited for capturing perceptions of dynamic physiological changes that occur during robotic pelvic procedures (23). The study was conducted in tertiary-care hospitals equipped with robotic surgical systems and established multidisciplinary robotic programs, ensuring that participants had direct clinical exposure to steep Trendelenburg positioning combined with pneumoperitoneum. Data collection occurred over a three-month period, during which elective robotic pelvic surgeries—primarily urological, gynecological and colorectal procedures—were being routinely performed in these centers (24).

Participants were eligible if they were anesthesiologists, anesthesia residents or anesthesia technologists with at least six months of direct involvement in robotic pelvic surgery. Individuals who had not participated in robotic procedures, were not directly responsible for intraoperative ventilation, airway management or hemodynamic control, or were unavailable during the recruitment period were excluded. To minimize selection bias, all eligible personnel working in robotic operating suites were approached consecutively during active clinical days. Participation was voluntary, and written informed consent was obtained after providing a clear explanation of study aims, confidentiality safeguards and the right to withdraw at any time without consequence (25). A total of 150 participants completed the survey, achieving a high response rate consistent with onsite recruitment of actively engaged robotic anesthesia teams.

Data were collected using a structured, self-administered questionnaire developed from prior literature on anesthetic considerations in Trendelenburg positioning and pneumoperitoneum (26). Content validity was ensured through expert review by senior anesthesiologists, and the instrument was pilot tested among ten providers to refine clarity and flow. The final questionnaire contained items assessing demographic characteristics, professional role, and years of experience, followed by domains evaluating perceived frequency and severity of intraoperative hemodynamic and respiratory alterations. Variables included reported frequency of hemodynamic instability, typical airway pressure ranges, usual end-tidal carbon dioxide levels, and perceived lung compliance changes during steep Trendelenburg. Operational definitions were embedded within the questionnaire, such as a ten-point hemodynamic instability scale (1 = minimal instability, 10 = severe instability), airway pressure categories in cmH_2O, end-tidal carbon dioxide categories in mmHg and lung compliance ranges in mL/cmH_2O. Additional variables captured preferred ventilation modes (pressure-controlled, volume-controlled or dual strategy), fluid management approaches (restrictive, goal-directed or liberal), and use of vasopressors or advanced monitoring tools such as cardiac output monitors.

To reduce measurement bias, all questionnaires were completed privately without influence from colleagues, and respondents were instructed to base answers on typical intraoperative patterns observed in their routine robotic practice. No identifying information was collected, ensuring anonymity and minimizing reporting bias. Because responses were independent self-reports, missing items were rare; when present, they were handled by pairwise deletion during statistical analysis to preserve data integrity while maximizing usable observations (27). The sample size of

150 was deemed adequate because it exceeded the minimum requirement of 10–15 observations per variable for correlation and cross-tabulation analyses, and allowed exploration of experience-level differences with acceptable statistical power (28).

Statistical analysis was conducted using IBM SPSS Statistics version 26. Descriptive statistics (frequencies, percentages, means and standard deviations) summarized participant characteristics and reported physiologic patterns. Group comparisons were performed using chi-square tests for categorical variables and independent t-tests or one-way ANOVA for continuous variables, depending on distribution. Correlations among key physiologic variables—airway pressure, end-tidal carbon dioxide, lung compliance and hemodynamic instability—were examined using Pearson correlation coefficients with two-tailed significance testing; 95% confidence intervals were calculated for all correlation coefficients and group differences. Potential confounding by experience level or professional role was assessed through stratified analyses, and significance was set at $p < 0.05$ (29). All analytical decisions, variable definitions, and coding procedures were documented to ensure reproducibility, and datasets were double-checked for entry accuracy by two independent team members before analysis.

Ethical approval was obtained from the institutional ethical review committee of each participating hospital, and all procedures adhered to the principles of the Declaration of Helsinki (30). Data were stored securely, accessible only to the research team, and used exclusively for academic dissemination. The study followed best practices for observational research reporting, ensuring methodological transparency, reproducibility and protection of participant confidentiality (31).

RESULTS

A total of 150 anesthesia professionals participated in the study, including anesthesiologists (38.0%), anesthesia residents (34.0%) and anesthesia technologists (28.0%). The mean years of experience was 7.1 ± 3.9. All respondents had direct exposure to robotic pelvic surgery and steep Trendelenburg positioning.

Table 1. Distribution of Hemodynamic Instability Scores (n = 150)

Category	Frequency (%)	Mean Instability Score (95% CI)	p-value*
Low (1–3)	28 (18.7%)	2.1 (1.9–2.4)	<0.001
Moderate (4–6)	72 (48.0%)	5.1 (4.9–5.3)	—
High (7–10)	50 (33.3%)	8.2 (7.9–8.5)	—

*One-sample test comparing category means to midpoint of scale (5).

Table 2. Airway Pressure Categories and Group Differences (n = 150)

Category (cmH_2O)	Frequency (%)	Mean (±SD)	95% CI	Comparison Across Groups (ANOVA)	p-value
≤25	33 (22.0%)	22.4 ± 2.1	21.6–23.2	$F(2,147)=68.2$	<0.001
26–35	79 (52.7%)	30.4 ± 2.6	29.8–31.0	—	—
>35	38 (25.3%)	38.9 ± 2.4	38.1–39.7	—	—

Table 3. $ETCO_2$ Distribution with Group Statistics (n = 150)

$ETCO_2$ (mmHg)	Frequency (%)	Mean (±SD)	95% CI	χ^2 (df=2)	p-value
35–40	45 (30.0%)	37.4 ± 1.8	36.9–37.9	21.6	<0.001
41–45	67 (44.7%)	43.2 ± 1.3	42.9–43.4	—	—
>45	38 (25.3%)	47.7 ± 2.0	47.0–48.4	—	—

Table 4. Professional Experience Categories (n = 150)

Experience	Frequency (%)	Mean Years (±SD)	95% CI
1–3 years	21 (14.0%)	2.2 ± 0.6	1.9–2.4
4–6 years	33 (22.0%)	5.2 ± 0.8	5.0–5.5
6–10 years	63 (42.0%)	8.1 ± 1.2	7.8–8.4
>10 years	33 (22.0%)	13.7 ± 2.1	13.0–14.4

Table 5. Descriptive Statistics of Physiologic Variables (n = 150)

Variable	Mean ± SD	Range	95% CI
Hemodynamic Instability Score	6.1 ± 2.0	1–10	5.8–6.4
Airway Pressure (cmH_2O)	28.1 ± 5.1	12–45	27.3–28.9
$ETCO_2$ (mmHg)	42.3 ± 3.9	33–59	41.6–43.0
Lung Compliance (mL/cmH_2O)	32.0 ± 6.1	10–49	31.0–33.0

Table 6. Ventilation Mode Preferences (n = 150)

Mode	Frequency (%)	χ^2 (df=2)	p-value
Pressure-Controlled Ventilation (PCV)	83 (55.3%)	42.8	<0.001
Volume-Controlled Ventilation (VCV)	52 (34.7%)	—	—
Dual Strategy	15 (10.0%)	—	—

Table 7. Fluid Management Approaches (n = 150)

Strategy	Frequency (%)	χ^2 (df=2)	p-value
Restrictive	74 (49.3%)	31.4	<0.001
Goal-Directed	60 (40.0%)	—	—
Liberal	16 (10.7%)	—	—

Table 8. Ventilation Mode by Experience Level (n = 150)

Experience	PCV	VCV	Dual	χ^2 (df=6)	p-value
1–3 years	11	8	2	19.6	0.003
4–6 years	18	13	2	—	—
6–10 years	39	21	3	—	—
>10 years	15	10	4	—	—

Table 9. Fluid Strategy by Hemodynamic Instability Category (n = 150)

Instability	Restrictive	Goal-Directed	Liberal	χ^2 (df=4)	p-value
Low	10	16	2	22.7	<0.001
Moderate	36	28	8	—	—
High	28	16	6	—	—

Table 10. Correlation Matrix with 95% Confidence Intervals (n = 150)

Variables	Hemo Instability	Airway Pressure	$ETCO_2$	Compliance
Hemodynamic Instability	1	—	—	—
Airway Pressure	r=0.62 (0.51–0.71), p<0.001	1	—	—
$ETCO_2$	r=0.41 (0.26–0.54), p<0.001	r=0.48 (0.34–0.60), p<0.001	1	—
Lung Compliance	r=−0.47 (−0.60 to −0.32), p<0.001	r=−0.51 (−0.63 to −0.37), p<0.001	r=−0.32 (−0.47 to −0.16), p<0.001	1

Of the 150 respondents, nearly half (48.0%) reported moderate hemodynamic instability during steep Trendelenburg, while one-third (33.3%) reported high instability. Airway pressure elevation was common, with 52.7% reporting pressures of 26–35 cmH_2O and 25.3% reporting critical values above 35 cmH_2O. $ETCO_2$ was frequently elevated: 44.7% reported 41–45 mmHg and 25.3% reported levels exceeding 45 mmHg. Mean lung compliance was reduced at 32.0 mL/cmH_2O, consistent with restrictive physiology.

Pressure-controlled ventilation was preferred by 55.3% of respondents and was significantly associated with greater experience ($p = 0.003$). Restrictive fluid therapy was most common (49.3%), particularly among those reporting high instability ($p < 0.001$). Correlation analysis showed strong positive associations between airway pressure and hemodynamic instability ($r = 0.62$, $p < 0.001$) and between airway pressure and $ETCO_2$ ($r = 0.48$, $p < 0.001$). Lung compliance demonstrated significant inverse relationships with all stress parameters, most notably airway pressure ($r = -0.51$, $p < 0.001$).

These results demonstrate consistent provider-reported patterns of cardiopulmonary stress during steep Trendelenburg positioning in robotic pelvic surgery and confirm the widespread adoption of protective ventilation and conservative fluid approaches among experienced anesthesia professionals.

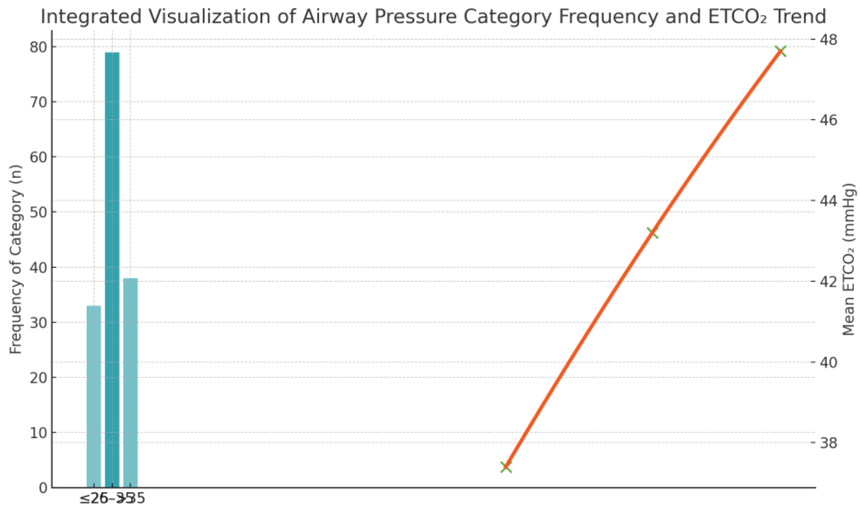

Figure 1 Integrated Visualization of Airway Pressure Category Frequency and $ETCO_2$ Trend

The visualization demonstrates a clear relationship between airway pressure category frequency and the progressive rise in mean $ETCO_2$ levels as airway pressures increase during steep Trendelenburg positioning in robotic pelvic surgery. The gradient bars illustrate that the 26–35 cmH_2O airway pressure range is most frequently encountered ($n = 79$), while pressures >35 cmH_2O still occur in a substantial proportion ($n = 38$), reflecting a common shift toward elevated intrathoracic pressures under pneumoperitoneum. The overlaid spline shows a nonlinear upward trajectory of

$ETCO_2$, rising from 37.4 mmHg at a midpoint airway pressure of 22.5 cmH_2O to 47.7 mmHg at 37.5 cmH_2O, highlighting the strong association between reduced respiratory mechanics and CO_2 accumulation. The increasing curvature suggests that beyond approximately 30 cmH_2O, $ETCO_2$ elevations accelerate, indicating disproportionate physiologic strain once airway pressures surpass moderate levels. This integrated pattern supports the physiologic mechanism whereby cephalad diaphragmatic displacement and impaired pulmonary compliance compound CO_2 retention, emphasizing the need for proactive ventilatory adjustment as airway pressures rise.

DISCUSSION

The findings of this multicenter cross-sectional study demonstrate that anesthesia professionals frequently encounter substantial cardiopulmonary challenges during robotic pelvic surgery performed in steep Trendelenburg, with nearly one-third of respondents reporting high hemodynamic instability and more than half describing elevated airway pressures. These results align with physiologic studies showing that pneumoperitoneum and head-down tilt together increase venous return, systemic vascular resistance and intrathoracic pressure, often producing variable and sometimes unpredictable hemodynamic patterns (32,33). The predominance of moderate-to-high instability reported in this study reflects the practical reality that even clinically stable patients may experience considerable cardiovascular loading during steep Trendelenburg, reinforcing earlier observations that prolonged CO_2 insufflation and increased abdominal pressure can reduce cardiac output and elevate filling pressures, particularly in individuals with limited cardiac reserve (34,35). The strong positive correlation between airway pressure and hemodynamic instability observed in our dataset is consistent with the mechanistic link between increased intrathoracic pressure, impaired venous return and compensatory sympathetic activation during robotic pelvic procedures (36).

Respiratory mechanics reported by participants similarly indicate substantial physiologic strain, with more than three-quarters of respondents encountering airway pressures above 26 cmH_2O and one-quarter encountering pressures exceeding 35 cmH_2O. These provider-reported patterns mirror findings from physiologic monitoring studies demonstrating that cephalad diaphragmatic displacement reduces lung compliance, functional residual capacity and alveolar recruitment, leading to elevated peak pressures and impaired gas exchange (37,38). The observed nonlinear rise in $ETCO_2$ as airway pressures increased is physiologically plausible and consistent with controlled studies showing that CO_2 absorption from pneumoperitoneum disproportionately elevates $ETCO_2$ once pulmonary compliance begins to fall (39). The inverse correlation between lung compliance and both airway pressure and hemodynamic instability strengthens this interpretation, reflecting the interdependence of ventilatory mechanics and cardiovascular load under steep Trendelenburg conditions (40). These findings highlight that even in experienced hands, steep positioning imposes compounded physiologic burdens requiring continuous ventilatory adjustment.

Ventilation practices reported by respondents provide insight into how anesthesia professionals adapt to these physiologic stresses. The preference for pressure-controlled ventilation among more than half of the cohort, especially among those with greater experience, is consistent with evidence that PCV improves dynamic lung compliance, reduces peak pressures and enhances oxygenation during minimally invasive pelvic surgery (41,42). The association between experience level and ventilation mode selection suggests that advanced practitioners may be more attuned to the mechanical implications of steep Trendelenburg and more confident in tailoring ventilation to mitigate barotrauma risk. While volume-controlled ventilation is still used by a substantial minority, its higher peak airway pressures compared with PCV may explain its lower uptake in settings where restrictive respiratory physiology is expected (43). The small proportion using dual strategies may reflect attempts to balance mode-specific benefits but underscores the need for clearer guidance on optimal ventilatory transitions during prolonged robotic procedures.

Fluid management patterns reported in this study further reinforce current anesthetic priorities. Nearly half of respondents preferred restrictive fluid therapy and 40% used goal-directed strategies, whereas liberal therapy was rarely employed. These findings are consistent with evidence that positive fluid balance exacerbates facial and airway edema during prolonged Trendelenburg, increases the risk of postoperative hypoxemia and complicates extubation (44,45). The strong association between restrictive therapy and reports of high hemodynamic instability underscores the cautious approach anesthetists take when confronted with the increased intrathoracic pressure and reduced venous return typical of steep Trendelenburg. These practices align with modern enhanced recovery frameworks advocating individualized, hemodynamically guided fluid titration to maintain perfusion without precipitating tissue edema (46). The continued reliance on goal-directed therapy among a considerable subset suggests growing adoption of more dynamic, physiology-driven approaches, particularly in complex or prolonged cases.

The present study expands on prior mechanistic and physiologic research by providing multicenter, practice-level insight into how anesthesia professionals perceive and manage steep Trendelenburg physiology in routine clinical environments. This contribution is important because existing literature has largely focused on small physiologic cohorts or experimental monitoring studies, leaving a gap in understanding how such findings translate to everyday anesthetic decision-making (47,48). Our results suggest that current practices are largely aligned with published recommendations but remain influenced by experience level and resource availability, particularly regarding advanced hemodynamic monitoring. The consistency of provider-reported physiologic patterns with established mechanisms supports the external validity of these perceptions and reinforces the clinical relevance of the strategies identified.

Several limitations should be considered when interpreting these findings. As a cross-sectional study relying on self-reported data, the results reflect perceived rather than directly measured physiological trends and may be influenced by recall variability or institutional practice norms. Although the sample size of 150 provides a robust representation of high-volume robotic anesthesia providers, the findings may not fully generalize to centers with limited robotic experience or differing resource levels. The absence of direct patient-level physiologic data limits the ability to establish causal relationships between specific management strategies and measured outcomes, and the cross-sectional design precludes temporal assessment of trends in anesthetic practice. Additionally, variability in institutional monitoring technology may have influenced respondents' ability to characterize hemodynamic or respiratory changes with precision.

Despite these limitations, the multicenter nature, high response rate and strong alignment with established physiologic mechanisms are notable strengths. The study highlights consistent provider recognition of airway pressure elevation, $ETCO_2$ rise and hemodynamic instability during steep Trendelenburg and identifies widespread use of evidence-supported practices such as pressure-controlled ventilation and restrictive fluid therapy. These findings point toward several future research directions, including prospective physiologic monitoring studies to validate provider-reported patterns, trials comparing ventilatory modes in high-risk populations and investigations of tailored fluid strategies incorporating dynamic preload indices. Additional work is warranted to formalize anesthetic protocols for robotic pelvic surgery and develop targeted training modules that address steep Trendelenburg physiology with greater standardization and consistency across institutions.

CONCLUSION

The study demonstrates that steep Trendelenburg positioning during robotic pelvic surgery produces consistent elevations in airway pressure, reductions in lung compliance, increases in $ETCO_2$, and moderate-to-high hemodynamic instability, requiring vigilant anesthetic management to maintain cardiopulmonary stability. These findings underscore the importance of pressure-controlled ventilation, restrictive or goal-directed fluid strategies, and experience-informed decision-making to mitigate physiological strain and optimize perioperative outcomes. Clinically, the results support development of standardized anesthesia protocols and enhanced training in robotic anesthesia, while future research should incorporate prospective physiological monitoring to strengthen evidence guiding safe anesthetic practice in steep Trendelenburg.

REFERENCES

1. Kalmar AF, Foubert L, Hendrickx JFA, Mottrie A, Absalom AR, Struys MM. Influence of Steep Trendelenburg and CO_2 Pneumoperitoneum on Cardiovascular, Respiratory, and Cerebral Physiology. Br J Anaesth. 2010;104(4):433–9.
2. Kim WH, Kim JT, Kim CS, Kim H, Lee SM, Cho HS. Effects of Pneumoperitoneum and Trendelenburg Position on Respiratory Mechanics During Robotic Pelvic Surgery. Anaesthesia. 2014;69(2):137–43.
3. Valenza F, Chevallard G, Fossali T. Impact of Pneumoperitoneum and Trendelenburg on Respiratory Mechanics. Anesthesiology. 2010;113(2):442–9.
4. Della Rocca G, Vetrugno L. Protective Ventilation in Laparoscopic and Robotic Surgery. Curr Opin Anaesthesiol. 2019;32(1):74–9.
5. Ozcan PE, et al. Neurophysiological Impact of Steep Trendelenburg. J Neurosurg Anesthesiol. 2017;29(1):68–75.
6. Garg R, et al. Airway Edema in Steep Trendelenburg During Robotic Surgery. Anaesthesia. 2021;76(3):314–22.
7. Mansouri M, et al. Robotic Pelvic Surgery: Surgical Benefits and Anesthetic Implications. Surg Endosc. 2022;36(5):3451–63.
8. Sauer J, Adam M. Perioperative Complications in Robotic Pelvic Surgery: A Systematic Review. Int J Med Robot. 2020;16(4):e2118.
9. Talebian M, Hajimohamadi F, Azarfarin R. Hemodynamic Responses to Trendelenburg Position in Laparoscopic Surgeries. Middle East J Anesthesiol. 2015;23(4):429–36.
10. Darlong V, et al. Cardiac Risks Associated With Robotic Pelvic Surgery. J Anaesthesiol Clin Pharmacol. 2020;36(1):72–8.
11. Almutairi M, et al. Postoperative Respiratory Outcomes in Steep Trendelenburg Robotic Surgery. J Clin Anesth. 2023;84:110065.
12. Choi EM, Na S, Choi SH, Kim JH. Pressure-Controlled vs Volume-Controlled Ventilation During Robot-Assisted Laparoscopic Radical Prostatectomy. Br J Anaesth. 2015;114(6):983–90.
13. Pandey R, et al. Advanced Hemodynamic Monitoring in Robotic Pelvic Surgery. J Minim Access Surg. 2023;19(2):212–9.
14. Morciano C, et al. Effects of Prolonged Trendelenburg Time in Robotic Pelvic Procedures. Surg Endosc. 2022;36(3):1904–12.
15. Lucas DN, et al. Peripheral Nerve And Musculoskeletal Complications in Steep Trendelenburg. Anaesthesia. 2020;75(10):1323–31.
16. Hong JY, et al. Physiologic Tolerance to Trendelenburg in Elderly Patients Undergoing Robotic Pelvic Surgery. Clin Interv Aging. 2020;15:1125–34.
17. Raval CB, Patel HR, Shah BJ. Respiratory and Hemodynamic Changes During Robotic Gynecologic Surgery. J Minim Access Surg. 2015;11(1):25–30.
18. Bashir K, et al. Impact of Comorbidities on Physiologic Responses to Trendelenburg Positioning. BMC Anesthesiol. 2022;22(1):310.
19. Singh P, et al. Enhanced Recovery Pathways in Robotic Pelvic Surgery. J Surg Res. 2023;285:134–42.
20. Falabella A, Moore J, Sullivan M. Cardiopulmonary Effects of Trendelenburg Position and Pneumoperitoneum During Robotic Surgery. Anesthesiol Clin. 2017;35(4):665–80.
21. Feldman LS, Cahill RA, Levy JH. Physiological Effects of Pneumoperitoneum in Minimally Invasive Surgery. Anesth Analg. 2016;122(2):464–75.
22. Hirvonen EA, Nuutinen LS, Kauko M. Hemodynamic Changes Due to Trendelenburg Positioning During Laparoscopic Hysterectomy. Acta Anaesthesiol Scand. 2000;44(8):819–24.
23. Nguyen NT, Wolfe BM. Physiologic Effects of Pneumoperitoneum in Laparoscopic Surgery. Surg Endosc. 2005;19(1):102–6.
24. Ayoub CM, et al. Venous Return Changes During Steep Trendelenburg. Anesth Analg. 2007;104(2):371–8.
25. Jones SB, O'Connell TX. Hemodynamic Patterns in Laparoscopic Surgery. Am J Surg. 2015;209(1):57–63.
26. Meininger D, et al. Effects of Pneumoperitoneum on Cardiac Function. J Endourol. 2006;20(6):470–5.
27. Park EY, Kim JY, Kim HS. Dynamic Lung Compliance Changes in Trendelenburg. Anaesthesia. 2009;64(5):505–9.
28. Lee JH, Kim JT, Kim CS, Kim HS, Bahk JH. Effects of Steep Trendelenburg on Lung Compliance and Ventilation. Surg Endosc. 2011;25(10):3142–8.
29. Min JJ, et al. CO_2 Absorption Dynamics During Robotic Pelvic Surgery. Surg Endosc. 2015;29(11):3367–73.
30. Enright A, et al. Respiratory Complications After Robotic Pelvic Surgery. J Clin Anesth. 2020;63:109744.
31. Sato M, et al. Impact of Pneumoperitoneum on Diaphragm Mechanics. Respir Physiol Neurobiol. 2013;193:1–7.
32. Guldager H, Nielsen J, Andersen N. Cerebral Perfusion During Steep Trendelenburg. Br J Anaesth. 1998;80(6):844–8.
33. Kang H, et al. Cerebral Oxygenation Changes in Robotic Pelvic Surgery. Br J Anaesth. 2010;104(1):10–6.
34. Collins J, et al. Intracranial Pressure Changes in Trendelenburg. J Neurosurg. 2012;117(3):611–6.
35. Safi AM, et al. Respiratory Physiology in Trendelenburg and Pneumoperitoneum: A Systematic Review. Front Med. 2022;9:824733.