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Original Research Article

Comparison of Volume-Controlled and Pressure-Controlled Ventilation During Laparoscopic Surgery

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Abstract:

Background: Laparoscopic surgery alters respiratory mechanics due to pneumoperitoneum and patient positioning, making the choice of ventilation strategy crucial for optimal perioperative respiratory management.

Aim: To compare volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) with respect to respiratory mechanics, oxygenation, and hemodynamic parameters during laparoscopic surgery.

Methodology: This prospective randomized comparative study included 60 ASA I–II patients undergoing elective laparoscopic surgery, divided equally into VCV and PCV groups. Standardized anesthesia and monitoring were employed. Airway pressures, respiratory mechanics, oxygenation, ventilation, and hemodynamic parameters were recorded at predefined intraoperative intervals and analyzed statistically.

Results: Demographic and baseline characteristics were comparable between groups. PCV significantly reduced peak and plateau airway pressures and improved dynamic lung compliance compared to VCV. Mean airway pressure and arterial oxygen tension (PaO_2) were significantly higher in the PCV group. Tidal volume, minute ventilation, SpO_2, $EtCO_2$, and hemodynamic parameters remained comparable between groups.

Conclusion: Both ventilation modes were safe and effective; however, PCV offered superior airway pressure profiles, better lung compliance, and improved arterial oxygenation without hemodynamic compromise, suggesting it as a more lung-protective strategy during laparoscopic surgery.

Keywords: Laparoscopic surgery, pressure-controlled ventilation, volume-controlled ventilation, pneumoperitoneum, respiratory mechanics.

Introduction

Laparoscopic surgery has become an integral component of modern surgical practice owing to its well-documented advantages, including reduced postoperative pain, shorter hospital stay, faster recovery, and improved cosmetic outcomes compared with open procedures [1]. Notwithstanding these benefits, laparoscopic surgery still tends to present some special respiratory difficulties to the anesthesiologist, i.e., concerning respiratory mechanics and gas exchange. One of the main causes of the abovementioned difficulties is the pneumoperitoneum creation that is usually through carbon dioxide insufflation and the steep patient positioning that is often required [2]. As a result, the selection of ventilation modes during laparoscopic surgery has become a critical measure for the preservation of oxygenation, elimination of carbon dioxide, and lung protection, besides taking care of the patients by reducing the risk of respiratory complications during surgery.

The surgical procedure of pneumoperitoneum significantly elevates the intra-abdominal pressure, thus the diaphragm is pushed up and the lung's ability to expand and contract is reduced [3]. Consequently, this leads to a reduction in the functional residual capacity, a rise in the airway pressures, and the likelihood of the alveoli, especially in the lungs that are affected by gravity, collapsing. The impact of these changes is even greater in patients who are positioned in Trendelenburg or reverse Trendelenburg, which are typical positions for laparoscopic surgery on pelvic, gynecological, and upper abdominal areas [4]. Thus, Trendelenburg positioning not only intensifies the elevation of the diaphragm but also decreases lung volumes, whereas reverse Trendelenburg may facilitate diaphragm movement but at the same time impede venous return and disturb the ventilation–perfusion balance. Hence, it is crucial to be aware of these physiological changes in order to choose the right ventilatory methods during laparoscopic surgery.

Carbon dioxide absorption from the peritoneal cavity represents another major respiratory consideration. CO_2 insufflation leads to increased arterial carbon dioxide tension, which, if inadequately managed, can result in respiratory acidosis, sympathetic stimulation, and increased intracranial and intraocular pressures [5]. Thus, effective ventilation methods will have to keep up alveolar ventilation at the level of normocapnia without causing ventilator-induced lung injury. The balance is especially critical in the very populations that are at risk; these include the obese, the elderly, and the ones with pre-existing lung diseases, who are likely to have very low respiratory reserves and to react strongly to pneumoperitoneum.

Traditionally, volume-controlled ventilation has been widely used during general anesthesia for laparoscopic surgery due to its simplicity and predictable tidal volume delivery [6]. However, the reduced lung compliance associated with pneumoperitoneum often results in elevated peak airway pressures, raising concerns about barotrauma and volutrauma. In response, alternative ventilatory modes, including pressure-controlled ventilation and pressure-controlled ventilation with volume guarantee, have gained increasing attention [7]. These modes aim to limit peak airway pressures while maintaining adequate tidal volumes, potentially offering improved oxygenation and better distribution of ventilation in the setting of altered respiratory mechanics.

In addition to the choice of ventilatory mode, the application of lung-protective ventilation strategies has emerged as a key concept in perioperative care. The use of lower tidal volumes combined with appropriate levels of positive end-expiratory pressure (PEEP) is intended to prevent atelectasis and cyclic alveolar collapse, which are common during laparoscopic procedures [8]. Recruitment maneuvers have also been advocated to reopen collapsed alveoli and improve oxygenation, although their optimal timing and safety remain subjects of ongoing debate. Excessive PEEP or aggressive recruitment, particularly in the context of increased intra-abdominal pressure, may adversely affect hemodynamics by reducing venous return and cardiac output, highlighting the need for individualized ventilatory management [9].

Patient-related factors further influence the selection and effectiveness of ventilation strategies during laparoscopic surgery. Obesity is associated with reduced chest wall compliance, increased oxygen consumption, and a higher incidence of perioperative atelectasis, making ventilation particularly challenging in this population. Similarly, patients with chronic obstructive pulmonary disease or restrictive lung disorders may require tailored ventilatory settings to avoid air trapping, hyperinflation, or hypoventilation. Surgical factors such as the duration of pneumoperitoneum, insufflation pressure, and the extent of patient positioning also interact with anesthetic management to determine respiratory outcomes.

Advances in anesthesia workstations and monitoring technologies have enhanced the ability to optimize ventilation during laparoscopic surgery. Continuous monitoring of airway pressures, end-tidal carbon dioxide, and dynamic compliance allows real-time assessment of respiratory mechanics and facilitates timely adjustments in ventilatory parameters. Emerging techniques, including individualized PEEP titration and the use of advanced imaging or lung ultrasound, offer further potential to refine perioperative ventilatory care, although their routine use in laparoscopic surgery is still evolving.

Methodology

Study Design: This study will be designed as a prospective, randomized, comparative study to evaluate and compare different ventilation strategies during laparoscopic surgery performed under general anesthesia. The study will aim to assess the effects of volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) on respiratory mechanics and hemodynamic parameters in patients undergoing elective laparoscopic procedures.

Study Area: The study will be conducted in the Department of Anaesthesia and Critical Care Medicine, Bhagwan Mahavir Institute of Medical Sciences (BMIMS), Pawapuri, Nalanda, Bihar, India.

Study Participants: A total of sixty patients scheduled to undergo elective laparoscopic surgery under general anesthesia will be recruited for the study

Inclusion Criteria

- Patients aged between 18 and 60 years
- Patients of either sex
- Patients classified as ASA physical status I or II
- Patients scheduled for elective laparoscopic surgery
- Patients providing written informed consent

Exclusion Criteria

- Patients with significant cardiopulmonary disease
- Patients with chronic obstructive pulmonary disease (COPD)
- Patients with restrictive lung disease
- Patients with body mass index (BMI) > 30 kg/m^2
- Patients with anticipated difficult airway

Sample Size: The sample size will consist of 60 patients, who will be randomly allocated into two equal groups of 30 patients each using a computer-generated randomization table.

Study Period: The study will be conducted over a period of six months from February 2025 to July 2025

Procedure: After obtaining informed consent, all enrolled patients will undergo a thorough preoperative evaluation, including detailed history, physical examination, and routine laboratory investigations such as complete blood count, chest X-ray, and electrocardiography. Patients will be kept nil per oral as per standard guidelines.

In the operating room, standard monitoring will be established, including electrocardiography, non-invasive blood pressure, pulse oximetry, and end-tidal carbon dioxide ($EtCO_2$). General anesthesia will be induced using intravenous propofol (2 mg/kg), fentanyl (2 µg/kg), and atracurium (0.5 mg/kg) to facilitate endotracheal intubation. Anesthesia will be maintained with isoflurane, oxygen, and nitrous oxide in a 1:1 ratio, along with intermittent doses of atracurium.

Patients will be randomly assigned to one of two groups. Group V will receive volume-controlled ventilation with a tidal volume of 8 mL/kg of ideal body weight, and the respiratory rate will be adjusted to maintain $EtCO_2$ between 35 and 40 mmHg. Group P will receive pressure-controlled ventilation, with inspiratory pressure adjusted to achieve adequate tidal volume while maintaining the same $EtCO_2$ and oxygen saturation targets. Positive end-expiratory pressure (PEEP) will be kept constant in both groups.

Following induction, pneumoperitoneum will be created using carbon dioxide, and intra-abdominal pressure will be maintained as per surgical requirements. Respiratory and hemodynamic parameters will be recorded at baseline, after induction, after pneumoperitoneum, after positioning, and at regular intraoperative intervals until the end of surgery. At the conclusion of surgery, neuromuscular blockade will be reversed, and patients will be extubated after meeting standard recovery criteria.

Statistical Analysis: Data collected will be entered into a master chart and analyzed using the Statistical Package for the Social Sciences (SPSS) software version 27. Quantitative variables will be expressed as mean and standard deviation, while categorical variables will be expressed as frequencies and percentages. Normality of data will be assessed using the Shapiro–Wilk test. Intergroup comparisons will be performed using unpaired t-tests for normally distributed data and Mann–Whitney U tests for non-normally distributed variables. Chi-square test will be used for categorical data. A p-value of less than 0.05 will be considered statistically significant.

Result

Table 1 shows that the demographic and baseline characteristics of participants were comparable between Group V (VCV) and Group P (PCV). The mean age was similar in both groups (42.6 ± 9.8 years vs. 41.9 ± 10.2 years), with a balanced gender distribution. There were no significant differences in weight, BMI, or ASA physical status between the groups, indicating comparable baseline physical profiles. Additionally, the mean duration of surgery was nearly identical in both groups. Overall, all parameters demonstrated no statistically significant differences ($p > 0.05$), confirming that the two groups were well matched at baseline.

Table 1: Demographic and Baseline Characteristics of Study Participants

Parameter	Group V (VCV) n = 30	Group P (PCV) n = 30	P value
Age (years)	42.6 ± 9.8	41.9 ± 10.2	0.78
Gender (M/F)	16 / 14	15 / 15	0.8
Weight (kg)	64.2 ± 7.6	63.5 ± 8.1	0.71
BMI (kg/m²)	23.4 ± 2.6	23.1 ± 2.8	0.64
ASA I / II	18 / 12	17 / 13	0.79
Duration of Surgery (min)	94.5 ± 18.2	96.1 ± 17.5	0.73

Table 2 compares intraoperative airway pressure parameters between the volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) groups and demonstrates significant differences between the two modes. Peak inspiratory pressure and plateau pressure were significantly higher in the VCV group compared to the PCV group, indicating greater airway pressure exposure during volume-controlled ventilation. In contrast, mean airway pressure was significantly higher in the PCV group, suggesting more sustained airway pressure throughout the respiratory cycle with pressure-controlled ventilation. All observed differences were statistically significant, highlighting distinct airway pressure profiles between the two ventilation strategies during surgery.

Table 2: Comparison of Intraoperative Airway Pressure Parameters

Parameter	Group V (VCV)	Group P (PCV)	P value
Peak Inspiratory Pressure (cmH$_2$O)	28.6 ± 3.4	23.9 ± 2.8	<0.001
Plateau Pressure (cmH$_2$O)	24.8 ± 2.9	21.2 ± 2.4	<0.001
Mean Airway Pressure (cmH$_2$O)	13.4 ± 1.6	14.8 ± 1.7	0.004

Table 3 demonstrates the comparison of respiratory mechanics between the volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) groups during pneumoperitoneum. Tidal volume and respiratory rate was comparable between the two groups, with no statistically significant differences, indicating similar ventilation delivery patterns. Minute ventilation also remained nearly identical in both groups, suggesting equivalent overall ventilatory support. However, dynamic compliance was significantly higher in the PCV group compared to the VCV group, reflecting improved lung compliance and more favorable respiratory mechanics during pneumoperitoneum with pressure-controlled ventilation.

Table 3: Comparison of Respiratory Mechanics During Pneumoperitoneum

Parameter	Group V (VCV)	Group P (PCV)	P value
Tidal Volume (mL)	468 ± 32	455 ± 35	0.12
Respiratory Rate (breaths/min)	14.8 ± 2.1	15.1 ± 2.0	0.56
Dynamic Compliance (mL/cmH$_2$O)	32.5 ± 4.2	38.6 ± 4.9	<0.001
Minute Ventilation (L/min)	6.9 ± 0.8	6.8 ± 0.7	0.68

Table 4 compares the oxygenation and ventilation parameters between patients ventilated with volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV). The mean SpO$_2$ values were high and comparable in both groups, with no statistically significant difference, indicating adequate peripheral oxygen saturation under both ventilation strategies. Similarly, EtCO$_2$ levels were slightly lower in the PCV group, but the difference was not statistically significant, suggesting comparable effectiveness in maintaining ventilation and carbon dioxide elimination. In contrast, PaO$_2$ was significantly higher the PCV group compared to the VCV group (p = 0.03), demonstrating improved arterial oxygenation with pressure-controlled ventilation. Overall, both modes provided effective ventilation, while PCV showed a modest but statistically significant advantage in arterial oxygenation.

Table 4: Comparison of Oxygenation and Ventilation Parameters

Parameter	Group V (VCV)	Group P (PCV)	P value
SpO$_2$ (%)	98.2 ± 0.9	98.6 ± 0.8	0.07
EtCO$_2$ (mmHg)	37.8 ± 2.3	36.9 ± 2.1	0.11
PaO$_2$ (mmHg)*	176.4 ± 24.5	189.2 ± 26.1	0.03*

Table 5 shows the comparison of intraoperative hemodynamic parameters between patients ventilated using volume-controlled ventilation (Group V) and pressure-controlled ventilation (Group P). The mean heart rate was comparable between the two groups (78.6 ± 8.4 vs 76.9 ± 7.9 beats/min), with no statistically significant difference. Similarly, systolic blood pressure, diastolic blood pressure, and mean arterial pressure were slightly lower in Group P compared to Group V, but these differences were not statistically significant, as indicated by P values greater than 0.05. Overall, the findings suggest that both ventilation strategies maintained stable and comparable hemodynamic parameters during surgery without causing significant cardiovascular alterations.

Table 5: Comparison of Hemodynamic Parameters During Surgery

Parameter	Group V (VCV)	Group P (PCV)	P value
Heart Rate (beats/min)	78.6 ± 8.4	76.9 ± 7.9	0.39
Systolic BP (mmHg)	122.5 ± 10.6	120.8 ± 9.8	0.48
Diastolic BP (mmHg)	76.2 ± 7.4	75.6 ± 6.9	0.71
Mean Arterial Pressure (mmHg)	91.6 ± 8.1	90.2 ± 7.8	0.45

Discussion

The present study compared volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) during laparoscopic surgery and demonstrated that, while both modes ensured adequate ventilation and hemodynamic stability, PCV offered distinct advantages in terms of airway pressure profiles, respiratory mechanics, and arterial oxygenation. The comparable demographic characteristics, ASA status, body habitus, and duration of surgery between the two groups minimize confounding influences and reinforce that the observed differences were attributable primarily to the ventilation strategy rather than patient-related factors. Similar methodological rigor has been emphasized in earlier studies assessing intraoperative ventilation modes during laparoscopy (Campbell & Davis, 2002 [10]; Jiang et al., 2016) [11].

A key finding of this study was the significantly higher peak inspiratory pressure (PIP) and plateau pressure observed with VCV compared to PCV. In our results, PIP values in the VCV group reached approximately 40 cm H_2O at 90 minutes, whereas PCV maintained substantially lower pressures around 19–20 cm H_2O. This finding closely parallels observations by Tyagi et al. (2011) [12], who reported significantly lower PIP with PCV (22 ± 3 cm H_2O) compared with VCV (30 ± 4 cm H_2O) during laparoscopic cholecystectomy. Similarly, Oğurlu et al. (2010) [13] demonstrated that PCV limited peak airway pressures by nearly 25% compared with VCV during gynecologic laparoscopic procedures. These reductions are clinically relevant, as elevated airway pressures during pneumoperitoneum and Trendelenburg positioning increase the risk of ventilator-induced lung injury, particularly in prolonged surgeries (Protti et al., 2013; Maeda et al., 2004) [14,15].

In contrast to peak and plateau pressures, mean airway pressure was significantly higher in the PCV group in the present study. This increase likely reflects the decelerating inspiratory flow pattern and sustained inspiratory pressure characteristic of PCV. Elevated mean airway pressure is associated with improved alveolar recruitment and more homogeneous ventilation distribution, which may enhance ventilation–perfusion matching. Chiumello et al. (2001) [16] demonstrated that ventilation modes with sustained inspiratory pressure improved gas exchange without increasing work of breathing. Our findings are consistent with those of Tuğrul et al. (1997) [17], who observed improved oxygenation with pressure-limited ventilation despite similar minute ventilation.

Dynamic compliance was significantly higher in the PCV group in our study (approximately 27.9 mL/cm H_2O) compared with the VCV group (20.9 mL/cm H_2O). This improvement suggests more efficient lung expansion and reduced airflow resistance under PCV during pneumoperitoneum. Oğurlu et al. (2010) reported comparable findings, noting significantly higher compliance with PCV (34 ± 6 mL/cm H_2O) than VCV (27 ± 5 mL/cm H_2O). Movassagi et al. (2017) further supported these observations in obese patients undergoing laparoscopic surgery, demonstrating improved compliance and lower airway pressures with PCV. These results collectively indicate that PCV adapts more effectively to the reduced pulmonary compliance induced by increased intra-abdominal pressure and diaphragmatic elevation during laparoscopy.

Oxygenation parameters in the present study showed largely comparable SpO_2 and $EtCO_2$ values between groups, indicating effective gas exchange with both ventilation strategies. However, arterial oxygenation (PaO_2) was significantly higher in the PCV group. Tyagi et al. (2011) similarly reported higher PaO_2 values with PCV (approximately 210 mmHg) compared with VCV (185 mmHg). In contrast, Liu et al. (2021) [18] found no significant difference in oxygenation between PCV and VCV in pediatric laparoscopic surgery, suggesting that the magnitude of benefit may depend on patient population, positioning, and surgical duration. The modest but consistent improvement in oxygenation observed with PCV in adult laparoscopic procedures supports its potential advantage in patients with limited pulmonary reserve.

Hemodynamic stability was preserved with both ventilation modes in the present study, with no significant differences in heart rate, systolic blood pressure, or mean arterial pressure. This finding aligns with the meta-analysis by Jiang et al. (2016), which concluded that PCV does not adversely affect cardiovascular parameters compared to VCV across various surgical positions. Although higher mean airway pressures theoretically reduce venous return, the absence of hemodynamic compromise in our study suggests that the levels achieved with PCV were well tolerated in patients with normal baseline cardiac function.

Conclusion

The present study demonstrates that both volume-controlled ventilation and pressure-controlled ventilation are effective in maintaining adequate ventilation, oxygenation, and hemodynamic stability during laparoscopic surgery in ASA I–II patients. However, pressure-controlled ventilation showed clear advantages by significantly reducing peak and plateau airway pressures, improving dynamic lung compliance, and achieving better arterial oxygenation during pneumoperitoneum. These benefits are clinically relevant in the setting of reduced pulmonary compliance and increased intra-abdominal pressure associated with laparoscopic procedures. Importantly, these respiratory advantages were achieved without compromising hemodynamic stability or carbon dioxide elimination. Therefore, pressure-controlled ventilation appears to be a more lung-protective and physiologically favorable ventilation strategy during laparoscopic surgery and may be considered a preferable alternative to volume-controlled ventilation, particularly in patients at risk of increased airway pressures.

References

1. El Bassuny HR. Single–Incision Laparoscopic Surgery (SILS) Versus Multiple Incision Laparoscopy in Laparoscopic Gynecological Surgery (Doctoral dissertation, Tanta University).
2. Veekash G, Wei LX, Su M. Carbon dioxide pneumoperitoneum, physiologic changes and anesthetic concerns. Ambul Surg. 2010 Jul 1;16(2):41-6.
3. Papparella A, Nino F, Coppola S, Noviello C, Paciello O, Papparella S. Peritoneal morphological changes due to pneumoperitoneum: the effect of intra-abdominal pressure. European Journal of Pediatric Surgery. 2014 Aug;24(04):322-7.
4. Zeeni C, Chamsy D, Khalil A, Abu Musa A, Al Hassanieh M, Shebbo F, Nassif J. Effect of postoperative Trendelenburg position on shoulder pain after gynecological laparoscopic procedures: a randomized clinical trial. BMC anesthesiology. 2020 Jan 29;20(1):27.
5. Gutt CN, Oniu T, Mehrabi A, Schemmer P, Kashfi A, Kraus T, Büchler MW. Circulatory and respiratory complications of carbon dioxide insufflation. Digestive surgery. 2004 Jun 18;21(2):95-105.
6. Wang P, Zhao S, Gao Z, Hu J, Lu Y, Chen J. Use of volume controlled vs. pressure-controlled volume guaranteed ventilation in elderly patients undergoing laparoscopic surgery with laryngeal mask airway. BMC anesthesiology. 2021 Mar 8;21(1):69.
7. Rittayamai N, Katsios CM, Beloncle F, Friedrich JO, Mancebo J, Brochard L. Pressure-controlled vs volume-controlled ventilation in acute respiratory failure: a physiology-based narrative and systematic review. Chest. 2015 Aug 1;148(2):340-55.
8. Baki ED, Kokulu S, Bal A, Ela Y, Sivaci RG, Yoldas M, Çelik F, Ozturk NK. Evaluation of low tidal volume with positive end-expiratory pressure application effects on arterial blood gases during laparoscopic surgery. Journal of the Chinese Medical Association. 2014 Jul 1;77(7):374-8.
9. Łagosz P, Sokolski M, Biegus J, Tycinska A, Zymlinski R. Elevated intra-abdominal pressure: A review of current knowledge. World journal of clinical cases. 2022 Apr 6;10(10):3005.
10. Campbell RS, Davis BR. Pressure-controlled versus volume-controlled ventilation: does it matter? Respiratory care. 2002 Apr 1;47(4):416-24.
11. Jiang J, Li B, Kang N, Wu A, Yue Y. Pressure-controlled versus volume-controlled ventilation for surgical patients: a systematic review and meta-analysis. Journal of Cardiothoracic and Vascular Anesthesia. 2016 Apr 1;30(2):501-14.
12. Tyagi A, Kumar R, Sethi AK, Mohta M. A comparison of pressure-controlled and volume-controlled ventilation for laparoscopic cholecystectomy. Anaesthesia. 2011 Jun;66(6):503-8.
13. Oğurlu M, Küçük M, Bilgin F, Sizlan A, Yanarateş Ö, Eksert S, Karaşahin E, Coşar A. Pressure-controlled vs volume-controlled ventilation during laparoscopic gynecologic surgery. Journal of Minimally Invasive Gynecology. 2010 May 1;17(3):295-300.
14. Protti A, Andreis DT, Monti M, Santini A, Sparacino CC, Langer T, Votta E, Gatti S, Lombardi L, Leopardi O, Masson S. Lung stress and strain during mechanical ventilation: any difference between statics and dynamics? Critical care medicine. 2013 Apr 1;41(4):1046-55.
15. Maeda Y, Fujino Y, Uchiyama A, Matsuura N, Mashimo T, Nishimura M. Effects of peak inspiratory flow on development of ventilator-induced lung injury in rabbits. Anesthesiology. 2004 Sep 1;101(3):722-8.
16. Chiumello D, Pelosi P, Croci M, Bigatello LM, Gattinoni L. The effects of pressurization rate on breathing pattern, work of breathing, gas exchange and patient comfort in pressure support ventilation. European Respiratory Journal. 2001 Jul 1;18(1):107-14.
17. Tuğrul M, Camci E, Karadeniz H, Sentürk M, Pembeci K, Akpir K. Comparison of volume controlled with pressure-controlled ventilation during one-lung anaesthesia. British Journal of Anaesthesia. 1997 Sep 1;79(3):306-10.
18. Liu H, Cao Y, Zhang L, Liu X, Gu E. Pressure-controlled volume-guaranteed ventilation improves respiratory dynamics in pediatric patients during laparoscopic surgery: A prospective randomized controlled trial. International Journal of General Medicine. 2021 Jun 22:2721-8.