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Effect of pressure-controlled recruitment maneuver on hemodynamics and respiratory mechanics during pneumoperitoneum

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ABSTRACT

Introduction: Laparoscopic surgery has become an increasingly preferred method due to the small size of the abdominal incision line, causing less tissue trauma, reduced post-operative analgesic requirement, providing early mobilization, decreased post-operative ileus, and shortened hospital stay. However, pneumoperitoneum may cause upward displacement of the diaphragm by increasing intra-abdominal pressure, decrease functional residual capacity and lung compliance, and develop atelectasis. The aim of this study is to investigate the effect of recruitment maneuver and positive end expiratory pressure (PEEP) applications performed together with graduated pressure levels and low O_2 concentration on respiratory mechanics, oxygenation, and hemodynamic parameters in patients who underwent laparoscopic cholecystectomy.

Materials and Methods: Sixty patients with laparoscopic surgery and ASA I and II were divided into three groups (n=20 in each group). Recruitment maneuvers were performed in the patients in Group R with a stepwise method twice, 5 min after insufflation and desufflation. While the patients were at 8 cmH_2O PEEP value, they were ventilated 10 times with 5 cmH_2O < PEEP increments while the Ppeak<50 cmH_2O up to 20 cmH_2O PEEP value. The gradually increased PEEP value was reduced again gradually and terminated at the initial PEEP value of 8 cmH_2O. In the patients in Group P, only 8 cmH_2O PEEP was initiated after intubation and recruitment maneuver was not performed. On the other hand, PEEP was not initiated and recruitment maneuver was not performed in the patients in Group C after intubation. In all patients, 5 min after insufflation and desufflation, intraoperative arterial blood gas analysis was performed twice, and simultaneous static and dynamic compliance values and hemodynamic values (systolic, diastolic, mean arterial pressure, and heart rate) were recorded.

Results: PaO_2 values 5 min after insufflation and desufflation in Group C (insufflation: 156.65±43.21 and desufflation: 165.45±35.83) were detected significantly lower than Group R (insufflation: 199.50±29.32 and desufflation: 253.33±37.93) and Group P (insufflation: 200.93±58.16 and desufflation: 202.84±47.13) ($p<0.05$). PaO_2 measurements 5 min after desufflation in the cases in the R group were found to be significantly higher than the cases in Group P ($p<0.05$). In the cases in Group R, the increase in the PaO_2 value 5 min after desufflation was significantly higher to the PaO_2 value 5 min after insufflation ($p<0.05$). The change in PaO_2 values in the cases in Group P and Group K was not statistically significant ($p>0.05$). Compliance measurements of the cases in Group R 5 min after desuflation were found to be significantly higher than the cases in Groups P and C.

Conclusion: It is thought that recruitment maneuver and PEEP application with gradually increasing pressure in patients undergoing laparoscopic surgery have positive effects on oxygenation, increases lung compliance and can be used safely.

Keywords: Anesthesia, Laparoscopic surgery, Positive end expiratory pressure, Recruitment maneuver

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Introduction

Laparoscopy is a minimally invasive procedure that provides an endoscopic approach by introducing gas into the peritoneal cavity to create a space between the anterior abdominal wall and viscera. This method, in which the sufficient view and surgical area are revealed by insufflating the gas, is called "pneumoperitoneum method."[1,2]

Laparoscopic surgery is preferred by patients due to small abdominal incision line, avoidance of prolonged manipulations of abdominal organs, less tissue trauma that results in reduced post-operative analgesic requirement, providing early mobilization, reduction in post-operative ileus, shortening of hospital stay, easier return to daily activities of the patient, reduced cost, and better cosmetic appearance.[1]

Pneumoperitoneum increases intra-abdominal pressure. This pressure increase causes the diaphragm shifts upward and along with the functional residual capacity, lung compliance decreases, and atelectasis may develop.[3,4] These conditions may impair the gas exchange by affecting the respiratory system. It has been shown that adverse effects on respiratory mechanics and oxygenation continue in the post-operative period in patients underwent pneumoperitoneum.[5] Mechanical ventilation and upper abdominal surgery are also factors that negatively affect respiratory functions.[6,7]

Recruitment maneuver is a procedure that is used to open collapsed lungs, to increase lung areas to be used for gas exchange, and consequently to increase oxygenation.[8] During this procedure, different oxygen concentration and pressure values were used and many different recruitment maneuvers have been defined. If 50% O_2 concentration and gradually increasing pressure values are chosen in the recruitment maneuver, it can be aimed to reduce hemodynamic effects and maximize the benefit of the respiratory system.

In this study, it was aimed to investigate the effects of recruitment maneuver and positive end-expiratory pressure (PEEP) procedures performed with gradual pressure values and low O2 concentration on respiratory mechanics, oxygenation, and hemodynamic parameters in patients who underwent laparoscopic cholecystectomy.

Materials and Methods

The study was conducted at a university hospital after the approval of the local Ethics Committee (Date: October 9, 2017, Number: 2017/299).

Sixty patients who were in American Society of Anesthesiology ASA I and II, aged 18–65 years, with a body mass index (BMI) <30 and were scheduled for laparoscopic cholecystectomy were included in the study.

Patients outside the age range of 18–65, ASA III and above, patients with lung pathologies such as bullous emphysema and pneumothorax, patients with congestive heart failure or coronary artery disease, patients with an ejection fraction of < 50%, with impaired liver and/or kidney function tests in the pre-operative period, smokers, patients with taking sympathomimetic or corticosteroid therapy, patients with negative modified Allen test, patients with hemodynamic instability such as hypotension that would prevent the application of recruitment maneuver, and patients who started laparoscopically and converted to laparotomy were excluded from the study.

The patients were randomly divided into three groups of 20, using a random number generator as follows Group R: Recruitment maneuver group (n=20), Group P: PEEP group (n=20), and Group C: Control group (n=20) (The group consisting of patients on whom recruitment/PEEP was not performed).

Standard monitoring with electrocardiography, non-invasive blood pressure, and pulse oximetry was applied to the patients who were taken into the operating room. Premedication (0.03 mg/kg midazolam) was applied to all patients whose vascular access was established with an 18 gauge angiocath before surgery. Following pre-oxygenation, anesthesia induction was achieved by 0.1–0.2 µg/kg remifentanil, 2–3 mg/kg propofol, and 0.6 mg/kg rocuronium administrations in all groups. After endotracheal intubation was completed, catheterization was performed from the non-dominant arm to the radial artery after the Allen test. Anesthesia maintenance was achieved with 1–2% sevoflurane, an oxygen-air mixture (FiO_2=50%), and 0.1–0.5 µg·kg-1·min-1 remifentanil infusion. For the continuation of neuromuscular block, rocuronium (0.1 mg/kg) administration was repeated at specified time intervals. The fluid maintenance was achieved by 0.9% isotonic NaCl (8 mg·kg-1·h-1). During anesthesia, 6–8 mL kg-1 tidal volume was applied with a mechanical ventilation anesthesia device (Mindray BeneView T8, United Kingdom) to achieve 12 breaths per minute and 50% FiO_2. Flow-time waveform was observed during the operation to omit expiratory flow limitation and dynamic hyperinflation during ventilator monitor.

In addition to standard anesthesia maintenance, PEEP (8 cmH_2O) was performed in the patients in Group Rafter orotracheal intubation. Recruitment maneuvers were performed with a stepwise method twice, 5 min after insufflation and desufflation. After orotracheal intubation, while the patients were at PEEP value = 8 cmH2O, they were ventilated 10 times and increased up to PEEP = 20 cmH_2O with Ppeak <50 cmH_2O with 5 cmH2O increments up to. At each PEEP value, patients were ventilated 10 times. The gradually increased PEEP value was reduced again gradually and terminated at the initial PEEP value of 8 cmH2O. Arterial blood gas (ABG) analysis was performed twice intraoperatively, after recruitment maneuvers, and static and dynamic compliance values were recorded simultaneously.

In patients in Group P, in addition to standard anesthesia management, only 8 cmH_2O PEEP was initiated after orotracheal intubation, but recruitment maneuver was not performed. Intraoperative ABG analysis was performed twice, 5 min after insufflation and desufflation, and simultaneous static and dynamic compliance values were monitored and recorded.

In the patients in Group C, in addition to standard anesthesia management, PEEP was not initiated and recruitment maneuver was not performed after orotracheal intubation. Similar to the patients in Group P, intraoperative ABG analysis was performed twice, 5 min after insufflation and desufflation, and simultaneous static and dynamic compliance values were monitored and recorded.

Systolic arterial pressure, diastolic arterial pressure, mean arterial pressure (MAP), heart rate, oxygen saturations, peak inspiratory pressures (Ppeak), and plateau inspiratory pressures (Pplateau) were recorded at intervals of 5 min after the induction of anesthesia. PaO2 and PaCO2 values of the patients were monitored through ABG examination. Dynamic and static compliance values (Cd and Cs, respectively) were recorded twice during the operation, 5 min after induction and desufflation, and calculated using formulas (Cd = Tidal volume/Ppeak-PEEP and Cs= Tidal volume/Pplateau-PEEP).

In the patients, a HR below 50 beats/min was evaluated as bradycardia, a MAP of more than 25% compared to the baseline as hypertension, and a lower heart rate as hypotension. Bradycardia was treated with 0.5 mg atropine bolus, hypotension with intravenous fluid administration and 5–10 mg ephedrine administration, and hypertension with 100–200 µg nitroglycerine bolus. The amounts of atropine, ephedrine, and nitroglycerin used during the surgery were recorded for all groups. At the end of the operation, all patients were extubated and transferred to the recovery unit after termination of the neuromuscular block with 0.01 mg/kg atropine and 0.02 mg/kg neostigmine administration.

SPSS 15.0 Statistical package program was used for the statistical analysis of the data. The number of patients to be included in the study was calculated with 90% power and 5% error level, a change of 5 mmHg in the value of CO2 was accepted as significant and power analysis was performed in accordance with this.[9] To test its statistical significance, the number of patients was determined as 20 in each group, as it was calculated to include at least 16 subjects for each group after the power analysis. The data were evaluated using descriptive statistical methods (frequency, percentage, mean, and standard deviation). Kolmogorov–Smirnov distribution test was performed to test the distribution of the data and Pearson Chi-square test was used. Kruskal–Wallis test was used for comparisons between groups. Friedman test was used to examine the changes of measurements within the group. A p value lower than 0.05 was accepted as statistically significant.

Results

Age, gender, BMI, duration of surgery, and ASA scores of the patients included in the study are indicated in Table 1. There was no statistically significant difference between the demographic data of the patients.

Table 1. Demographic data of the groups and duration of the operation times

	Group R (n=20)	Group P (n=20)	Group C (n=20)	p
Age (years)	44.8±10.6	46.8±10.6	43.0±13.4	0.623
Gender (Female / male)	10/10	11/9	8/12	0.935
BMI (kg.m-2)	30.2±4.9	30.5±6.0	30.2±3.1	0.999
Duration of operation	51.5±19.6	55.5±12.8	53.2±13.6	0.528
ASA (1/2)	8/12	6/14	9/11	0.610

Dataaregiven as Mean ± Standard deviationornumber of patients. BMI: Body Mass Index; Group R: Recruitment group; Group P: PEEP group; Group C: Control Group.

The PaO_2 values of the patients in Group C, 5 min after insufflation and desufflation were found to be significantly lower than those in Group R and Group P ($p<0.05$). The PaO_2 values 5 min after desufflation in the patients in the Group R were significantly higher than those in Group P ($p<0.05$).In the patients in Group R, the increase in the PaO2 values 5 min after desufflation was statistically significant compared to the PaO_2 values 5 min after insufflation ($p<0.05$). However, the alterations in PaO_2 values in the cases in Group P and Group C were not statistically significant ($p>0.05$). The change in PaO_2 values of the groups is shown in Figure 1, and PaO_2 values according of the groups are shown in Table 2. There was no significant difference between the groups in terms of oxygen saturations measurements ($p>0.05$).

In all groups, Ppeak and Pplateau values increased on carbon dioxide insufflation. Ppeak values of the patients in Group R were found to be significantly higher than Group C ($p<0.05$). In the patients in Group R, the Pplateau values were closest to the pre-operative values in the period after desufflation.

Static and dynamic compliance values decreased with insufflation in patients in all groups. Static and dynamic compliance measurements of the patients in Group C after intubation, 5 min after insufflation and 5 min after desufflation were found to be significantly lower than the cases in Group R and Group P ($p<0.05$). Compliance measurements of the cases in the Group R, 5 min after desufflation were found to be significantly higher than those in Group P ($p<0.05$). When compared to the post-insufflation period, the compliance values of the patients in the Group P after desufflation were found to be significantly higher than in those in Group C ($p<0.05$). Moreover, comparison of static and dynamic compliance values after induction and after desufflation revealed a decrease of 15% in Group P and 20% in Group C was found. However, in Group R, static and dynamic compliance values increased by 5% compared to the post-induction period. In Figure 2, changes in the static compliance values according to the groups and in Figure 3 changes in the dynamic compliance values according to the groups were implicated.

$PaCO_2$ values were found elevated on insufflation ($p<0.05$). The $PaCO_2$ value at post-insufflation (38.0±3.1) increased at post-desufflation (41.5±3.2) in Group R. On the other hand,

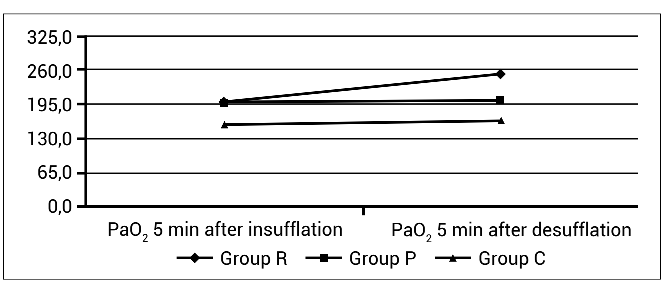

Figure 1. Change of partial oxygen pressure over time (PaO_2) (mmHg).

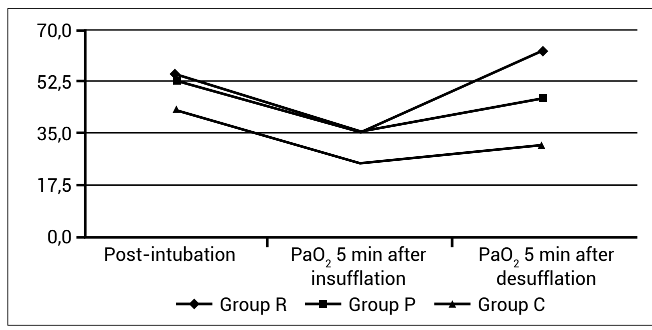

Figure 2. Static compliance values over time (Cs) (mL/cm/H_2O).

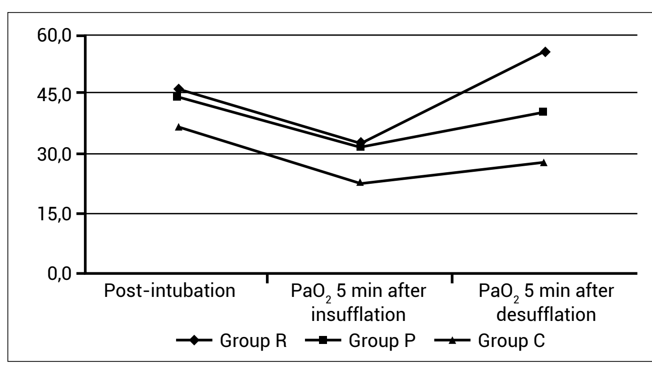

Figure 3. Dynamic compliance data (CD) over time (mL/cm/H_2O).

Table 2. Partial oxygen pressure values (PaO_2) (mmHg)

	Group R		Group P		Group C		KW*	p
	Mean	SD	Mean	SD	Mean	SD		
PaO_2 5 min after insufflation	199.500	29.325	200.935	58.165	156.650	43.211	10.352	0.006
PaO_2 5 minutes after desufflation	253.335	37.931	202.845	47.132	165.450	35.836	26.142	0.000

KW*: Kruskal Wallis test.

The $PaCO_2$ value of 40.42±5.9 after insufflation was found to be 43.0±3.8 after desufflation in Group P. Moreover, in Group C, the $PaCO_2$ values were 38.0±2.9 and 44.1±3.5 at post-insufflation and post-desufflation, respectively. Although the increases in $PaCO_2$ values in all groups were statistically significant within the groups, no significant differences were observed between the groups.

EtCO2 values were 34.5±3.3 at t = 0 min and 38.75±3.8 at t = 60 min in Group R, were 33.4±4.2 at t = 0 min and 35.8±2.5at t = 60 min in Group P, and 33.9±2.6 at t = 0 min and 36.2±2.0 at t = 60 min. No significant differences were observed between the groups.

In the group on whom the recruitment maneuver was performed (Group R), static compliance values were 52.3 mL/cm/H_2O in the pre-insufflation period, 36.1 mL/cm/H_2O in the post-insufflation period, and 62.9 mL/cm/H_2O in the post-desufflation period. Lung compliance increased by 15%. On the other hand, the static compliance values were 54.6 mL/cm/H_2O in the pre-insufflation period, 35.4 mL/cm/H_2O in the post-insufflation period, and 46.8 mL/cm/H_2O in the post-desufflation period, in Group P. However, lung compliance decreased by 14%. Moreover, in Group C, the static compliance values were found as 42.8 mL/cm/H2O in the pre-insufflation period, 24.7 mL/cm/H_2O in the post-insufflation period, and 31.5 mL/cm/H_2O in the post-desufflation period and lung compliance decreased by up to 20%.

MAP values in Group R were found to be significantly lower than Group C at some time points, while HR was found to be significantly higher in Group R compared to Group C at some time points during the procedures. The alterations in MAP and HR over time are given in Figure 4 and 5, respectively.

Hypotension occurred in four patients in Group R, two patients in Group P, and three patients in Group C. Hemodynamic stability was achieved in a short time with fluid therapy and ephedrine administration. No other adverse conditions or complications occurred in the patients.

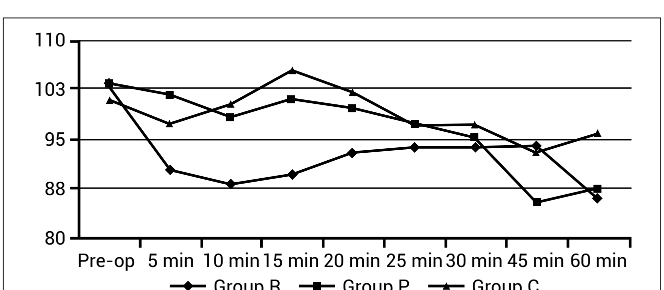

Figure 4. Mean arterial pressure (MAP) over time (mmHg).

Discussion

In recent years, recruitment maneuvers have been recommended to clear atelectasis and/or collapsed lung areas and provide oxygenation during general anesthesia.[4] Studies on recruitment maneuver and performing it have been shown to have many positive effects in terms of respiration.[9,10] It is possible to perform recruitment maneuvers with high or low pressure. There are studies showing that low-pressure recruitment maneuver (15 cmH_2O pressure) also provides similar efficacy to medium-pressure recruitment maneuver (30–40 cm H_2O) in terms of pneumoperitoneum height that is measured on chest radiography, ambulation time, and hospital stay.[10] Although the traditional approach is to perform 40 cmH_2O for 30–40 s, there are other studies indicating that the hemodynamic instability will be less in the recruitment maneuver when the pressure is increased gradually.[9] Again, although it is known that absorption atelectasis occurs due to rapid absorption of inhaled gas in ventilation with high concentration O_2, there is no consensus on many issues such as oxygen concentration or application time, just like pressure values.[11] In this study, the effects of performing PEEP on respiratory mechanics, ABG, and hemodynamics together with the recruitment maneuver with gradually increased pressure were investigated. It was observed that 8 cmH_2O PEEP applications together with the recruitment maneuver provided a significant increase on oxygenation in patients without causing significant hemodynamic impairment, and despite laparoscopy, lung compliance values were improved by 5% compared to pre-pneumoperitoneum.

In a study conducted by Cakmakkaya et al. performed on the cases underwent laparoscopic radical nephrectomy, it was shown that lung mechanics did not return to normal after pneumoperitoneum was cleared, and normal compliance values could be achieved after recruitment maneuver applied to the lungs with a pressure of 40 cmH_2O

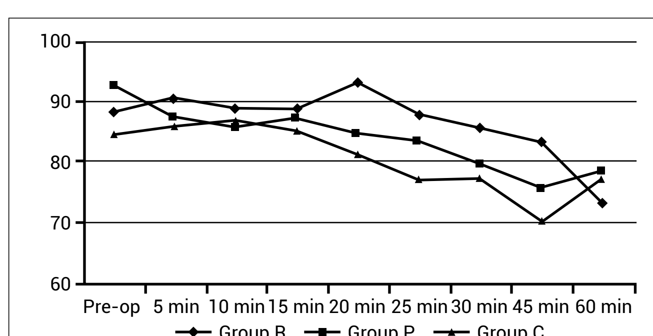

Figure 5. Heart rate (HR) over time to time (Beats/min).

pressure for 10 s.[3] In another study conducted with extremely obese patients with BMI between 40 and 55 and undergoing laparoscopic sleeve gastrectomy, recruitment maneuver led to increased pO_2 and decreased pCO_2 values in the patients, and this decrease continued even in the post-operative care unit.[8] In another study investigating the effects of pneumoperitoneum in laparoscopic cholecystectomy cases, it was reported that PEEP application alone had positive effects on ventilation and oxygenation.[4] However, there are not enough studies investigating the effects of recruitment maneuver with gradually increasing pressure and PEEP application.

It should always be kept in mind that the recruitment maneuver poses a risk of barotrauma when applied above the appropriate inspiratory pressure level and for a long period. Therefore, to avoid barotrauma, we determined the lung peak pressure limit as 50 cmH_2O, and the PEEP value applied after the maneuver as 8 cmH_2O. Oxygenation in Group R was found to be significantly higher than the other two groups without altering the hemodynamic changes. Contrary to the literature, 8 cmH_2O PEEP applications in Group P had a significant effect on oxygenation without causing significant hemodynamic side effects compared to Group C. No complications mediated by barotrauma were observed in the perioperative period.

Iwasaka et al. reported that $PaCO_2$ and $EtCO_2$ values increased during the CO_2 insufflation of in patients who underwent laparoscopic cholecystectomy, leading to a decrease in pH, but no change in HCO-3 concentration.[12] In our study, both $PaCO_2$ and $EtCO_2$ values increased significantly compared to the baseline level; however, there was no statistically significant difference between the groups in terms of the increase. They also stated that with the effect of increased intra-abdominal pressure during laparoscopic intervention, the Ppeak value increased from 15.9 cmH_2O to 18.9 cmH_2O, the dynamic compliance values of 49.6 mL/cm/H_2O decreased by approximately 40% and were found as 30.9 mL/cm/H_2O and that increased to 45.1 mL/cm/H_2O after desufflation and they suggested these changes were due to pressing the diaphragm during insufflations.[12]

There are also studies showing that lung compliance increases after recruitment maneuver.[13-16] In a study conducted with patients who had major abdominal surgery, Weingarten et al. showed that the dynamic compliance of patients was increased on PEEP application along with the recruitment maneuver and their respiratory mechanics were improved.[15] Almarakbi et al., in their study on obese patients who underwent laparoscopic surgery, observed that the compliance of patients increased on PEEP along with recruitment maneuver, but that there was no change in the compliance of patients on whom PEEP or recruitment maneuver was performed alone.[14] In our study, in accordance with the literature, a 15% increase in the compliance values of Group R, but a decrease by 14% in Group P and 20% in Group C were observed.

In a study conducted by Joris et al., in patients who underwent laparoscopic cholecystectomy surgery reported that MAP increased by 35% and heart index declined by 20% on peritoneal insufflation after induction.[17] PEEP application decreases cardiac output by increasing intra-thoracic pressure and decreasing venous return to the heart. The negative effect of PEEP application in this case is observed especially in intensive care patients and in case of when the applied pressure is high. Physiologically, acceptable PEEP values of 5–7 cmH_2O have minimal effects on hemodynamics in intensive care patients and perioperative patients. Studies on patients in whom PEEP was applied have also reported a decrease in the HR. In our study, HR <50 bpm was accepted as bradycardia and no bradycardia occurred in any of the three groups. Hypotension occurred in four, two, and three patients in Group R, Group P, and Group C, and quickly resolved with intravenous vasopressor and ephedrine administration. The frequency of hypotension due to recruitment maneuver or PEEP application among the groups was not significantly different and hemodynamics was not affected in both groups.

Conclusion

It was determined that recruitment maneuver and 8 cmH2O PEEP application with gradually increased pressure in patients who underwent laparoscopic surgery had positive effects on oxygenation and increased lung compliance without altering hemodynamics. In this study, it was determined that in patients with high risk of developing intraoperative hypoxia and/or atelectasis, PEEP application with recruitment maneuver had positive effects on respiratory mechanics and oxygen values without affecting hemodynamics.

Disclosures

Ethichs Committee Approval: The study was conducted at a university hospital after the approval of the local Ethics Committee (Date: October 9, 2017, Number: 2017/299).

Peer-review: Externally peer-reviewed.

Conflict of Interest: None declared.

Authorship Contributions: Concept – Z.S., K.A.; Design – Z.S., K.A.; Supervision – Z.S., H.Y.A.; Materials – K.A.; Data collection and/or processing – K.A., Y.Ö., H.Y.A.; Analysis and/ or interpretation – Z.S., Y.Ö., H.Y.A.; Literature search – Y.Ö., H.H.A., K.A.; Writing – Y.Ö., K.A., H.Y.A.; Critical review – Z.S., H.Y.A.

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