Comparative Study of Effects of Intraoperative Use of Positive End-Expiratory Pressure, Intermittent Recruitment Maneuver, and Conventional Ventilation on Pulmonary Functions during Long-Duration Laparotomy

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Abstract

Background: With an increase in the duration of general anesthesia, there is a gradual deterioration in pulmonary functions. Intraoperative atelectasis is the major cause of deterioration in pulmonary functions. This study was performed to compare and determine the best ventilatory strategy among conventional ventilation, application of positive end-expiratory pressure (PEEP), and intermittent recruitment maneuver.

Materials and Methods: Seventy-five patients were divided into three groups each of 25 patients. In the first group (zero positive end-expiratory pressure [ZEEP]), we have applied zero PEEP intraoperatively. In the second group (PEEP), we have applied PEEP of 6 cm of H₂O. In the third group (intermittent lung recruitment maneuver [IRM]), we have done intermittent recruitment maneuver intraoperatively. Pulmonary functions were analyzed by partial pressure of oxygen (PaO₂)/fraction of inspired oxygen (FiO₂) ratio (P/F) and static lung compliance (Cₘₜₐₜ).

Results: While comparing the mean P/F ratio between the groups, a significant decrease in P/F ratio of the ZEEP group was found from 90 min after induction up till the end (i.e., 24 h after extubation) of our observations as compared to both the PEEP and IRM groups. However, it did not differ (P > 0.05) between the PEEP and IRM groups at all time points on statistical analysis. On comparing the mean of Cₘₜₐₜ between the groups, there was a significant decrease in lung compliance of the ZEEP group as compared to both the PEEP and IRM groups at all time points. However, like P/F ratio, compliance was also found to be statistically insignificant between the PEEP and IRM groups.

Conclusions: Pulmonary functions are relatively preserved with application of either PEEP or doing intermittent recruitment maneuver.

Keywords: Intraoperative ventilation strategy, lung atelectasis, partial pressure of oxygen/fraction of inspired oxygen ratio, positive end-expiratory pressure, static lung compliance

Introduction

It is a well-established fact that with an increase in the duration of general anesthesia, there is a gradual deterioration in pulmonary functions which has largely been attributed to progressive alveolar collapse and ventilation–perfusion mismatch.[1] After induction of general anesthesia, combined effects of supine position, muscle paralysis, loss of physiological positive end-expiratory pressure (PEEP), and surgical manipulations result in atelectasis, reduced functional residual capacity (FRC), and increased closing volume.

General anesthesia causes impairment in pulmonary gas exchange and respiratory mechanics, even in patients with healthy lungs.[2] Atelectasis has been described both during laparotomy and laparoscopic surgery.[3] It invariably develops within minutes after the induction of general anesthesia[4] and is the major cause of alterations in gas exchange.[5] Intraoperative changes in pulmonary functions may extend into postoperative period. It may delay discharge from

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postanesthesia care unit and increase the need for respiratory physiotherapy and the probability of ventilator support. These all lead to increased morbidity as well as cost burden to the patients.

There is a lack of randomized controlled trials to define optimal intraoperative tidal volume, PEEP, and the use of intraoperative lung recruitment.[6]

Anesthetic management, particularly mechanical ventilation settings, can influence the extent and course of deterioration of pulmonary functions. Various intraoperative ventilatory strategies have been studied to improve gas exchange in these patients including large tidal volume, high ventilatory frequency, or both,[7] use of PEEP,[8] and reverse Trendelenburg position.[9] However, the effects of these interventions have been variable.

There had been studies which compared different levels of PEEP and different recruitment maneuvers during laparotomies, but there is no study which compared the efficacy of PEEP and intraoperative intermittent recruitment maneuver with no PEEP in preserving pulmonary functions in perioperative period of laparotomies of prolonged duration. We designed the present study to compare the effects of conventional ventilation with PEEP, conventional ventilation without PEEP, and intermittent lung recruitment maneuver (IRM) on pulmonary functions in patients undergoing prolonged laparotomies under general anesthesia.

**Materials and Methods**

*Study design and settings*

It was a comparative, prospective, monocentric, interventional study commenced after obtaining approval from Institute’s Ethical Committee (no. 17/16). This study was conducted between April 2017 and December 2018 at a tertiary care center.

*Inclusion criteria*

The American Society of Anesthesiologists (ASA) physical status Class I–II patients of either sex belonging to the age group of 18–65 years, undergoing laparotomy in supine position with an expected duration of 3 h or more, were included in the study.

*Exclusion criteria*

Patients who were expected to have or were having hemodynamic instability and had any preexisting comorbidity including any pulmonary pathology, body mass index (BMI) ≥30 kg/m², and preoperative anemia (hemoglobin <10 gm.dl⁻¹) were excluded from the study.

*Sample size*

It was determined by taking partial pressure of oxygen (PaO₂)/fraction of inspired oxygen (FiO₂) ratio as a primary outcome. On the basis of data available from previous study[7] that tested the effect of ventilatory strategy on perioperative arterial oxygenation, it was determined that for the primary outcome, i.e., PaO₂/FiO₂ ratio, a sample size of twenty patients per group would provide statistical power (two-tailed, α = 0.05) of ≥80% to detect a difference of 10 kPa or 75 mmHg. To take care of dropouts, 25 patients were recruited in each group.

After obtaining informed written consent, 84 patients were enrolled for this study, out of which 9 patients were dropped from the study. The rest 75 patients were divided into 3 groups each of 25 by sequential sampling. The first patient was allocated to the first group, the second patient was allocated to the second group, and the third patient in the third group, and then, sampling was continued in the same cyclical order.

Following were the three study groups:

- **Zero positive end-expiratory pressure (ZEEP) group:** Patients were ventilated intraoperatively with zero PEEP
- **PEEP group:** Patients were ventilated intraoperatively with PEEP of 6 cm of water
- **IRM group:** Patients were ventilated intraoperatively with intermittent recruitment maneuver, by sustained inflation using a pressure of 30 cm H₂O for 20 s, every 30 min, by shifting the mechanical ventilation to manual mode.
  - **Primary outcome measure – Ratio of PaO₂/FiO₂, i.e., P/F ratio**
  - **Secondary outcome – Static lung compliance (Cst).**

All patients were premedicated with tablet ranitidine 150 mg and alprazolam 0.5 mg, the night before surgery, and at 6:00 a.m. on the day of surgery. All patients fasted for minimum 6 h preoperatively. Patients were allowed to drink water till 2 h before taking to operation suite.

On arrival in the operation theater, intravenous (i.v.) access was established and an i.v. fluid was started. Standard monitors were attached.

Epidural catheter was placed after proper cleaning and draping in appropriate space according to surgery planned. After a test dose of 3 mL of 2% lignocaine with adrenaline (1 in 200,000), a bolus dose of 10 mL of 0.125% bupivacaine was given through epidural catheter in all patients.

Radial artery was cannulated under local anesthesia to measure blood pressure as well as for repeated arterial blood gas (ABG) sampling.

Patients were preoxygenated with 100% oxygen using a Drager Primus anesthesia workstation and then induced with i.v. midazolam (1–2 mg stat), fentanyl (1–2 μg.kg⁻¹), and i.v. 1% propofol (1–2 mg.kg⁻¹). After assessing for mask ventilation, vecuronium (0.08–0.12 mg.kg⁻¹) was administered to achieve muscle relaxation. Bag-and-mask ventilation was continued with 100% oxygen.

Tracheal intubation was performed with appropriate-sized endotracheal tube (ETT), cuff inflated with the help of cuff pressure monitor. Anesthesia was maintained in all cases with 30% oxygen and 70% air along with isoflurane 0.8%–1.2%. Bolus doses of i.v. fentanyl 1 μg.kg⁻¹ and i.v. vecuronium 0.08–0.12 mg.kg⁻¹ were supplemented intermittently.
Patients were ventilated in volume-controlled mode with a tidal volume of 6–8 mL·kg\(^{-1}\), respiratory rate of 10–12 min\(^{-1}\), Fi\(_O\_2\) of 0.3, and I:E ratio of 1:2 to maintain end-tidal carbon dioxide in the range of 30–35 mm of Hg.

Five minutes after intubation and ventilation, patients were allocated to one of the three groups—ZEEP, PEEP, and IRM.

All the hemodynamic parameters (mean arterial blood pressure [MAP], heart rate [HR], and oxygen saturation [Sp\(_O\_2\)]) were noted before intubation, after intubation, every 30 min after intubation intraoperatively and after extubation till 24 h.

ABG sample was taken 5 min after intubation and thereafter every 30 min in intraoperative period. In postoperative period, ABG analysis was done after 30 min, 6 h, 12 h, 18 h, and 24 h of arrival in the postoperative ward.

C\(_{\text{stat}}\) was noted in this study after intubation (baseline) and thereafter every 30 min till the end of surgery as displayed on anesthesia workstation.

C\(_{\text{stat}}\) is derived from plateau pressure, PEEP, and expiratory tidal volume.

\[
C_{\text{stat}} = \frac{V_T}{P_{\text{plat}} - \text{PEEP}}
\]

Where \(P_{\text{plat}}\) = plateau pressure; \(V_T\) = tidal volume; PEEP = positive end-expiratory pressure.

All patients received i.v. ondansetron (0.1 mg·kg\(^{-1}\)) and i.v. paracetamol (15 mg·kg\(^{-1}\)) approximately 30 min before the end of surgery. Isoflurane was tapered at the beginning of skin suturing and stopped after skin closure. Neuromuscular blockade was reversed with i.v. neostigmine 0.05 mg·kg\(^{-1}\) and glycopyrrolate 0.01 mg·kg\(^{-1}\).

Once satisfactory extubation criteria were met as led down in ether.stanford.edu., patients were extubated. After extubation, oxygen was supplemented by Hudson mask. Thereafter, assessment of neurological and neuromuscular recovery was done once again, and if found satisfactory, patients were shifted to postoperative ward.

In postoperative ward, patients received oxygen supplementation by Venturi mask ventilation Fi\(_O\_2\) of 0.4 for 6 h. After 6 h, oxygen support was withdrawn. If on discontinuation of oxygen support, Sp\(_O\_2\) was <95%, then such patients were continued with oxygen therapy. Patients were reasessed every hour, and if able to maintain Sp\(_O\_2\) of >95%, without oxygen supplementation, then Venturi mask was removed and a patient was allowed to breathe room air.

Postoperative pain was managed with continuous epidural infusion of a mixture of bupivacaine 0.0625% and fentanyl 2 µg·mL\(^{-1}\) and titrated according to postoperative pain using the Numerical Rating Scale (NRS) till 48 h along with injection paracetamol 1 g 6 hourly. NRS was done in postanesthesia care unit at 3 h, 6 h, 12 h, 18 h, 24 h, 48 h, and at the time of discharge. Target was to maintain NRS ≤3.

**RESULTS**

The demographic characteristics (age, sex, BMI, and ASA grade) of three groups were found to be comparable [Table 1].

| Variable       | Group 1 (ZEEP) | Group 2 (PEEP) | Group 3 (IRM) | P     |
|----------------|----------------|----------------|---------------|-------|
| Age (years)    | 40.72±2.16     | 40.12±2.13     | 41.40±2.03    | 0.745 |
| Sex            |                |                |               |       |
| Female         | 9 (36.0)       | 9 (36.0)       | 7 (28.0)      | 0.78  |
| Male           | 16 (64.0)      | 16 (64.0)      | 18 (72.0)     |       |
| BMI (kg/m\(^2\)) | 22.38±0.58     | 21.82±0.45     | 22.68±0.49    | 0.48  |
| ASA grade      |                |                |               |       |
| I              | 18 (72)        | 16 (64)        | 15 (60.0)     | 0.662 |
| II             | 7 (28)         | 9 (36)         | 10 (40)       |       |

ZEEP=Zero positive end-expiratory pressure, PEEP=Positive end-expiratory pressure, IRM=Intermittent lung recruitment maneuver, BMI=Body mass index
reached near baseline value at 3:00 h after intubation. On intergroup analysis of $C_{stat}$ using the Newman–Keuls test, it showed a significant ($P < 0.001$) decrease in lung compliance in the ZEEP group as compared to the PEEP as well as IRM groups [Table 4]. However, an intergroup comparison of $C_{stat}$ between the PEEP and IRM groups [Table 5] showed no significant difference in change of $C_{stat}$ at all time periods.

**Discussion**

This was the first-ever study which involved a head-to-head comparison of the effects of conventional ventilation with or without PEEP and IRM on pulmonary functions in patients undergoing prolonged laparotomies under general anesthesia. Lung recruitment is a maneuver aimed to revert atelectasis by means of a brief controlled increase in airway pressure.[10] Clinical studies demonstrated that the alveolar recruitment strategy, a cycling recruitment maneuver combined with an adequate level of PEEP also improved lung physiology in thoracic surgery with open-lung ventilation (OLV).[11,12] In a recent meta-analysis, it was concluded that the use of IRM reduced the incidence of postoperative pulmonary complication (PPC), especially combined with lung protection ventilation strategy. Combining with PEEP, there was no remarkable reduction in the incidence of PPC.[13] Alveolar recruitment is achieved broadly by two types – sustained inflation of the lungs for 5–30 sec to a predetermined peak inspiratory pressure of 30–40 cm of H$_2$O or incrementally increasing PEEP in a stepwise manner.[14] In the meta-analysis, it was found that sustained inflation technique may be better than stepwise lung recruitment maneuver in preventing PPC.[13] We utilized sustained manual inflations of the lungs to a peak inspiratory pressure of 30 cm H$_2$O.

**Partial pressure of oxygen/fraction of inspired oxygen ratio**

On comparing the mean P/F ratio among groups, there was a significant decrease in P/F ratio in the ZEEP group as compared to both the PEEP and IRM groups from 2 h after intubation till 24 h after extubation [Table 2]. However, P/F ratio did not differ between the PEEP and IRM groups [Table 3] at all time periods. Application of either PEEP or doing IRM has probably prevented atelectasis during the intraoperative period,[7,15,16] improving pulmonary mechanics and decreasing pulmonary shunt,[2] resulting in improvement of P/F ratio. A previous study reported that during OLV-related hypoxemia in a healthy lung model, increasing PEEP had a beneficial effect on oxygenation, based on its effect on lung inspiratory recruitment and its ability.
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to preserve end-expiratory lung volume (EELV).[[17]] Tusman et al. reported that an increase in arterial oxygenation after the recruitment maneuver suggests a reversal of anesthesia-induced atelectasis and the ventilation/perfusion inhomogeneity.[[11]] PEEP can counterbalance the decrease in EELV, thereby preventing atelectasis during the intraoperative period,[[7,15,16]] improving pulmonary mechanics, and decreasing pulmonary shunt.[[2]] Further, the application of PEEP minimizes lung collapse and prevents the repeated opening and collapse of lung units.[[18]] In patients with OLV, it had been reported that the better the underlying lung function, the better the response to PEEP.[[19,20]] In this situation, the improvement of oxygenation by PEEP of 5 cm H\textsubscript{2}O was shown to be mainly related to an increase in FRC.[[20]] We have used PEEP of 6 cm of H\textsubscript{2}O as the BMI of our patients was in the normal range. It was reported that the level of effective PEEP in patients with normal BMI was 6-8 cm of H\textsubscript{2}O. In obese patients, higher PEEP (10 cm H\textsubscript{2}O or higher) might be needed. Low PEEP will not be enough to keep the airways open and may therefore not be expected to recruit or even keep all lung open.[[21]]

Static lung compliance

In the ZEEP group, there is a significant decrease in C\textsubscript{st} at all time periods as compared to baseline [Table 4 and Figure 3]. In the PEEP and IRM groups, C\textsubscript{st} decreased marginally from baseline after intubation till 1:30 h of intubation but later on started improving during intraoperative period. The decrease in C\textsubscript{st} in initial 1:30 h period would be attributed to atelectasis and reduced lung volume which happens at the time of induction. Institution of PEEP probably leads to alveolar recruitment which is a continuum process and probably takes 1:30 h for all alveoli to recruit to approximately to the level of preinduction state.

Lung compliance reached near baseline value at 3:00 h after intubation and above baseline value at 3:30 h and thereafter [Table 4 and Figure 3]. On intergroup analysis, there was a significant decrease in lung compliance of the ZEEP group as compared to both the PEEP and IRM groups at all time periods [Table 5]. C\textsubscript{st} was comparable between the PEEP and IRM groups at all time intervals.

This study is comparable with a previous study,[[22]] in which three levels of PEEP were applied in random order:

### Table 3: Intergroup analysis of mean partial pressure of oxygen/fraction of inspired oxygen ratio by Newman-Keuls test

| Time periods      | ZEEP versus PEEP | ZEEP versus IRM | PEEP versus IRM |
|-------------------|------------------|-----------------|-----------------|
| Before intubation | 0.994            | 0.960           | 0.677           |
| After intubation  | 0.986            | 0.856           | 0.991           |
| 30 min after intubation | 0.969       | 0.946           | 0.996           |
| 1:00 h after intubation | 0.678       | 0.793           | 0.985           |
| 1:30 h after intubation | 0.294       | 0.562           | 0.712           |
| 2:00 h after intubation | 0.007       | 0.007           | 0.992           |
| 2:30 h after intubation | <0.001     | <0.001          | 0.968           |
| 3:00 h after intubation | <0.001     | <0.001          | 0.998           |
| 3:30 h after intubation | <0.001     | <0.001          | 0.986           |
| 4:00 h after intubation | <0.001     | <0.001          | 0.986           |
| 4:30 h after intubation | <0.001     | <0.001          | 0.946           |
| 5:00 h after extubation | <0.001     | <0.001          | 0.987           |
| 6:00 h after extubation | <0.001     | <0.001          | 0.998           |
| 12:00 h after extubation | <0.001     | <0.001          | 0.995           |
| 18:00 h after extubation | 0.003      | <0.001          | 0.971           |
| 24:00 h after extubation | 0.024      | 0.006           | 0.929           |

ZEEP=Zero positive end-expiratory pressure, PEEP=Positive end-expiratory pressure, IRM=Intermittent lung recruitment maneuver

### Table 4: Intragroup analysis of static lung compliance by Newman-Keuls test

| Time periods      | ZEEP (P) | PEEP (P) | IRM (P) |
|-------------------|----------|----------|---------|
| After intubation  | Reference| Reference| Reference|
| 30 min intubation | 0.002    | 0.836    | 0.968   |
| 1:00 h after intubation | <0.001   | 0.545    | 0.347   |
| 1:30 h after intubation | <0.001   | 0.327    | 0.309   |
| 2:00 h after intubation | <0.001   | 0.567    | 0.280   |
| 2:30 h after intubation | <0.001   | 0.747    | 0.785   |
| 3:00 h after intubation | <0.001   | 0.899    | 0.714   |
| 3:30 h after intubation | <0.001   | 0.944    | 0.137   |
| 4:00 h after intubation | <0.001   | 0.788    | 0.126   |
| 4:30 h after intubation | <0.001   | 0.771    | 0.101   |

ZEEP=Zero positive end-expiratory pressure, PEEP=Positive end-expiratory pressure, IRM=Intermittent lung recruitment maneuver

### Table 5: Intergroup analysis of static lung compliance between groups by Newman-Keuls test

| Time periods      | ZEEP versus PEEP | ZEEP versus IRM | PEEP versus IRM |
|-------------------|------------------|-----------------|-----------------|
| After intubation  | 0.763            | 0.861           | 0.979           |
| 30 min after intubation | <0.001       | <0.001          | 0.852           |
| 1:00 h after intubation | <0.001       | <0.001          | 0.902           |
| 1:30 h after intubation | <0.001       | <0.001          | 0.387           |
| 2:00 h after intubation | <0.001       | <0.001          | 0.948           |
| 2:30 h after intubation | <0.001       | <0.001          | 0.983           |
| 3:00 h after intubation | <0.001       | <0.001          | 0.938           |
| 3:30 h after intubation | <0.001       | <0.001          | 0.674           |
| 4:00 h after intubation | <0.001       | <0.001          | 0.511           |
| 4:30 h after intubation | <0.001       | <0.001          | 0.650           |

ZEEP=Zero positive end-expiratory pressure, PEEP=Positive end-expiratory pressure, IRM=Intermittent lung recruitment maneuver

Figure 3: Mean static lung compliance of three groups over the time periods

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(1) zero (ZEEP), (2) PEEP of 5 cm of H₂O, and (3) PEEP of 10 cm H₂O. It was reported that a more aggressive PEEP level is required to reduce shunt and to maximize compliance in case of laparoscopic surgery.

Our result is also comparable with another study[18] where the authors tested the hypothesis that during laparoscopic surgery, Trendelenburg position and pneumoperitoneum may worsen chest wall elanastase, concomitantly decreasing transpulmonary pressure, and that a protective ventilator strategy applied after pneumoperitoneum induction, by increasing transpulmonary pressure, would result in alveolar recruitment and improvement in respiratory mechanics and gas exchange. They concluded that in patients submitted to laparoscopic surgery in Trendelenburg position, an open-lung strategy applied after pneumoperitoneum induction increased transpulmonary pressure and led to alveolar recruitment and improvement of elasticity of chest wall and gas exchange.[16]

Our results are comparable with another study of elderly patients (>65 years), who underwent major open abdominal surgery.[23] In that study, OLV (recruitment maneuvers, tidal volume of 6 ml.kg⁻¹, and PEEP of 12 cm H₂O) was compared with conventional ventilation (no recruitment maneuvers, tidal volume 10 ml.kg⁻¹, and zero end-expiratory pressure) with regard to oxygenation, respiratory system mechanics, and hemodynamic stability, and their result was that lung recruitment strategy in elderly patients is well tolerated and improves intraoperative oxygenation as well as lung mechanics during laparotomy.

The above findings of our study show that the use of either PEEP or IRM prevents a decrease in Cstat in long-duration surgery under general anesthesia.

Limitations of the study
We understand that the sample sizes were small and so we suggest that larger, multicentric studies might be conducted to confirm the findings of the present study.

Conclusions
From the findings of this study, we may conclude that the decline in pulmonary functions (P/F ratio and compliance) that occurs during laparotomies of prolonged duration under general anesthesia can be prevented effectively by application of PEEP, and whenever application of PEEP is not feasible due to patient’s hemodynamic compromise or due to nature of surgery (as in neurosurgical patients), intermittent recruitment maneuver may be instituted.

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Conflicts of interest
There are no conflicts of interest.

References
1. Sykes MK, Young WE, Robinson BE. Oxygenation during anaesthesia with controlled ventilation. Br J Anaesth 1965;37:314-25.
2. Hedenstierna G, Edmark L. The effects of anesthesia and muscle paralysis on the respiratory system. Intensive Care Med 2005;31:1327-35.
3. Hedenstierna G, Rothen HU. Atelectasis formation during anesthesia: Causes and measures to prevent it. J Clin Monit Comput 2000;16:329-35.
4. Gunnarsson L, Tokics L, Gustavsson H, Hedenstierna G. Influence of age on atelectasis formation and gas exchange impairment during general anaesthesia. Br J Anaesth 1991;66:423-32.
5. Bendixen HH, Hedley-Whyte J, Laver MB. Impaired oxygenation in surgical patients during general anaesthesia with controlled ventilation. A concept of atelectasis. N Engl J Med 1963;269:991-6.
6. Beck-Schimmer B, Schimmer RC. Perioperative tidal volume and intraoperative lung strategy in healthy lungs: Where are we going? Best Pract Res Clin Anaesthesiol 2010;24:199-210.
7. Pelosi P, Ravagnan I, Giurati G, Panigada M, Bottino N, Tredici S, et al. Positive end-expiratory pressure improves respiratory function in obese but not in normal subjects during anesthesia and paralysis. Anesthesiology 1999;91:1221-31.
8. Perilli V, Solazzi 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;91:1520-5.
9. Chalhoub V, Yazigi A, Slelatty H, Haddad F, Noun R, Madi-Iebra S, et al. Effect of vital capacity manoeuvres on arterial oxygenation in morbidly obese patients undergoing open bariatric surgery. Eur J Anaesthesiol 2007;24:283-8.
10. Rothen HU, Sporre B, Engberg G, Wegenius G, Hedenstierna G. Re-expansion of atelectasis during general anaesthesia: A computed tomography study. Br J Anaesth 1991;71:788-95.
11. Tusman G, Böhm SH, Vazquez de Anda GF, do Campo JL, Lachmann B. ‘Alveolar recruitment strategy’ improves arterial oxygenation during general anaesthesia. Br J Anaesth 1999;82:8-13.
12. Whalen FX, Gajic O, Thompson GB, Kendrick ML, Que FL, Williams BA, et al. The effects of the alveolar recruitment maneuver and positive end-expiratory pressure on arterial oxygenation during laparoscopic bariatric surgery. Anesth Analg 2006;102:298-305.
13. Cui Y, Cao R, Li G, Gong T, Ou Y, Huang J. The effect of lung recruitment maneuvers on post-operative pulmonary complications for patients undergoing general anaesthesia: A metaanalysis. PLoS ONE 2019;14:E0217405.
14. Hartland BL, Newell TJ, Damico N. Alveolar recruitment maneuvers under general anesthesia: A systematic review of the literature. Respir Care 2015;60:609-20.
15. Duggan M, Kavanagh BP. Pulmonary atelectasis: A pathogenic perioperative entity. Anesthesiology 2005;102:838-54.
16. 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;118:114-22.
17. Michelet P, D’Journo XB, Roch A, Doddioli C, Marin V, Papazian L, et al. Protective ventilation influences systemic inflammation after esophagectomy: A randomized controlled study. Anesthesiology 2006;105:911-9.
18. Richard JC, Brochard L, Vandelet P, Breton L, Maggiore SM, Jonson B, et al. Respective effects of end-expiratory and end-inspiratory pressures on alveolar recruitment in acute lung injury. Crit Care Med 2003;31:89-92.
19. Cohen E, Eisenkraut JB. Positive end-expiratory pressure during one-lung ventilation improves oxygenation in patients with low arterial oxygen tensions. J Cardiothorac Vasc Anesth 1996;10:578-82.
20. Slinger PD, Kruger M, McRae K, Winton T. Relation of the static compliance curve and positive end-expiratory pressure to oxygenation during one-lung ventilation. Anesthesiology 2001;95:1096-102.
21. Hedenstierna G, Edmark L. Protective ventilation during anesthesia: Is it meaningful? Anesthesiology 2016;125:1079-82.
22. Spadaro S, Karbing DS, Mauri T, Marangoni E, Mojoli F, Valpiani G, et al. Effect of positive end-expiratory pressure on pulmonary shunt and dynamic compliance during abdominal surgery. Br J Anaesth 2016;116:855-61.
23. Weingarten TN, Whalen FX, Warner DO, Gajic O, Schears GJ, Snyder MR, et al. Comparison of two ventilatory strategies in elderly patients undergoing major abdominal surgery. Br J Anaesth 2010;104:16-22.