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Effect of Different Levels of Positive End-Expiratory Pressure (PEEP) on Respiratory Status during Gynecologic Laparoscopy

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Abstract

Background: During gynecologic laparoscopy, pneumoperitoneum, and the position of the patient's head can lead to pathophysiologic changes in cardiovascular and respiratory systems, complicating the management of anesthesia in these patients. One of the strategies for improving the respiratory status of patients undergoing laparoscopy is the use of Positive End-Expiratory Pressure (PEEP).

Objectives: This study aimed to evaluate the effect of different levels of PEEP on the respiratory status of patients undergoing gynecologic laparoscopy.

Methods: In this clinical trial, 60 patients with ASA I were randomly assigned to three groups to control anesthesia: ZEEP (PEEP 0 cmH_2O; 20 cases), $PEEP_5$ (PEEP 5 cmH_2O; 20 cases), and $PEEP_{10}$ (PEEP 10 cmH_2O; 20 cases). Respiratory and hemodynamic variables of patients were compared before general anesthetic induction and immediately after CO_2 insufflation at intervals of 5, 10, 20, 30, and 60 min and the end of the operation in the three study groups.

Results: The PEEP application improved pH, $PaCO_2$, and PaO_2 levels at the end of pneumoperitoneum compared to baseline when compared with the non-use of PEEP (ZEEP group). Also, the frequency of dysrhythmia in the use of PEEP in controlled ventilation was significantly lower in patients with $PEEP_{10}$ ($P < 0.05$). The application of $PEEP_5$ resulted in similar effects to $PEEP_{10}$ in the levels of respiratory variables.

Conclusions: The PEEP application is associated with improved arterial blood gas in patients with gynecologic laparoscopy. The use of $PEEP_{10}$ has a greater effect on the improvement of respiratory parameters and complications of pneumoperitoneum.

Keywords: Laparoscopy, Pneumoperitoneum, Positive End-Expiratory Pressure, Respiratory Status

1. Background

Laparoscopic surgery is increasing in frequency in many laparotomy procedures. It is also well-established in gynecological surgeries in the Trendelenburg position (1-3). Laparoscopy is used to diagnose and treat gynecological pathologies such as pelvic lymphadenectomy, ovarian cyst removal, myomectomy, fallopian tube ligation, hysterectomy, and diagnosis of infertility (2, 4). Although it can provide distinct advantages by decreasing the length of hospitalization, offering better cosmetic outcomes, and reducing the bleeding and pain after the surgery, pneumoperitoneum requirement and the position during laparoscopy raise concerns about the management of anesthesia during the surgery (5, 6). The insufflation of carbon dioxide (CO_2) into the peritoneum to keep away the abdominal organs increases the Intra-abdominal Pressure (IAP) up to 12 - 14 mmHg, which affects respiratory and cardiac function (7). The Trendelenburg position also increased IAP from 8.8 to 13.3 mmHg (8). All of these can predominantly increase intraperitoneal CO_2, resulting in the cranial displacement of the diaphragm (9). This displacement can lead to decreased respiratory capacity, including Functional Residual Capacity (FRC), decreased compliance, increased airway pressure, and increased resistance and ventilation-perfusion mismatch (7, 10-12). On the other hand, general anesthesia can also impair respiratory function by developing atelectasis (12, 13). Taken together, during prolonged laparoscopic procedures, changes in cardiorespiratory parameters can have clinically significant adverse effects such as reduced arterial oxygenation in the patient (12, 13). Various intraoperative ventilatory techniques have been used to prevent these changes. positive-

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pressure ventilation (PPV) has been widely used for controlling ventilation, but it can increase the airway pressure in pneumoperitoneum and Trendelenburg position (14, 15). Pressure-controlled ventilation (PCV) is one of the suggested methods to be used during general anesthesia. Mechanical ventilation with Positive End-Expiratory Pressure (PEEP) can affect respiration and hemodynamics during pneumoperitoneum by increasing FRC and reducing atelectasis (10, 15, 16). It is not common to use PEEP routinely in the surgical situation, and it is preferred to be used in high-risk patients such as CO_2 embolization cases (1).

2. Objectives

Based on the paucity of data regarding the effect of PEEP and its amount during laparoscopy, we aimed to evaluate the effect of different levels of PEEP on the respiratory status of patients undergoing gynecologic laparoscopy.

3. Methods

3.1. Study Population

After gaining approval from the Ethics Committee (code 1395.1277.IR.TBZMED.REC) and obtaining written informed consent for the double-blind randomized clinical trial, the study was conducted prospectively on 60 patients (ASA physical status I, aged 18 - 60 years) who underwent general anesthesia for gynecologic laparoscopy in the Shohada Tajrish Medical Center. Consecutive patients were selected based on their entrance. The technique of randomization was performed via randomly permuted blocks using online software (www.randomizer.org). The double-blind technique was used to blind both participants and members of the research team. Patients were excluded from the study if they had BMI > 30, systemic diseases including cardio-cerebrovascular, hepato-renal, and respiratory diseases, psychological disorders, emergency surgery, cigarette smoking, the history of atopy and refusal to participate.

The patients were randomized to treatment by the 1:1:1 ratio. The randomization was done by online rand list software into three groups (n = 20 in each group): ZEEP (PEEP = 0 cmH_2O), $PEEP_5$ (PEEP = 5 cmH_2O), and $PEEP_{10}$ (PEEP = 10 cmH_2O). Respiratory and hemodynamic variables of patients including heart rate (HR), blood pressure (BP), mean arterial pressure (MBP), peripheral capillary oxygen saturation (SPO_2), and end-tidal carbon dioxide ($EtCO_2$) pressure were compared before general anesthetic induction and immediately after CO_2 insufflation at intervals of 5, 10, 20, 30, and 60 min and the end of the operation in the three study groups. Operative and postoperative variables, including operation time, duration of anesthesia, pneumoperitoneum time, intravenous (IV) volume, bleeding volume, urine output, and dysrhythmia, were recorded. Blood samples were obtained for arterial blood gas (ABG) analysis after anesthetic induction, immediately before CO_2 insufflation, and 30 min after the initiation of operation. The infusion of ephedrine (5 - 20 mg) and atropine (0.5 - 3 mg) was given to the patients if blood pressure and heart rate reduced more than 25%, and adrenaline (0.1 - 5 mg) was infused to maintain the anesthesia. If their blood pressures and heart rates did not increase, they were excluded from the study. Figure 1 illustrates the patient selection process of the study in three groups.

3.2. Anesthetic Induction

As premedication, the patients received 10 - 12 mL/kg/h normal saline intravenously. General anesthesia was induced with 0.03 mg/kg midazolam, 1 μg/kg remifentanil, 2 mg/kg propofol, and 0.5 mg/kg atracurium. After induction, the trachea was intubated with an endotracheal tube of appropriate size (7 - 7.5). During the operation, patients' non-invasive blood pressure (NIBP), electrocardiography (ECG), SpO_2, and $EtCO_2$ were monitored. After the insertion of a Veress needle, carbon dioxide (CO_2) was insufflated into the peritoneum. The insufflation of the peritoneum with CO_2 was maintained at a pressure of 12 - 14 mmHg with a flow of 1 - 2.5 L/min. Thereafter, the reverse Trendelenburg position was standardized at an angle of 30 degrees. Anesthesia was maintained with the infusion of propofol 50 - 150 μg/kg/min, remifentanil 0.1 - 1 μg/kg/min, and atracurium 0.2 - 0.3 mg/kg, if needed. The patients were mechanically ventilated (Fabius, Drager Medical; S-ORC AG&CO.kg Germany, D023452 Lubeck). They were ventilated with positive pressure ventilation (PPV) and volume-controlled ventilation (VCV) with a tidal volume (TV) of 10 mL/min, respiratory rate of 12 breaths/min, an inspiratory-to-expiratory ratio of 1:2 to maintain $EtCO_2$ between 35 and 45 mmHg, and airway pressure of 30 mmHg.

3.3. Statistical Analysis

The statistical analysis was performed using IBM SPSS software for Windows (version 16.0). The data were expressed as mean $\pm$ standard deviation. Statistical comparison of variables was conducted by the chi-square test. The multivariate analysis of variance (repeated-measures ANOVA) was used to evaluate the differences in variables. For evaluating the effect of time, we used the post hoc test. Multiple regression analysis was performed to predict the multivariate effect of variables. A P value of less than 0.05 was considered statistically significant.

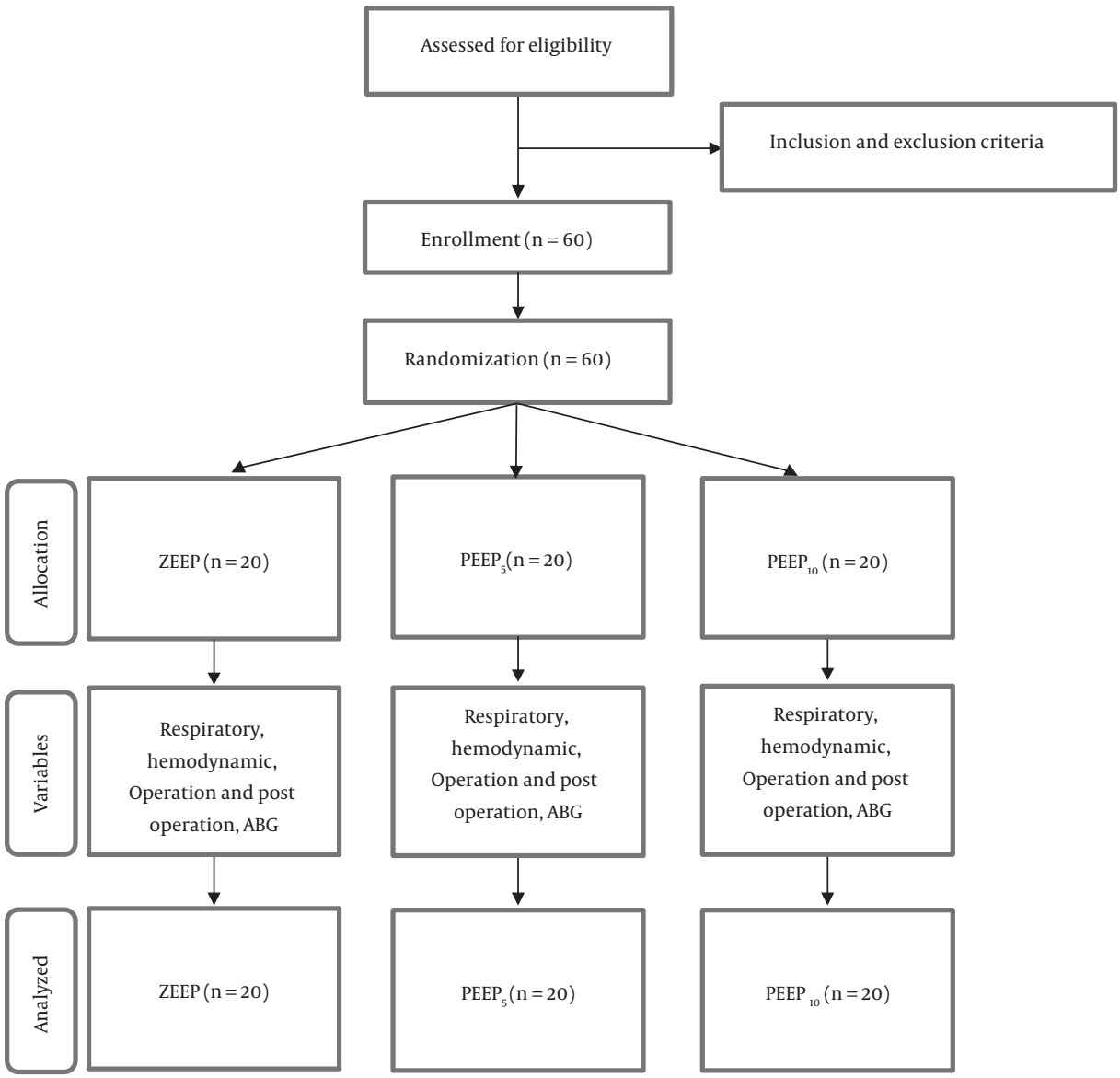

Figure 1. Flowchart of the study design. PEEP: Positive end-expiratory pressure; ZEEP: PEEP 0 cmH_2O; $PEEP_5$: PEEP 5 cmH_2O; $PEEP_{10}$: PEEP10 cmH_2O

4. Results

In this study, 60 women (mean age: 30.28 years) with ASA I underwent gynecological laparoscopy under general anesthesia and were included in the final analysis. The mean pneumoperitoneum time was 61.81 ± 17.68, the operation time was 70.43 ± 18.42, and anesthesia time was 81.73 ± 18.42. The most performed surgery was ovarian cystectomy, with a frequency of 24 (40%) patients (Table 1).

4.1. Hemodynamics and Respiration Variables

Systolic blood pressure difference was statistically significant between ZEEP and $PEEP_5$ (P = 0.016) immediately after pneumoperitoneum induction and also between ZEEP and $PEEP_{10}$ (P = 0.012) 10 min after induction. Diastolic blood pressure, MBP, and HR were statistically significantly different between ZEEP and $PEEP_{10}$ groups 10 min after induction (P = 0.009, P = 0.003, and P = 0.002, respectively). The $EtCO_2$ difference between ZEEP and $PEEP_{10}$ was also significant at 10, 20, 30, and 60 min and after the operation (P = 0.001, P = 0.002, P = 0.001, P = 0.019, and P = 0.004, re-

Table 1. Demographic Characteristics of the Study Population[a, b]

Variables	ZEEP (N = 20)	PEEP5 (N = 20)	PEEP10 (N = 20)	P Value
Age, y	30.05 ± 7.42	28.35 ± 6.58	32.45 ± 7.47	0.201
Weight, kg	68.80 ± 11.21	68.45 ± 11.21	74.50 ± 9.79	0.080
Height, cm	160.35 ± 4.33	161.85 ± 5.28	162.30 ± 3.98	0.374
Type of surgery				0.180
Ovarian cyst	25 (5)	50 (10)	45 (9)	
EP	35 (7)	35 (7)	15 (3)	
Infertility	40 (8)	15 (3)	40 (8)	
Pneumoperitoneum time, min	57.95 ± 23.18	68.95 ± 13.51	58.55 ± 13.07	0.085
Operation time, min	66.00 ± 24.54	76.95 ± 13.77	68.35 ± 13.86	0.141
Anesthesia time, min	77.90 ± 24.85	88.00 ± 13.39	79.30 ± 13.83	0.172

[a] Continuous variables are presented as mean ± SD) or median (25th, 75th percentiles) and Categorical variables are described as frequency (%); n (%).
[b] A value of $P < 0.05$ was accepted to be statistically significant.

spectively). In comparison, SPO_2 was not statistically significant between the three groups ($P > 0.05$) (Figure 2).

4.2. Gas Exchange

Table 2 demonstrates the ABG analysis immediately before CO_2 insufflation and also 30 min after the initiation of operation. Besides, pH after pneumoperitoneum was statistically significantly different between the ZEEP and $PEEP_5$ groups ($P = 0.016$) and also between ZEEP and $PEEP_{10}$ ($P = 0.006$). After the pneumoperitoneum, the reduction of pH was significantly more in the ZEEP group than in the other groups.

In addition, PaO_2 was statistically significantly different between ZEEP and $PEEP_{10}$ after pneumoperitoneum with the P value of 0.028. The reduction in PaO_2 after pneumoperitoneum was significantly more in the ZEEP group than in the other groups before pneumoperitoneum. In addition, the increase in PaO_2 was significantly more in the $PEEP_{10}$ group than in the $PEEP_5$ group after pneumoperitoneum.

However, $PaCO_2$ showed no statistically significant differences between the groups. The increase in $PaCO_2$ was higher in the ZEEP group than in other groups after pneumoperitoneum, and it was significantly higher in $PEEP_5$ than in $PEEP_{10}$. Besides, HCO_3, BE, and SPO_2 showed no statistically significant differences between the groups. There were no differences between the groups before and after pneumoperitoneum in HCO_3. However, BE had statistically significant differences within the groups. Also, SPO_2 was significantly lower after pneumoperitoneum in the ZEEP group than in other groups. Although SPO_2 was higher in the $PEEP_5$ and $PEEP_{10}$ groups after pneumoperitoneum, the amount of SPO_2 did not show any difference in these groups.

4.3. Complications and Treatment After Operation

Table 3 demonstrates major complications and management after pneumoperitoneum induction in the three groups. The mean IV volume was 1800 ± 368.11 milliliter (mL). There were significant differences between ZEEP and $PEEP_{10}$ ($P = 0.001$) and also between $PEEP_5$ and $PEEP_{10}$ ($P = 0.002$) in the IV volume infusion, while $PEEP_{10}$ received the least IV volume infusion.

The mean bleeding volume was 86.33 ± 75.88 mL. There were statistically significant differences between the groups. The bleeding volume was lower in $PEEP_{10}$ than in ZEEP (0.001) and $PEEP_5$ ($P = 0.001$). The lowest bleeding volume was seen in the $PEEP_{10}$ group.

The mean urinary output was 160.08 ± 84.39 mL. The $PEEP_{10}$ group had the lowest volume of urinary output, and there were significant differences between $PEEP_{10}$ and ZEEP ($P = 0.003$) and $PEEP_5$ ($P = 0.002$).

The most frequent complication after pneumoperitoneum induction was dysrhythmia, which occurred in nine patients (15%), mostly in the ZEEP and $PEEP_5$ groups. It was statistically significant between ZEEP and $PEEP_{10}$ ($P = 0.004$). The most medical treatment after dysrhythmia was lidocaine injection in nine patients (15%). There were significant differences between ZEEP and $PEEP_5$ ($P = 0.002$) and also between ZEEP and $PEEP_{10}$ ($P = 0.007$) in receiving lidocaine injection, with the ZEEP group being at the top.

5. Discussions

Because the diaphragm is mechanically attached to the abdominal wall, an increase in intra-abdominal pressure can cause a cranial shift of the diaphragm and decrease FRC (2, 17-19). Pneumoperitoneum induction also affects

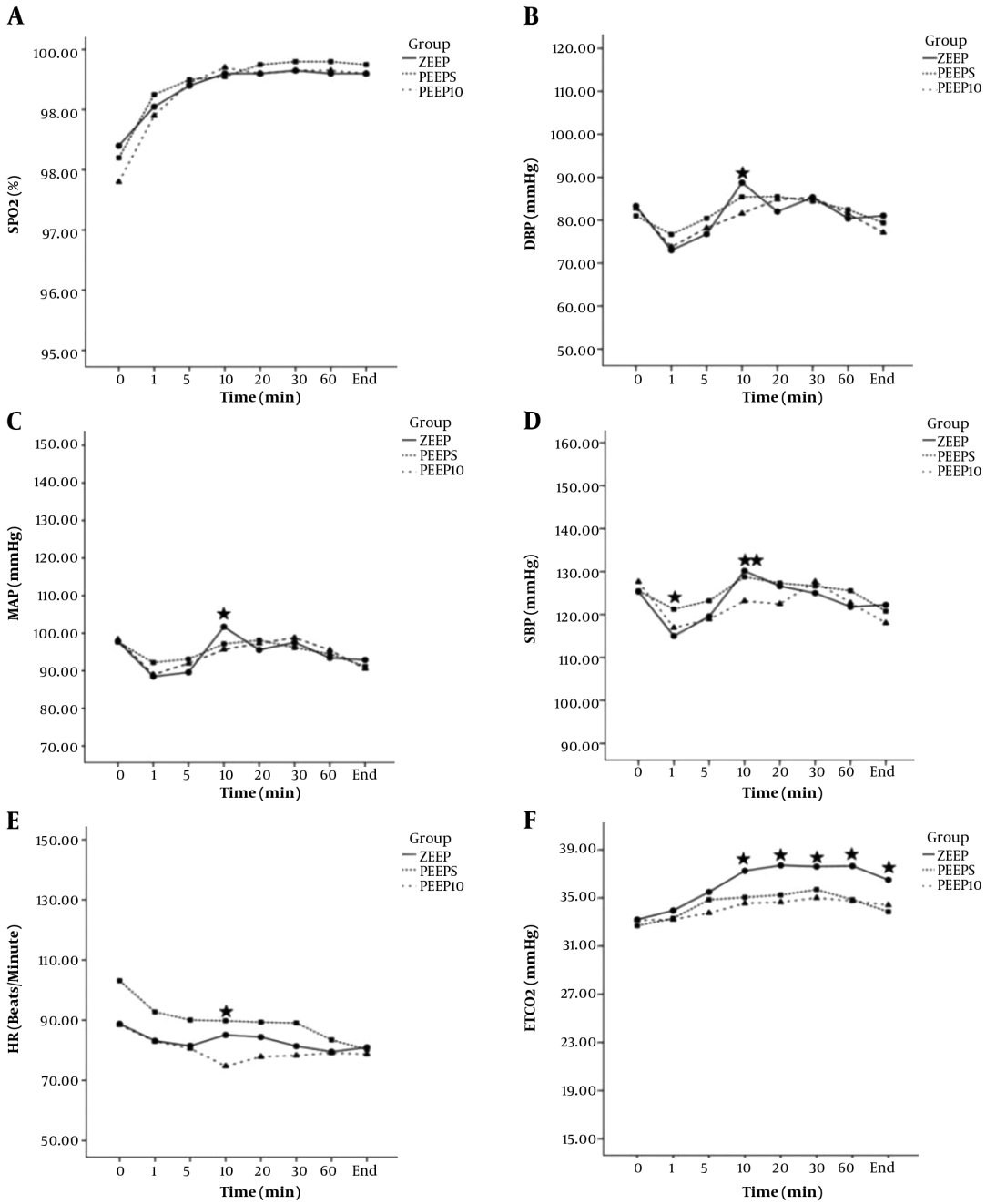

Figure 2. ZEEP group: (-); $PEEP_5$ group: (—); $PEEP_{10}$: (- - -); A, peripheral capillary oxygen saturation; B, diastolic blood pressure; C, mean atrial pressure; D, systolic blood pressure; E, heart rate; F, end-tidal carbon dioxide

the circulatory system by increasing MAP and mean systemic filling pressure. The application of PEEP has been beneficial for both prophylaxis and therapy of the patients during laparoscopy to improve oxygenation, decrease atelectasis in the lungs, increase FRC (12, 20), and preserve the circulatory system (12). In this study, we aimed to evaluate the effects of different levels of PEEP on respiratory function during gynecologic laparoscopy. In all three groups, respiratory status was not affected by confounding variables such as age, weight, and height. Although

Table 2. Gas Exchanges[a, b, c]

Variables	ZEEP (N = 20)	$PEEP_5$ (N = 20)	$PEEP_{10}$ (N = 20)
pH			
T1	7.42 ± 0.02	7.42 ± 0.03	7.42 ± 0.03
T2	7.26 ± 0.07	7.31 ± 0.04	7.32 ± 0.05
P value	0.003	0.198	0.201
PaO_2			
T1	248.30 ± 127.59	196.50 ± 153.21	138.75 ± 108.85
T2	208.10 ± 146.87	201.79 ± 147.76	244.75 ± 145.76
P value	0.005	0.289	0.028
$PaCO_2$			
T1	31.51 ± 4.79	35.11 ± 13.34	32.75 ± 4.56
T2	45.88 ± 8.86	46.16 ± 12.73	39.60 ± 7.32
P value	0.047	0.034	0.047
HCO_3-			
T1	20.54 ± 2.56	20.57 ± 2.06	20.70 ± 1.80
T2	20.11 ± 2.34	19.89 ± 5.43	20.47 ± 2.47
P value	0.978	0.781	0.977
BE			
T1	-2.79 ± 1.87	-2.60 ± 1.78	-2.62 ± 2.07
T2	-6.42 ± 3.03	-5.01 ± 1.94	-5.02 ± 2.71
P value	0.001	0.003	0.010
SPO_2			
T1	98.74 ± 1.82	95.36 ± 10.51	97.05 ± 2.37
T2	87.06 ± 27.11	97.20 ± 3.33	98.20 ± 3.22
P value	0.089	0.098	0.103

Abbreviations: BE, base excess; HCO_3-, end-tidal carbon dioxide; $PaCO_2$, partial pressure of carbon dioxide; PaO_2, partial pressure of oxygen; pH, potential of hydrogen; SPO_2, peripheral capillary oxygen saturation; T1, before pneumoperitoneum; T2, After pneumoperitoneum.
[a] Continuous variables are presented as mean ± SD or median (25th, 75th percentiles) and categorical variables are described as frequency (%); n (%)
[b] A value of $p < 0.05$ was accepted to be statistically significant.
[c] PaCO2, PaO2, SPO2, HCO3-, BE, and pH are the results of arterial blood gases.

PEEP can interfere with intra-thoracic pressure and reduce venous return and cardiac output, the administration of adequate levels of PEEP has been advocated as a therapeutic modality to improve oxygenation and hemodynamics (AHSHEMZADEH) (VMF Mendez). In our study, the use of $PEEP_5$ caused a modification in blood pressure, MAP, HR, and SPO_2, and $PEEP_{10}$ had more hemodynamic effects than $PEEP_5$. Our study showed that the application of PEEP after pneumoperitoneum induction in patients submitted to gynecological laparoscopy surgery in the Trendelenburg position under general anesthesia could improve the ABG exchange such as pH and PaO_2.

Luz et al. performed laparoscopic lymphadenectomy in a dog model study. Their study demonstrated that the combination of increased intra-abdominal pressure and PEEP could significantly reduce the hemodynamic variables during laparoscopy. Our result is in line with their results. Although, in our study, MAP increased 20 ± 10 min after pneumoperitoneum induction, this may be due to the differences in human and animal species (20).

Cinnella et al. performed a study on patients undergoing pelvic laparoscopy in the Trendelenburg position. They showed the application of PEEP after pneumoperitoneum induction led to the improvement of the chest wall and lung elastance. Moreover, they found that PEEP of 5 cmH_2O led to the improvement of HR (2). Our result showed that the induction of PEEP of 10 cmH_2O could increase HR after 10 min.

In the current study, those patients who received $PEEP_{10}$ had less IV volume requirement than patients in other groups, and they had less bleeding volume, as well. It is suggested that the increased bleeding volume can be the result of increased afterload in the left ventricle due to pneumoperitoneum induction. However, the application of $PEEP_{10}$ reduced the bleeding volume during the surgery, so increased left ventricular afterload could be reserved by applying moderate $PEEP_{10}$. Fellahi et al. investigated eight healthy individuals to evaluate the effect of PEEP on hemodynamics during abdominal hyper-pressure. They found that the application of moderate PEEP of 10 cmH_2O could significantly decrease the intra-abdominal pressure and consequently decrease the left ventricular end-diastolic volume (21). In this study, we demonstrated that the application of PEEP could decrease the hemodynamic instability by increasing intra-abdominal pressure as a result of the decrease in end-systolic left ventricular wall stress.

In our study, SaO_2 was higher in the $PEEP_5$ group than in other groups. In patients undergoing pneumoperitoneum induction, abdominal hyper-pressure and reduction in lung capacity would decrease the FRC. Previous studies showed the main effect of PEEP is to increase FRC by eliminating atelectasis formation. Neumann et al. conducted a study on 13 patients undergoing elective diagnostic gynecologic laparoscopy. They observed that using $PEEP_{10}$ could improve SaO_2 and prevent atelectasis formation (22).

Russo et al. investigated the effects of ventilation with PEEP of 5 cmH_2O and 10 cmH_2O on the respiratory system and cardiac function by using transthoracic echocardiography. They showed that PaO_2 values were improved in the PEEP groups, and both $PaCO_2$ and $EtCO_2$ increased after gas insufflation in the control group. Although both were decreased with $PEEP_{10}$, using $PEEP_5$ only improved the $EtCO_2$ values (7). In the current study, the increases in $PaCO_2$ and $EtCO_2$ were lower in $PEEP_{10}$ than in other groups after pneu-

Table 3. Complications and Treatment After Induction of General Anesthesia[a, b]

Variables	ZEEP (N = 20)	$PEEP_5$ (N = 20)	$PEEP_{10}$ (N = 20)	Total	P Value
Intraoperative fluid, mL	19.60 ± 335.84	1940 ± 237.64	1500 ± 330.47	1800 ± 368.11	0.001
Bleeding, mL	112 ± 92.88	108 ± 50.01	39 ± 56.65	86.33 ± 75.88	0.002
Urinary output, mL	182 ± 92.99	187.50 ± 85.77	110.75 ± 47.46	160.08 ± 84.39	0.004
Complications, %					
Hypertension	1 (5)	2 (10)	2 (10)	5 (8.3)	0.804
Tachycardia	2 (10)	2 (10)	1 (5)	5 (8.3)	0.804
Dysrhythmia	4 (20)	4 (20)	1 (5)	9 (15)	0.308
Treatment, %					
Ephedrine	1 (5)	0	2 (10)	3 (5)	0.349
Phenylephrine	0	3 (15)	0	3 (5)	0.043
Atropine	2 (10)	5 (1)	5 (1)	4 (6.7)	0.765
Lidocaine	4 (20)	4 (20)	1 (5)	9 (15)	0.308

[a] Continuous variables are presented as mean ± SD or median (25th, 75th percentiles) and categorical variables are described as frequency (%); n (%)
[b] A value of $P < 0.05$ was accepted to be statistically significant.

moperitoneum induction. In addition, similar to Russo et al. study, $EtCO_2$ was lower only in $PEEP_5$.

Dysrhythmia was the most frequent complication that occurred after pneumoperitoneum induction in our study. It was significantly lower in the $PEEP_{10}$ than in other groups, which could lead to the absorption of CO_2 and the increase of $PaCO_2$. Applying a high level of PEEP demonstrated to eliminate this complication. Gutt et al. investigated the effect of CO_2 insufflation on the occurrence of complications after laparoscopy. They found that hypercarbia and acidosis following CO_2 insufflation could lead to hemodynamic changes through the cardiovascular system and sympathoadrenal stimulation. The direct effects of increased $PaCO_2$ and acidosis include decreasing cardiac contractility and sensitization to the arrhythmogenic effects of catecholamines (9).

The laparoscopic procedure is increasingly performed under general anesthesia, but respiratory compromises after pneumoperitoneum induction raise concerns about the adverse effects on respiratory mechanics. Despite different factors affecting the respiratory status, applying PEEP demonstrated to improve atelectasis caused by pneumoperitoneum, as well as gas exchange and oxygenation.

5.1. Conclusion

Based on the results, the PEEP application was associated with the improvement of ABG in patients with gynecologic laparoscopy. The application of PEEP of 10 cm H_2O had a greater effect on the improvement of respiratory parameters and complications of pneumoperitoneum such as hemodynamic instability including hemorrhage, tachycardia, and hypertension. Further studies are required to perform on larger populations and the elderly because age can influence respiratory mechanisms and SPO_2.

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Footnotes

Authors' Contribution: SA, MZ, and EB designed the trial. NY, MZ, and SZ collected the data. SA, MZ, and EB conducted the procedures. NY and SZ analyzed the data. NY, MZ, and SZ drafted the manuscript. NY designed the tables. All authors read and approved the final version of the manuscript.

Clinical Trial Registration Code: IRCT20191019045155N1.

Conflict of Interests: The authors do not have any conflicts of interest.

Ethical Approval: The protocol of this study was reviewed by the Research Committee of the Tabriz Faculty of Medicine for dissertations and the Ethics Committee of the Research Vice-Chancellor Office, Tabriz University of Medical Sciences, Tabriz, Iran. The ethical code was 1395.1277.IR.TBZMED.REC.

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Informed Consent: Written informed consent was obtained from the participants.

References

1. Valenza F, Chevallard G, Fossali T, Salice V, Pizzocri M, Gattinoni L. Management of mechanical ventilation during laparoscopic surgery. *Best Pract Res Clin Anaesthesiol*. 2010;**24**(2):227–41. doi: 10.1016/j.bpa.2010.02.002. [PubMed: 20608559].
2. Cinnella G, Grasso S, Spadaro S, Rauseo M, Mirabella L, Salatto P, et al. Effects of recruitment maneuver and positive end-expiratory pressure on respiratory mechanics and transpulmonary pressure during laparoscopic surgery. *Anesthesiology*. 2013;**118**(1):114–22. doi: 10.1097/ALN.0b013e3182746a10. [PubMed: 23196259].
3. Rauh R, Hemmerling TM, Rist M, Jacobi KE. Influence of pneumoperitoneum and patient positioning on respiratory system compliance. *J Clin Anesth*. 2001;**13**(5):361–5. doi: 10.1016/s0952-8180(01)00286-0. [PubMed: 11498317].
4. Do AT, Cabbad MF, Kerr A, Serur E, Robertazzi RR, Stankovic MR. A warm-up laparoscopic exercise improves the subsequent laparoscopic performance of Ob-Gyn residents: a low-cost laparoscopic trainer. *JSLS*. 2006;**10**(3):297–301. [PubMed: 17212883]. [PubMed Central: PMC3015706].
5. Kwak HJ, Park SK, Lee KC, Lee DC, Kim JY. High positive end-expiratory pressure preserves cerebral oxygen saturation during laparoscopic cholecystectomy under propofol anesthesia. *Surg Endosc*. 2013;**27**(2):415–20. doi: 10.1007/s00464-012-2447-5. [PubMed: 22752286].
6. Bajwa SJ, Kulshrestha A. Anaesthesia for laparoscopic surgery: General vs regional anaesthesia. *J Minim Access Surg*. 2016;**12**(1):4–9. doi: 10.4103/0972-9941.169952. [PubMed: 26917912]. [PubMed Central: PMC4746973].
7. Russo A, Di Stasio E, Scagliusi A, Bevilacqua F, Isgro MA, Marana R, et al. Positive end-expiratory pressure during laparoscopy: cardiac and respiratory effects. *J Clin Anesth*. 2013;**25**(4):314–20. doi: 10.1016/j.jclinane.2013.01.011. [PubMed: 23712068].
8. Jo YY, Lee JY, Lee MG, Kwak HJ. Effects of high positive end-expiratory pressure on haemodynamics and cerebral oxygenation during pneumoperitoneum in the Trendelenburg position. *Anaesthesia*. 2013;**68**(9):938–43. doi: 10.1111/anae.12284. [PubMed: 23841822].
9. Gutt CN, Oniu T, Mehrabi A, Schemmer P, Kashfi A, Kraus T, et al. Circulatory and respiratory complications of carbon dioxide insufflation. *Dig Surg*. 2004;**21**(2):95–105. doi: 10.1159/000077038. [PubMed: 15010588].
10. Lee HJ, Kim KS, Jeong JS, Shim JC, Cho ES. Optimal positive end-expiratory pressure during robot-assisted laparoscopic radical prostatectomy. *Korean J Anesthesiol*. 2013;**65**(3):244–50. doi: 10.4097/kjae.2013.65.3.244. [PubMed: 24101959]. [PubMed Central: PMC3790036].
11. Futier E, Constantin JM, Pelosi P, Chanques G, Kwiatkoskwi F, Jaber S, et al. Intraoperative recruitment maneuver reverses detrimental pneumoperitoneum-induced respiratory effects in healthy weight and obese patients undergoing laparoscopy. *Anesthesiology*. 2010;**113**(6):1310–9. doi: 10.1097/ALN.0b013e3181fc640a. [PubMed: 21068660].
12. Meininger D, Byhahn C, Mierdl S, Westphal K, Zwissler B. Positive end-expiratory pressure improves arterial oxygenation during prolonged pneumoperitoneum. *Acta Anaesthesiol Scand*. 2005;**49**(6):778–83. doi: 10.1111/j.1399-6576.2005.00713.x. [PubMed: 15954959].
13. Hirvonen EA, Poikolainen EO, Paakkonen ME, Nuutinen LS. The adverse hemodynamic effects of anesthesia, head-up tilt, and carbon dioxide pneumoperitoneum during laparoscopic cholecystectomy. *Surg Endosc*. 2000;**14**(3):272–7. doi: 10.1007/s004640000038. [PubMed: 10741448].
14. Choi EM, Na S, Choi SH, An J, Rha KH, Oh YJ. Comparison of volume-controlled and pressure-controlled ventilation in steep Trendelenburg position for robot-assisted laparoscopic radical prostatectomy. *J Clin Anesth*. 2011;**23**(3):183–8. doi: 10.1016/j.jclinane.2010.08.006. [PubMed: 21377341].
15. Kim JY, Shin CS, Kim HS, Jung WS, Kwak HJ. Positive end-expiratory pressure in pressure-controlled ventilation improves ventilatory and oxygenation parameters during laparoscopic cholecystectomy. *Surg Endosc*. 2010;**24**(5):1099–103. doi: 10.1007/s00464-009-0734-6. [PubMed: 19915912].
16. Baki ED, Kokulu S, Bal A, Ela Y, Sivaci RG, Yoldas M, et al. Evaluation of low tidal volume with positive end-expiratory pressure application effects on arterial blood gases during laparoscopic surgery. *J Chin Med Assoc*. 2014;**77**(7):374–8. doi: 10.1016/j.jcma.2014.04.007. [PubMed: 24950920].
17. Perilli V, Sollazzi L, Bozza P, Modesti C, Chierichini A, Tacchino RM, et al. The effects of the reverse trendelenburg position on respiratory mechanics and blood gases in morbidly obese patients during bariatric surgery. *Anesth Analg*. 2000;**91**(6):1520–5. doi: 10.1097/00000539-200012000-00041. [PubMed: 11094011].
18. Ranieri VM, Brienza N, Santostasi S, Puntillo F, Mascia L, Vitale N, et al. Impairment of lung and chest wall mechanics in patients with acute respiratory distress syndrome: role of abdominal distension. *Am J Respir Crit Care Med*. 1997;**156**(4 Pt 1):1082–91. doi: 10.1164/ajrccm.156.4.97-01052. [PubMed: 9351606].
19. Sprung J, Whalley DG, Falcone T, Wilks W, Navratil JE, Bourke DL. The effects of tidal volume and respiratory rate on oxygenation and respiratory mechanics during laparoscopy in morbidly obese patients. *Anesth Analg*. 2003;**97**(1):268–74. table of contents. doi: 10.1213/01.ane.0000067409.33495.1f. [PubMed: 12818980].
20. Luz CM, Polarz H, Bohrer H, Hundt G, Dorsam J, Martin E. Hemodynamic and respiratory effects of pneumoperitoneum and PEEP during laparoscopic pelvic lymphadenectomy in dogs. *Surg Endosc*. 1994;**8**(1):25–7. doi: 10.1007/bf02909488. [PubMed: 8153860].
21. Fellahi JL, Caille V, Charron C, Daccache G, Vieillard-Baron A. Hemodynamic effects of positive end-expiratory pressure during abdominal hyperpression: a preliminary study in healthy volunteers. *J Crit Care*. 2012;**27**(1):33–6. doi: 10.1016/j.jcrc.2011.03.003. [PubMed: 21514092].
22. Neumann P, Rothen HU, Berglund JE, Valtysson J, Magnusson A, Hedenstierna G. Positive end-expiratory pressure prevents atelectasis during general anaesthesia even in the presence of a high inspired oxygen concentration. *Acta Anaesthesiol Scand*. 1999;**43**(3):295–301. doi: 10.1034/j.1399-6576.1999.430309.x. [PubMed: 10081535].