Original Article

Effects of Different Levels of Positive End-Expiratory Pressure on Respiratory and Hemodynamic Changes in Laparoscopic Abdominal Surgeries

Ettaboina Indrani[1], Chandravathi Banothu[2], Pushpalatha Vantepaka[3]

[1]Post Graduate, Department of Anesthesiology, Gandhi Medical College and Hospital, Secunderabad, Telangana, India. [2]Associate Professor, Department of Anesthesiology, Govt Medical College and Hospital, Suryapet, Telangana, India. [3]Assistant Professor, Department of Anesthesiology, Gandhi Medical College and Hospital, Secunderabad, Telangana, India

Abstract

Background: Laparoscopic abdominal surgeries require carbon dioxide pneumoperitoneum for better visibility. However, it alters respiratory mechanics and may influence hemodynamic stability. Positive end-expiratory pressure (PEEP) is commonly used during mechanical ventilation to improve oxygenation by preventing alveolar collapse; however, the optimal PEEP level during laparoscopic procedures remains uncertain. This study was designed to compare the effects of 5 cmH_2O and 10 cmH_2O PEEP on respiratory and hemodynamic parameters during laparoscopic abdominal surgeries. **Material and Methods:** This prospective comparative study included 70 adult patients undergoing elective laparoscopic abdominal surgeries under general anesthesia. Patients were divided into two equal groups of n=35 each, the 5 PEEP group and the 10 PEEP group, based on a computer-generated random number. Hemodynamic parameters recorded were heart rate, systolic blood pressure, diastolic blood pressure, and mean arterial pressure. The recordings were done at defined time points throughout the anesthesia. The respiratory parameters recorded were peak airway pressure (P peak), plateau pressure (P plat), mean airway pressure (P mean), end-tidal carbon dioxide ($ETCO_2$), and arterial blood gas parameters (PaO_2 and $PaCO_2$). The results of the groups were compared with appropriate statistical analysis. **Results:** Both groups had similar Baseline demographic and anthropometric parameters. There were no significant differences in heart rate, peak airway pressure, plateau pressure, and $ETCO_2$ over the course of the study. The mean airway pressure was significantly elevated in the 10 PEEP group at both intraoperative time points ($p\leq0.001$). During pneumoperitoneum, arterial oxygenation was significantly better with 10 cm H_2O PEEP (PaO_2: 177.37 ± 38.64 mmHg vs. 136.31 ± 37.84 mmHg and $p<0.001$), while arterial carbon dioxide levels were significantly lower at T2 and T3 ($p<0.01$). In the final observation, SBP, DBP, and MAP were significantly reduced in the 10 PEEP group ($p\leq0.001$), while HR was not significantly different between groups. **Conclusion:** The study found that application of 10cm H_2O PEEP during laparoscopic abdominal surgeries significantly improves intraoperative oxygenation and carbon dioxide elimination without causing clinically significant changes in heart rate. Arterial blood pressure decreased slightly in this group, but haemodynamics remained stable. The results confirm that 10 cm H_2O PEEP is a successful lung-protective ventilation strategy for use during laparoscopic abdominal surgery.

Keywords: Positive End-Expiratory Pressure, Laparoscopy, Pneumoperitoneum, Mechanical Ventilation, Hemodynamics.

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Introduction

Laparoscopic abdominal surgeries are now frequently used for a wide range of abdominal surgical procedures because of their advantages of small incision, reduced pain, earlier mobilization, and shorter hospital stay. Although all these benefits are obtained, pneumoperitoneum achieved by insufflation with carbon dioxide (CO_2) and general anesthesia still cause significant alterations in several physiological parameters, particularly of the respiratory and cardiovascular systems. In patients with limited cardiopulmonary reserve, these changes may be accentuated during the extended procedure.[1,2] The establishment of pneumoperitoneum leads to an increase in intra-abdominal pressure, causing the displacement of the diaphragm in a cephalad position, consequently leading to decreased functional residual capacity (FRC); lung compliance also decreases as the dependent lung areas are compressed. These changes lead to atelectasis, ventilation/perfusion mismatch, elevated airway pressures, and gas exchange deficits. In addition, these respiratory changes are worsened by the Trendelenburg position, which is often used in the course of laparoscopic operations on the pelvis, and which raises the diaphragm and lowers pulmonary compliance. As a result, optimization of intraoperative ventilation becomes an important component of

Address for correspondence: Dr. Pushpalatha Ventepaka, Assistant Professor, Department of Anesthesiology, Gandhi Medical College and Hospital, Secunderabad, Telangana, India.
E-mail: pushpamedico@gmail.com

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anesthetic management in laparoscopic surgery.[3,4] Mechanical ventilation during general anesthesia uses positive pressure ventilation to ensure adequate ventilation and carbon dioxide elimination. However, patients are at risk of alveolar collapse due to effects of anaesthetic and loss of normal respiratory muscle tone. Positive end-expiratory pressure (PEEP) is a common method for preventing end-expiratory alveolar collapse by allowing positive airway pressure during the expiration phase. When used appropriately, PEEP will increase FRC, recruit alveoli, improve oxygenation, and decrease the incidence of postoperative atelectasis. However, the best level of PEEP for laparoscopic abdominal surgery is still controversial, with low and high levels of PEEP having advantages and disadvantages.[5,6]

PEEP at lower levels may not be sufficient to prevent alveolar collapse during pneumoperitoneum, and at higher levels, PEEP can increase intrathoracic pressure, diminish venous return, diminish cardiac preload, and may affect cardiac output. These hemodynamic changes might be more apparent in hypovolemic patients or those with underlying cardiovascular conditions. Therefore, it is important to carefully select the right PEEP that will bring the benefits of the respiratory system without causing circulatory compromise. Multiple clinical trials have evaluated the effect of various PEEP levels during laparoscopy and found better lung mechanics and oxygenation with moderate PEEP levels, though hemodynamic stability and postoperative pulmonary function have shown mixed results.[7–9] There is current evidence to support the idea of lung-protective ventilation, which involves using low tidal volume, individualized PEEP, and, if appropriate, recruitment maneuvers to reduce ventilatory-induced lung injury. Ideal PEEP setting, however, can vary depending on patient characteristics, surgical position, duration of pneumoperitoneum, and type of laparoscopic procedure. Additional studies of respiratory mechanics and associated hemodynamics are required to determine the strategies used for ventilation that maximize pulmonary function without sacrificing cardiovascular stability (6,8,10). Based on this background, the present study was designed to evaluate the effects of different levels of positive end-expiratory pressure on respiratory and hemodynamic changes occurring in patients undergoing laparoscopic abdominal surgeries in general anesthesia.

Materials and Methods

This Prospective randomized comparative study was conducted in the Department of Anesthesiology, Gandhi Medical College and Hospital, Secunderabad. Institutional Ethical approval was obtained for the study with Rc. No. IEC/GMC/2023/04/76. The study was conducted over a period of 18 months from January 2023 to June 2024. Written consent was obtained from all the participants of the study after explaining the nature of the study in the vernacular language.

Inclusion criteria

1. Patients belonging to ASA grade I and II
2. Patients aged between 18 and 50 years
3. Patients willing to give informed written consent
4. Surgeries scheduled for laparoscopic abdominal surgery

Exclusion criteria

1. Patient's refusal
2. Hemodynamically unstable patients and ASA grade III or IV
3. Patients with a history of systemic hypertension, diabetes mellitus, cerebrovascular disease, bronchial asthma, ischemic heart disease (history of angina or myocardial infarction), seizure disorder
4. Pregnancy
5. Anticipated difficult airway

Based on the duration of the study and inclusion and exclusion criteria, a total of 70 patients undergoing elective laparoscopic abdominal surgeries were enrolled in the study. Patients were randomly allocated into two groups: Group A (PEEP 5): 35 patients receiving 5 cm H_2O PEEP. Group B (PEEP 10): 35 patients receiving 10 cm H_2O PEEP by computer generated random number.

Pre-Anesthetic Evaluation: Pre-anesthetic evaluation was done one day before surgery. A detailed history of cardiovascular, respiratory, and central nervous systems, ongoing medications, and any drug allergies was taken. A thorough clinical examination, including general physical and systemic examination, was done. Airway assessment was performed using Mallampati grading to anticipate difficult intubation. Routine investigations included complete blood picture, blood grouping and Rh typing, urine analysis, BUN, serum creatinine, fasting blood sugar, and ECG. Patients were kept nil per oral for 6 hours for solids and 2 hours for clear liquids. Written informed consent was obtained after explaining the procedure.

Technique of Procedure: After confirming pre-anesthetic check-up, investigation reports, and NPO status, patients were shifted to the operating room. Standard ASA monitoring was applied and baseline values for ECG, heart rate (HR), mean arterial pressure (MAP), oxygen saturation (SpO_2), and end-tidal carbon dioxide ($EtCO_2$) were recorded. Premedication included Inj. Glycopyrrolate 0.2 mg IV and Inj. Midazolam 1 mg IV. Preoxygenation with 100% oxygen was done for 3 Min. Inj. Fentanyl 2 μg/kg IV was administered. Anesthesia was induced using Inj. Propofol 2mg/kg and Inj. Vecuronium 0.1mg/kg. Intubation was performed with an appropriately sized endotracheal tube. Anesthesia was maintained with 1.0MAC of sevoflurane in a mixture of N_2O and O_2(2:1). Minute ventilation was set with a tidal volume of 8 mL/kg based on predicted body weight and a respiratory rate to maintain normocapnia, using an I: E ratio of 1:2. Group A received 5cm H_2O PEEP, and Group B received 10cm H_2O PEEP. Pneumoperitoneum was created using CO_2, maintaining intra-abdominal pressure at 14 mmHg.

Monitoring And Data Collection: HR, MAP, SpO_2, and $EtCO_2$ were recorded at three time points:

T1: Before intubation

T2: 30 minutes after pneumoperitoneum

T3: After desufflation

Arterial blood gases were sampled and analysed at the same time points.

Reversal and Postoperative Care: Neuromuscular blockade was reversed using Inj. Neostigmine 0.05 mg/kg and Inj. Glycopyrrolate 0.01 mg/kg. Tracheal extubation was done after ensuring the patient was fully awake with adequate spontaneous respiratory efforts.

Statistical Analysis: Data were entered in Microsoft Excel, and Statistical Packages for the Social Sciences was used for statistical analysis. The association between categorical variables was done using the Chi-square test, and the significance between the two groups for continuous variables following normality was assessed using Repeated measures ANOVA. A P-value <0.05 was considered significant.

Results

The demographic and anthropometric characteristics of the study groups are depicted in [Table 1]. Analysis of the table showed that the mean age of patients in the 5 PEEP group was 42.87 ± 4.62 years, while that in the 10 PEEP group was 44.78 ± 3.76 years (p=0.232). Female patients were slightly higher in both groups, 60.0% in the 5PEEP and 74.3% in the 10 PEEP group, although not statistically significant. The mean body weight was 76.24 ± 12.84 kg in the 5 PEEP group and 73.49 ± 11.82 kg in the 10 PEEP group (p=0.354). Similarly, the mean height was 165.57 ± 12.49 cm and 166.18 ± 13.01 cm, respectively (p=0.842). The results of the present study suggest that both study groups had similar baseline demographic and anthropometric parameters.

Table 1: Baseline demographic and anthropometric characteristics of the study groups

Parameter	5 PEEP Group (n=35)	10 PEEP Group (n=35)	P-value
Age (years) Mean ± SD	42.87 ± 4.62	44.78 ± 3.76	0.232
Gender			0.203
Male, n (%)	14 (40.0%)	9 (25.7%)	
Female, n (%)	21 (60.0%)	26 (74.3%)	
Weight (kg) Mean ± SD	76.24 ± 12.84	73.49 ±11.82	0.354
Height (cm) Mean ± SD	165.57 ± 12.49	166.18 ± 13.01	0.842

Comparison of hemodynamic parameters recorded at different time points is given in [Table 2]. There were no significant differences in heart rate between the groups at any time during the study (T1 p=0.081, T2 p=0.259, T3 p=0.141). Likewise, baseline (T1) and after pneumoperitoneum (T2) values of systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) were similar. However, there were some notable differences in the groups at T3. The mean SBP was significantly higher in the 5 PEEP group (141.97 ± 10.07 mmHg) compared with the 10 PEEP group (118.91 ± 13.35 mmHg) (p=0.001). Similarly, DBP was significantly higher in the 5 PEEP group (88.97 ± 1.08 mmHg) than in the 10 PEEP group (83.40 ± 9.86 mmHg) (p=0.001). Mean arterial pressure also remained significantly higher in the 5 PEEP group (110.02 ± 10.6 mmHg) compared to the 10 PEEP group (91.46 ± 9.34 mmHg) (p<0.001).

Table 2: Comparison of hemodynamic parameters between 5 PEEP and 10 PEEP Groups at different time points

Parameter	Time Point	5 PEEP Group (n=35) Mean	10 PEEP Group (n=35) Mean	P-value
Heart Rate (beats/min)	T1	76.71 ± 6.81	80.47 ± 10.57	0.081
	T2	82.82 ± 11.07	78.94 ± 16.84	0.259
	T3	83.99 ± 5.22	79.82 ± 16.57	0.141
SBP (mmHg)	T1	132.11 ± 18.47	132.21 ± 22.84	0.984
	T2	120.14 ± 27.41	125.49 ± 13.72	0.306
	T3	141.97 ± 10.07	118.91 ± 13.35	0.001*
DBP (mmHg)	T1	81.34 ± 16.2	85.74 ± 10.49	0.182
	T2	76.51 ± 17.01	84.68 ± 19.63	0.067
	T3	88.97 ± 5.08	83.4 ± 9.86	0.001*
MAP (mmHg)	T1	104.84 ± 12.84	107.82 ± 16.57	0.403
	T2	97.78 ± 20.01	104.23 ± 11.37	0.102
	T3	110.02 ± 10.6	91.46 ± 9.34	<0.001*

The respiratory parameters are summarized in [Table 3]. The difference in peak airway pressure (P peak) was not significant at either T1 (p=0.928) or T2 (p=0.307). Similarly, there were no differences between the groups at T1 (p=0.545) or T2 (p=0.059) in terms of plateau pressure (Pplat). The mean airway pressure (Pmean) was, on the other hand, significantly increased in all 10 PEEP groups during the two observation points. At T1, Pmean was 12.56 ± 1.47 cm H_2O in the 10 PEEP group compared to 9.62 ± 1.52 cmH_2O in the 5 PEEP group (p=0.001). At T2, the corresponding values were 13.89 ± 1.46 cmH_2O and 10.37 ± 1.19 cm H_2O, respectively (p<0.001). There was no significant difference between the two groups at T1 (p=0.361) or T2 (p=0.092) in terms of end-tidal carbon dioxide ($ETCO_2$) values.

Table 3: Comparison of Respiratory Parameters Between 5 PEEP and 10 PEEP Groups

Parameter	Time Point	5 PEEP Group Mean ± SD	10 PEEP Group Mean ± SD	P-value
P peak (cmH2O)	T1	21.1 ± 5.87	21.2 ± 2.91	0.928
	T2	24.42 ± 3.91	25.2 ± 2.2	0.307
P plato (cmH2O)	T1	19.75 ± 5.12	19.0 ± 5.2	0.545
	T2	21.97 ± 3.82	23.46 ± 2.16	0.059
P mean (cmH2O)	T1	9.62 ± 1.52	12.56 ± 1.47	0.001*
	T2	10.37 ± 1.19	13.89 ± 1.46	<0.001*
ETCO2 (mmHg)	T1	32.64 ± 4.82	33.49 ± 2.57	0.361
	T2	33.27 ± 4.38	34.91 ± 3.61	0.092

The results of the arterial blood gases are shown in [Table 4]. Analysis of the table showed that there was no difference between the baseline arterial oxygen tension (PaO_2) of the two groups (p=0.066). The 10 PEEP group had significantly higher oxygenation (mean PaO_2 177.37 ± 38.64 mmHg) than the 5 PEEP group (mean PaO_2 136.31 ± 37.84 mmHg) (p<0.001). No difference in PaO_2 was found between the groups at T3 (p=0.263). There was no significant difference in baseline arterial carbon dioxide tension ($PaCO_2$) (p=0.110). At T2, $PaCO_2$ was significantly lower in the 10 PEEP group (36.86 ± 5.63 mmHg) than in the 5 PEEP group (42.84 ± 5.63 mmHg) (p<0.001). At T3, there was a significant difference between the $PaCO_2$ in the 10 PEEP group (35.12 ± 5.19 mmHg) and the 5 PEEP group (39.72 ± 4.83 mmHg) (p=0.003).

Table 4: Comparison of Arterial Blood Gas Parameters Between 5 PEEP and 10 PEEP Groups

Parameter	Time Point	5 PEEP Group Mean ± SD	10 PEEP Group Mean ± SD	P-value
PaO2 (mmHg)	T1	86 ± 16.84	92.84 ± 13.57	0.066
	T2	136.31 ± 37.84	177.37 ± 38.64	<0.001*
	T3	97.58 ± 21.96	92.67 ± 13.45	0.263
PaCO2 (mmHg)	T1	38.61 ± 4.72	36.84 ± 4.42	0.110
	T2	42.84 ± 5.63	36.86 ± 5.63	<0.001*
	T3	39.72 ±4.83	35.12 ±5.19	0.003*

[Table 5] presents an overall summary of clinically significant findings between the 5 PEEP and 10 PEEP groups. The 10 PEEP group showed higher mean airway pressure at time intervals of T1 and T2 with significant p values indicating improved alveolar recruitment. It also produced a higher level of arterial oxygenation during pneumoperitoneum, as shown by higher PaO_2 values at T2 (p<0.001). Similarly, it also demonstrated lower $PaCO_2$ at both T2 (p<0.001) and T3 (p=0.003), features of effective improved ventilation. Conversely, patients receiving 5 cm H_2O PEEP had significantly higher SBP, DBP, and MAP at T3 ($p \leq 0.001$). Heart rate, peak airway pressure, plateau pressure, and $ETCO_2$ remained comparable between the two groups throughout the study.

Table 5: Summary of Clinically Significant Findings Between 5 PEEP and 10 PEEP Group

Parameter	Time Point	5 PEEP Group	10 PEEP Group	P-value
SBP (mmHg)	T3	141.97 ± 10.7	118.91± 13.35	0.001*
DBP (mmHg)	T3	88.97 ± 10.8	83.4 ± 9.86	0.001*
MAP (mmHg)	T3	114.02 ±1.06	91.46 ± 9.34	<0.001*
P mean (cmH2O)	Tl, T2	Lower	Higher	<0.001*
PaO2 (mmHg)	T2	136.31 ± 37.84	177.37 ± 38.64	<0.001*
PaCO2 (mmHg)	T2, T3	Higher	Lower	<0.001, 0.003*

Discussion

The present study evaluated the effects of Positive end-expiratory pressure (PEEP) levels (5 cm H_2O & 10 cm H_2O) on respiratory and hemodynamic parameters during laparoscopic abdominal surgeries. The results of our study showed significantly higher mean airway pressure and better arterial oxygenation during pneumoperitoneum and lower arterial carbon dioxide levels with the application of 10 cm H_2O PEEP as compared with 5 cm H_2O PEEP cases. The values of blood pressures were found to be lower in the 10 PEEP group, although heart rates remained similar in both groups throughout the study. These findings indicate that laparoscopic surgeries require an optimal level of PEEP to improve pulmonary gas exchange and acceptable hemodynamic changes in otherwise stable patients. The respiratory changes seen in this study were consistent with physiological actions produced by pneumoperitoneum. Insufflation with carbon dioxide raises the diaphragm, reduces the functional residual capacity, lowers pulmonary compliance, and causes collapse of alveoli. The use of adequate PEEP is required to reverse these effects, keep alveoli patent, and enlarge the FRC, improving ventilation-perfusion matching.[3,10] Airway pressure levels were significantly elevated in the 10 PEEP group at both time points of the present study [Table 2]. This rise is anticipated as higher PEEP will keep positive pressure in the alveoli during expiration, allowing for alveolar recruitment but not a significant rise in peak and plateau airway pressures. The same has been reported by Park et al., who showed an improvement in respiratory mechanics with higher PEEP during laparoscopy without clinically significant increases in airway pressures.[7] The present study revealed a significantly higher

PaO_2 in the 10 PEEP group during pneumoperitoneum. Better oxygenation in this group is associated with better alveolar recruitment and decreased intrapulmonary shunting, which are beneficial in laparoscopic procedures. The results of our study are consistent with the observations of Futier et al,[6] and Hemmes et al,[8] who found that moderate-to-high PEEP during lung-protective ventilation strategies resulted in better intraoperative oxygenation. Similarly, Cinnella et al,[2] showed that recruitment maneuvers combined with the use of the appropriate PEEP during laparoscopy improve oxygenation and respiratory mechanics. Intraoperatively, the benefits of increased PEEP are most obvious, as no difference in PaO_2 was seen at the final measurement. The present study also found significantly lower $PaCO_2$ levels in the 10 PEEP group before, during, and after pneumoperitoneum. Hypercapnia during laparoscopy is due to absorption of carbon dioxide from the peritoneal cavity, but with high PEEP, adequate alveolar ventilation can help to eliminate carbon dioxide. Similar improvements in CO2 exchange have been reported by other studies where individualized PEEP was applied during abdominal surgical procedures.[9,11] The higher level of PEEP did not result in a significant difference in either peak airway pressure or plateau pressure between the groups. This observation suggests that there were no significant changes in airway resistance or excessive airway pressures when PEEP was raised to 10 cm H_2O. Similar results have been reported by Meininger et al., who found that recruitment maneuvers and moderate PEEP led to increased pulmonary compliance without significant changes in airway pressure.[12] Hemodynamic parameters were significantly lower at the final observation between the 10 PEEP group and the 5 PEEP group. Increased PEEP leads to an increase in intrathoracic pressure, which can decrease venous return and cardiac preload and cause a modest decrease in arterial pressure.[13] But the heart rate did not change in either group, indicating that the hemodynamic changes were tolerable. Moderate PEEP levels have also been shown to have beneficial effects on the respiratory system, with limited cardiovascular effects, in patients without significant cardiac disease,[14] and similar results have been reported by Aldenkortt et al,[14] in their study. The results of the present study agree with the present recommendations for lung protection ventilation during general anesthesia. Recent evidence has shown that the use of low tidal volume and adequate PEEP can help to prevent atelectasis, to supply optimal oxygenation during surgery, and to prevent ventilator-induced lung injury.[5,6,15] These results suggest that during laparoscopic abdominal surgery, 10 cm H_2O PEEP is more effective at improving respiratory function than 5 cm H_2O PEEP, although the optimal PEEP level may differ among patients and surgical conditions. The study has certain limitations. It was done in one centre and on a relatively small number of subjects and may not be representative. All patients with major cardiopulmonary disease were excluded, and long-term pulmonary outcomes were not assessed. More large multicenter studies with individualised PEEP titration and larger numbers of patients may yield additional information about the best ventilatory management during laparoscopy.

Conclusion

In the present study, use of 10 cm H_2O positive end-expiratory pressure (PEEP) during laparoscopic abdominal surgery proved to be more advantageous with regard to the respiratory outcome than 5 cm H_2O PEEP. We found a significantly higher mean airway pressure and better arterial oxygenation, and lower arterial carbon dioxide levels during pneumoperitoneum in the 10 PEEP group. The 10 PEEP group also had lower systolic, diastolic, and mean arterial pressures at the end of surgery, with a stable heart rate, which suggested good hemodynamic tolerance. These results indicate that 10cmH_2O PEEP is an effective ventilatory strategy without compromising hemodynamic stability for patients with laparoscopic surgery in the abdomen.

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Conflicts of interest

There are no conflicts of interest.

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